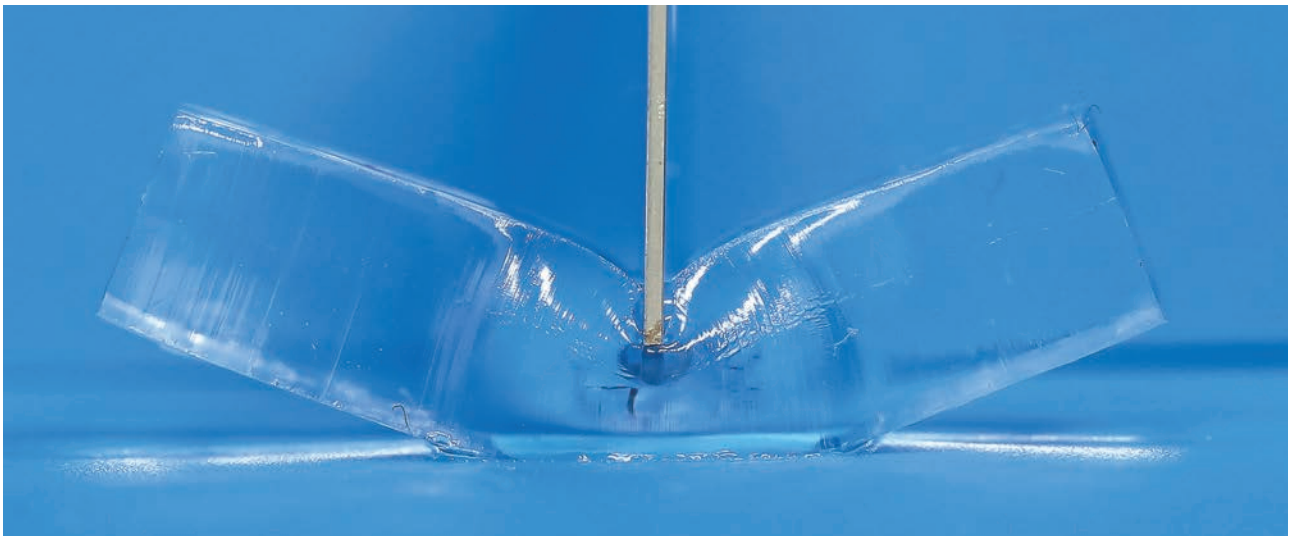
Global Station for Soft Matter

Global Institution for Collaborative Research and Education(GI-CoRE)

Hokkaido University

Final Evaluation Report



北海道大学　国際連携研究教育局

ソフトマターグローバルステーション

外部評価報告書

July 2021

2021 年 7 月

Final Evaluation Report
(brief version in Japanese)

外部評価報告書（日本語・概要版）

もくじ（日本語版）

はじめに

国際連携研究教育局（GI-CoRE）は、北海道大学の強みや特色を活かした国際連携研究教育の推進と、部局が独自に進める国際連携研究教育の支援を目的とし、世界トップレベルの教員を国内外及び学内から結集した総長直轄の教員組織です。

GI-CoRE 内には研究領域ごとの活動拠点である「グローバルステーション（GS）」を置き、各 GS において、原則 5 年間の設置期間内に重点的に研究教育活動を進めています。これまでに、延べ 8 つの GS（下記※を参照）を設置し、研究活動を推進するとともに、最先端の研究成果を大学院教育などに還元してきました。

GI-CoRE では、GS の設置期間満了を迎える年度に、各 GS でのこれまでの活動を振り返るとともに、今後、より強固かつ持続可能な研究教育体制を確立していくため、国内外の有識者により構成される外部評価委員会において、評価を実施することとしています。

この外部評価報告書は、2020 年 9 月に実施したソフトマターGS（GSS）の自己点検成果報告書及び外部評価結果を一冊に収録した、いわば GSS の研究教育活動の集大成です。

なお、ソフトマターGS は設置期間満了に伴い、先端生命科学研究院・次世代物質生命科学研究センターに定着化し、新たに「GI-CoRE 協力拠点」として認定を受けたソフトマター国際連携ユニットとして、2021 年 4 月以降も GI-CoRE と連携しながら研究教育活動を継続しています。

本学では、外部評価結果を踏まえ、より充実した研究教育活動を実践していくことにより、世界の課題解決に貢献していきたいと考えております。

北海道大学 国際連携研究教育局長
寶　金　清　博

※これまでに設置したグローバルステーション（GS）

GS 名	設置期間（年度）	主な学内連携部局等
量子医理工学	2014～2019	医学研究院、大学病院ほか
人獣共通感染症	2014～2019	人獣共通感染症国際共同研究所、獣医学研究院
食水土資源	2015～2019	農学研究院ほか
ソフトマター	2016～2020	先端生命科学研究院ほか
ビッグデータ・サイバーセキュリティ	2016～2020	情報科学研究院ほか
北極域研究	2016～2020	北極域研究センターほか
バイオサーフィス創薬	2019～2023	薬学研究院ほか
先住民・文化的多様性研究	2021～2025	アイヌ・先住民研究センターほか

国際連携研究教育局 (GI-CoRE)
ソフトマターグローバルステーション
外部評価委員

*東京大学大学院　新領域創成科学研究科　伊藤　耕三　教授

アメリカ合衆国　ノースウェスタン大学　　ケネス・シュル　教授

ハンガリー　センメルヴェイス大学　ミクローシュ・ズリーニー　名誉教授

*委員長

国際連携研究教育局 (GI-CoRE)
ソフトマターグローバルステーション
外部評価委員会実地調査要領

１．調査日程

令和２（2020）年９月１日（火）

２．詳細スケジュール

９月１日（火）日本時間			
日本時間	次第	米国中部標準時	中央ヨーロッパ時間
21:00	開会 外部評価について説明 （出村教授）	7：00	14：00
21:10～21:40	GSS の活動説明 （Gong 教授）	7：10～7：40	14：10～14：40
21:40～21:45	GSS の活動説明 （Creton 教授）	7：40～8：45	14：40～14：45
21:45～21:50	GSS の活動説明 （Rubinstein 教授）	7：45～7：50	14：45～14：50
21:50～22：10	質疑応答（参加者）	7：50～8：10	14：50～15：10
22:10～22:30	評価委員ディスカッション	8：10～8：30	15：10～15：30
22:30～22:40	総括 閉会挨拶（出村教授）	8：30～8：40	15：30～15：40

国際連携研究教育局 (GI-CoRE)
ソフトマターグローバルステーション
外部評価調書の概要（参考和訳）

総合評価：S

（評価コメント）

GI-CoRE と GSS の活動実績は、全員一致で、国際的な連携研究および教育の両面において、当初計画を超える成果をあげており、卓越していると評価した。

国際連携を含む研究成果は、Nature, Science, Advanced Materials など多くの著名ジャーナルに掲載されている。研究の生産性は、北大ユニット主導の取り組みが大半であったが、我々の期待を上回っている。この生産性の高さのほとんどは、GSS によって培われてきた国際連携研究の本質に直接起因している。そして優れた国際サマースクールは、ソフトマター科学分野における基礎および最先端のテーマについて、世界的に卓越した研究者から、若手研究者や学生に、直接、学ぶ機会を与える場となった。これは、当初設定されていた全ての研究・教育目標どおり、もしくはそれを上回る程度に、非常によく運営されている取り組みである。この非常に高い基準は、科学的なホスピタリティにも及んでおり、GSS が主催するワークショップの成功にもつながっている。

したがって、国際連携研究・教育を促進する体制と枠組みがうまく確立されていると言える。これらの努力のすべてが集合的に、ソフトマター科学の発展と社会実装に重要な役割を果たしている。生活の質を向上させるための生命科学の急速な発展には、そのような学際的な知識とソフトマター科学における国際連携研究が必要である。GI-CoRE/GSS の将来像としては、今後、生命科学に関する社会の課題解決だけでなく、環境問題の解決にもつながることを、我々は強く確信している。

日本では、国際連携研究と教育とを両立している成功例は稀である。この(GSS の)ように、成功を収めた国際連携研究・教育を今後も持続的に発展させるため、北大及び日本の資金提供機関が強力な支援を継続していくことを、我々は心から望んでいる。

Final Evaluation Report
(original version in English)

外部評価報告書（英語・オリジナル版）

Contents

Foreword

Hokkaido University established the Global Institution for Collaborative Research and Education (GI-CoRE) as a faculty organization under the direct control of the President that brings together world-class researchers from around the world and within the University. It aims to promote international collaborative research and education that leverages the University's strengths and distinctive features as well as to provide support for international collaborative research and education promoted by faculties and centers, respectively.

Under the GI-CoRE system, a research and education hub known as a Global Station (GS) is implemented for each research field. GSs have a finite implementation period of five (5) years in principle to conduct intensive research and education activities. Thus far, eight (8) GSs in total (see * below) have been implemented to further develop research activities and contribute the resulting cutting-edge research outcomes to graduate school education.

In the final year of the GI-CoRE project period, a Final Evaluation is conducted by the External Evaluation Committee composed of global experts outside Hokkaido University for each GS to not only review GS activities from past years but also build a stronger and more sustainable research and education system in the future.

This Final Evaluation Report contains the Research Progress Report of GS for Soft Matter (GSS) conducted in September 2020 and the evaluation results. This report is a compilation of the research and education activities of GSS.

After the implementation period, GSS project was transitioned into Frontier Research Center for Advanced Material and Life Science, Faculty of Advanced Life Science, and it was certified as Soft Matter Collaborative Research Unit, one of the "GI-CoRE Cooperating Hubs," to continue research and education activities in cooperation with GI-CoRE after April 2021.

Hokkaido University remains committed to continuing its efforts to contribute to resolving global issues by conducting advanced research and education activities based on evaluation results.

Kiyohiro Houkin,
Director,
Global Institution for Collaborative Research and Education (GI-CoRE),
Hokkaido University
(President, Hokkaido University)

*The Global Stations (GSs) implemented thus far.

Name of the GS	Implementation Period (FY)	Main Internal Affiliation
Quantum Medical Science and Engineering	2014–2019	Faculty of Medicine, University Hospital, and others
Zoonosis Control	2014–2019	International Institute for Zoonosis Control and Faculty of Veterinary Medicine
Food, Land and Water Resources	2015–2019	Research Faculty of Agriculture and others
Soft Matter	2016–2020	Faculty of Advanced Life Science and others
Big Data and Cybersecurity	2016–2020	Faculty of Information Science and Technology and others
Arctic Research	2016–2020	Arctic Research Center and others
Biosurfaces and Drug Discovery	2019–2023	Faculty of Pharmaceutical Sciences and others
Indigenous Studies and Cultural Diversity	2021-2025	Center for Ainu and Indigenous Studies and others

Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
External Evaluation Committee

*Professor Kohzo Ito,
Department of Advanced Materials Science /Group of New Materials and Interfaces, Division of Transdisciplinary Sciences, The University of Tokyo (Japan)

Professor Kenneth R. Shull,
Department of Materials Science and Engineering, Northwestern University (United States of America)

Professor Miklós Zrínyi,
Department of Biophysics and Radiation Biology, Semmelweis University (Hungary)

*Chair

承　諾　書

東大創域第20-2-8 号
令和２年６月３日

国立大学法人　北海道大学
　国際連携研究教育局　局長職務代理　殿

職名　東京大学
　　大学院新領域創成科学研究科長
氏名　大崎博之　印

令和２年３月30日付けで依頼のありましたことについて、下記の者がソフトマターグローバルステーション外部評価委員会委員長となることは差し支えありません。

記

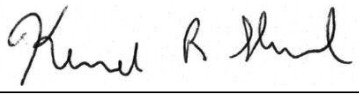
大学院新領域創成科学研究科教授　　伊藤　耕三

Letter of Acceptance

18/06/ 2020

To Acting Director Kasahara Masanori of the Global Institution for Collaborative Research and Education (GI-CoRE), the National University Corporation Hokkaido University.

I hereby accept my appointment to serve as a member of the External Evaluation Committee for the Global Station for Soft Matter at the Global Institution for Collaborative Research and Education (GI-CoRE), Hokkaido University.

Signature 

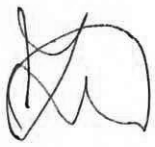
Professor Kenneth Shull

Letter of Acceptance

23 / 3 / 2020

To Acting Director Kasahara Masanori of the Global Institution for Collaborative Research and Education (GI-CoRE), the National University Corporation Hokkaido University.

I hereby accept my appointment to serve as a member of the External Evaluation Committee for the Global Station for Soft Matter at the Global Institution for Collaborative Research and Education (GI-CoRE), Hokkaido University.



Signature

Professor Emeritus Miklos Zrínyi

Global Station for Soft Matter
Global Institution for Collaborative Research and Education(GI-CoRE)
Schedule of the External Evaluation Committee

1. Date of Implementation
   Tuesday, July 7, 2020

2. Investigation Schedule

Tuesday, July 7, 2020			
JST	Session	CST	CET
21:00	Opening Explanation about External Evaluation (Prof. Demura)	7:00	14:00
21:10-21:40	Explanation about GSS Activities (Prof. Gong)	7:10-7:40	14:10-14:40
21:40-21:45	Explanation about GSS Activities (Prof. Creton)	7:40-8:45	14:40-14:45
21:45-21:50	Explanation about GSS Activities (Prof. Rubinstein)	7:45-7:50	14:45-14:50
21:50-22:10	Q&A Session	7:50-8:10	14:50-15:10
22:10-22:30	Evaluation Discussion	8:10-8:30	15：10-15：30
22:30-22:40	Summary Report (Prof. Shull) Closing (Prof. Demura)	8:30-8:40	15:30-15:40

Results of the Evaluation Committee

Evaluation Committee
Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
Hokkaido University

October 2020

Summary Report

Professor Kohzo Ito, the University of Tokyo (Japan)
Professor Kenneth Shull, Northwestern University (United States)
Professor Emeritus Miklós Zrínyi, Semmelweis University (Hungary)

Comprehensive Evaluation (S) A / B / C / D (circle one)

We all agreed that the performance of GI-CoRE and GSS was evaluated as outstanding to have achieved outcomes beyond the original plan in both international research collaboration and education. Research outcomes including international collaboration were published in many high impact journals such as Nature, Science, Advanced Materials, and so on. The research productivity has exceeded our expectations, which was mainly led by Hokkaido group. Much of this enhanced productivity can be traced directly to the nature of the international collaborations that have been fostered by GSS. And the excellent international summer schools gave young researchers and students an opportunity to study the fundamental and cutting-edge topics directly from world-wide outstanding scientists in the soft matter science. It is very well-managed effort meeting or exceeding all of the research and educational goals that have been set. This very high standard extends to scientific hospitality as well, leading to the success of the GSS sponsored workshops. Therefore, we are sure that the system and framework promoting the international collaboration and education has been successfully established. All of these efforts collectively are playing a substantial role in advances in the science and application of soft materials. The rapid development of life science with efforts to improve the quality of life needs such an interdisciplinary knowledge and international collaboration in soft matter science. We are highly confident that the future of GI-CoRE GSS will not solve only the social issues in life science but also the emerging environmental problems.
It seems rare in Japan that such international collaboration and education both succeeded. We really hope that the strong support of HU and Japanese funding agencies will continue the support to keep such a successful international collaboration and education active in the future.

Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
Final Evaluation

External Evaluation Committee Member Name: Kohzo Ito

Choose one of the five Evaluation Ratings options below as explained by the Evaluation Explanation for each Evaluation Item on the form.

Evaluation Ratings	Evaluation Explanation
S	Achieved outcomes surpassed the original plan (Outstanding)
A	Good progress has been maintained and expected outcomes have been achieved (Excellent)
B	Most expected outcomes have been achieved with some slight delays (Good)
C	Although certain outcomes were achieved, overall results were insufficient (Satisfactory)
D	No expected outcomes were achieved (Unsatisfactory)

I. Research

1. Has construction of an international research and education center capable of attracting outstanding researchers from around the world (including from HU) been achieved?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

The Hokkaido University (HU) has a world-wide reputation in the research field of soft matter science with outstanding researchers, of which Prof. Jian Ping Gong is world-widely regarded as a leading scientist. In addition, GI-CoRE has Profs. Michael Rubinstein and Costantino Creton as core collaborating scientists, each of which is also one of the most famous researchers in the field of polymer physics and soft matter physics. And other domestic and foreign principal researchers do not only include outstanding and established scientists but also young rising stars that will create novel scientific area in near future. Therefore, I am confident that this project is successfully constructed from enough outstanding researchers from both within and outside of HU.

Specific points

(Outstanding points)

This project is well organized by three core research institutes and other universities in Japan, USA, and France, where established and young researchers are easily collaborating with each other.

(Suggestions for improvement)

2. Is world-leading cutting-edge international cooperative research underway?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

HU is world-widely known by the strong soft matter science, especially Prof. Gong's group. The tough hydrogels for biomedical applications are based on this group's original idea of sacrifice bonds. This creative and original science leads to a lot of internationally cooperative researches and publications in high impact journals.

Specific points

(Outstanding points)

(Suggestions for improvement)

3. Are research outcomes from GI-CoRE being actively utilized to solve social issues?

Evaluation Results and Reasons

(Your Evaluation Results)

(S / A) / B / C / D (circle one)

A+

(Reasons)

Tough gels have quite high potential to be used for biomaterials such as artificial cartilage, artificial lens, tissue engineering, and so on, which will solve important social issues in aging society. This project has successfully encouraged close collaboration between medical doctors and materials scientists to promote biomedical application of gels. Some important and creative outcomes have been obtained but it takes a long time to apply the innovative materials to patients in practice, especially in Japan with many strict regulations. On the other hand, it is unique that the idea of sacrifice bond has been applied to the development of tough elastomers, which can be used for highly durable tire with low energy consumption. The outcomes may also solve the social issues sooner in a different field from biomedical application.

Specific points

(Outstanding points)

(Suggestions for improvement)

II. Education

Is the educational system and curriculum designed to help develop researchers who possess specialized knowledge and are capable of working internationally?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

The educational performance of GSS is really excellent and should be most highly evaluated. Especially, the summer school is greatly impressive with the most important topics and distinguished international lecturers in the soft matter science. It seems quite rare that such a really international summer school was held in Japan even in other fields. I believe that the well-organized interdisciplinary summer school was really effective to develop human resources in soft matter science. It was a shame that next summer school was unfortunately postponed by covid-19 problem. I hope that it will be held next year.

Specific points

(Outstanding points)

(Suggestions for improvement)

III. Establishment of Framework

Are the necessary systems and frameworks being established in order to conduct international cooperative research and education?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

The system and framework have worked excellently on the international collaboration in research and education and established successfully. I think that there are two reasons for the successful establishment: One is that they are based on the close collaboration among three principal scientists leading in this field, Profs. Gong, Rubinstein, and Creton, and the other is the fully strong support of HU and funding agencies. It is not a common in Japan that such an international system and framework is succeeded in a fundamental science. I really hope that they will continue after this project finished.

Specific points

(Outstanding points)

(Suggestions for Improvement)

IV. Overall Evaluation

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

Specific points

I was so impressed with the successful performance of GSS in both international research collaboration and education. Research outcomes including international collaboration were published in many high impact journals such as Nature, Science, and Advanced Materials. And the excellent international summer schools gave young researchers and students the opportunity to study the fundamental and cutting-edge topics directly from world-wide outstanding scientists in the soft matter science. The system and framework promoting the international collaboration and education has been successfully established. I feel it rare in Japan that such international collaboration and education both succeeded. I hope that they will continue by the support of HU and Japanese funding agencies.

Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
Final Evaluation

External Evaluation Committee Member Name: Kenneth R. Shull

Choose one of the five Evaluation Ratings options below as explained by the Evaluation Explanation for each Evaluation Item on the form.

Evaluation Ratings	Evaluation Explanation
S	Achieved outcomes surpassed the original plan (Outstanding)
A	Good progress has been maintained and expected outcomes have been achieved (Excellent)
B	Most expected outcomes have been achieved with some slight delays (Good)
C	Although certain outcomes were achieved, overall results were insufficient (Satisfactory)
D	No expected outcomes were achieved (Unsatisfactory)

I. Research

1. Has construction of an international research and education center capable of attracting outstanding researchers from around the world (including from HU) been achieved?

Evaluation Results and Reasons

(Your Evaluation Results)

S

(Reasons)

The program is very well designed in the way the international contributors are utilized. Regular visits of sufficient length to promote active discussions have been promoted with the French and U.S. partners. These visits have been of sufficient duration for the visitors to understand the strengths of the host institution and prevailing research culture, resulting in connections that would certainly not have without the Global Station for Soft Matter.

Specific points

(Outstanding points)

Attention has been paid the career stage of the participants, with a good mix of established and young investigators. The research productivity overall has been outstanding.

(Suggestions for improvement)
A younger person needs to be identified to whom eventual leadership of the effort can be transferred, as has been recognized by the current leadership.

2. Is world-leading cutting-edge international cooperative research underway?

Evaluation Results and Reasons
(Your Evaluation Results)
S
(Reasons)
The soft matter group is generally acknowledged as the worldwide leader in the development of tough hydrogels for biomedical applications. This leadership position brings considerable leverage to the project, which is utilized very effectively. The international visibility of the Hokkaido team as enabled them to establish a network of truly excellent collaborators.

Specific points
(Outstanding points)
Development of a mechanistic understanding of mechanical toughness in hydrogels is an important area that has benefited from the international collaborations.

(Suggestions for improvement)
Perhaps the network can be broadened a bit in the future. Having said this, I do think that the decision was to focus on two, cohesive groups of investigators was the right decision for the GSS.

3. Are research outcomes from GI-CoRE being actively utilized to solve social issues?

Evaluation Results and Reasons
(Your Evaluation Results)
A
(Reasons)
The center has a strong focus on the development of materials for biomedical applications, particularly in orthopedics.

Specific points
(Outstanding points)
Close collaborations with biomaterials specialists has the potential for the development of important new biomaterials.

(Suggestions for improvement)
While some applications in non-biomaterials areas were mentioned, I expect that even greater opportunities might exist in these areas. Biomaterials development and approval is a notoriously slow and painstaking process, and it would be useful for additional avenues of application to be developed. The program has already made progress in this direction, although more can be done.

II. Education

Is the educational system and curriculum designed to help develop researchers who possess specialized knowledge and are capable of working internationally?

Evaluation Results and Reasons
(Your Evaluation Results)
S
(Reasons)
This is one of the areas of the GSS with which I was most impressed. Inclusion of the international partners has brought a truly international flavor to some of the workshops and other educational efforts. These programs, and in particular the International Soft Matter Summer School, have a very high visibility that reflects well on the University of Hokkaido.

Specific points
(Outstanding points)
The topics at the workshops are state-of-the art, and are playing an important role in the training of the next generation of scientists.

(Suggestions for improvement)
Nothing to mention here. It's difficult to see how they could be doing more in this area.

III. Establishment of Framework

Are the necessary systems and frameworks being established in order to conduct international cooperative research and education?

Evaluation Results and Reasons

(Your Evaluation Results)

S

(Reasons)

Everything is in place for continued international collaborative research to continue. The program has high visibility internationally, a lot of scientific momentum and is at the center what is an exciting and growing research field.

Specific points

(Outstanding points)

The program has established a reputation for the high quality scientific interaction and discourse in a very hospitable environment. Simply put, it is where many scientists working in the soft matter field would like to spend some time as they develop their careers.

(Suggestions for Improvement)

The program might want to consider bilateral arrangements with international organizations that provide opportunities for scientists at Hokkaido to participate in research at the partner institutions. My sense is that scientists at the University of Hokkaido, and perhaps other Japanese institutions, would benefit greatly from these sorts of opportunities.

IV. Overall Evaluation

(Your Evaluation Results)

S

Specific points

My impressions of the program are extremely favorable in all respects. The research productivity has exceeded my expectations, which for an effort led by Hokkaido group were already very high. Much of this enhanced productivity can be traced directly to the nature of the international collaborations that have been fostered by GSS. It is very well-managed effort meeting or exceeding all of the research and educational goals that have been set. This very high standard extends to scientific hospitality as well, leading to the success of the GSS sponsored workshops. All of these efforts collectively are playing a substantial role in advances in the science and application of soft materials. My understanding is that the program is not likely to be funded at the same level by Japanese sources in the future. Assuming this is true, partnerships should be made with international funding organizations in order maintain and grow the program. Currently leadership of the program should play a role in this, but a leadership successor should be identified who can take the lead on these international partnership efforts.

Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
Final Evaluation

External Evaluation Committee Member Name: Miklos Zrinyi

Choose one of the five Evaluation Ratings options below as explained by the Evaluation Explanation for each Evaluation Item on the form.

Evaluation Ratings	Evaluation Explanation
S	Achieved outcomes surpassed the original plan (Outstanding)
A	Good progress has been maintained and expected outcomes have been achieved (Excellent)
B	Most expected outcomes have been achieved with some slight delays (Good)
C	Although certain outcomes were achieved, overall results were insufficient (Satisfactory)
D	No expected outcomes were achieved (Unsatisfactory)

I. Research

1. Has construction of an international research and education center capable of attracting outstanding researchers from around the world (including from HU) been achieved?

Evaluation Results and Reasons

(Your Evaluation Results)

Ⓢ/ A / B / C / D (circle one)

(Reasons)

The Hokkaido University has a long-term tradition in the research of soft and wet materials. As consequence of success and strength of previous achievements, HU has become a world leader in the research of soft matter. The Global Station of Soft Matter (GSS) aims to establish global community for international research and education of Soft matter, hosted in Hokkaido University. This international research and education center has invited top-class researcher from both domestic and international institutions. From 2016 several outstanding professors were invited form US and from France. The GSS includes three units, the Hokkaido University has 33 faculty members, The US unit has 5 faculty members and the France unit has 7 faculty members.

The objective of the foundation of GSS and GI-CoRE are:

- to further strengthen the understanding of fundamental properties of soft matter,
- to develop new materials with functions mimicking the properties of natural biological substances.
- to accelerate the development of soft matter application with industry collaboration,
-to attract outstanding researchers from all over the world,

-to establish international cross-disciplinary graduate school for education of Soft Matter science,

The international research and education project succeed in gathering outstanding researches from Japan, USA and France.

Specific points

(Outstanding points)

To prepare advanced polymer hydrogels with hierarchical structures and functions inspired by living organism. To develop new synthesis of soft matter using bottom-up self a-assembly combined with traditional techniques.

GSS wants to strengthen the industrial collaboration with companies to achieve fast technological transfer from academic knowledge to industry.

(Suggestions for improvement)

Soft matter is a rather young science, with rather rare application possibilities.

2. Is world-leading cutting-edge international cooperative research underway?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

The answer is definitely yes. Several original, cutting edge research achievements have been published in high profile scientific papers (Nature, Science, Advanced Materials, Soft Matter…) that have given significant impact on the University strength and results in high appreciation of the University. The high number of citation evidences this. There is no doubt that Hokkaido University maintains world leadership in the soft matter research.

This makes the world-wide recognition of Hokkaido University.

Specific points

(Outstanding points)

The widespread interdisciplinary collaboration is very effective.

The good research activity together with the outstanding results mean high reputation for the University.

Beside the fundamental research, application oriented research, like medical applications is particularly straightforward and promising.

(Suggestions for improvement)

It would be good to widen the international collaboration with other countries, where the development of soft matter science is remarkable.

3. Are research outcomes from GI-CoRE being actively utilized to solve social issues?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

Soft matter science is a broad interdisciplinary science that, among others, aims to improve the quality of life by medical means and try to contribute in eliminating or decreasing as possible, some of the risks including ages and environmental pollution. As the society age is considered, there is rapidly increasing need to develop living organism friendly medical materials, soft tissues, such as blood vessels, cartilage and tendon and so on. One of the dedicated aims of the Gi-CoRE members to prepare synthetic hydrogel biomaterials for the medical doctors to use them as implant.

The GSS has made several efforts sharing the research achievement with the society. Large number of domestic and international press release that initiated many responses from newspapers, magazines, radio- and TV broadcasting.

Specific points

(Outstanding points)

Application of strong and tough hydrogel as load bearing biomaterials for artificial cartilage and ligaments. Very active science outreach to share the results with the society.

(Suggestions for improvement)

-

II. Education

Is the educational system and curriculum designed to help develop researchers who possess specialized knowledge and are capable of working internationally?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)

The Graduate school has established the first international graduate course majoring in Soft Matter. It offers both Master's course and a Doctoral course. The curriculum makes possible to educate students who could be the leader in the research and development of soft matter. This is a unique educational course where cross-disciplinary education is targeted to Soft Matter science. I am convinced that the Graduate school through the framework of GI- CoRE Global Station for Soft Matter, Hokkaido University is able to provide excellent educational environment in this multi-disciplinary subject. It includes chemistry, physics, material-, and life science and medicine from theoretical and experimental perspectives. Overseas faculty members are also contribute in the education, by giving courses and providing information about study and make research work in abroad. Many students from Hokkaido University participated in the student international exchange. Beside the Students form HU, overseas students could benefit the exchange program. There unit leaders of GSS agreed to organize large-scale international summer school regularly in Japan, Europe and USA. The Hokkaido Summer Institute also organizes international soft matter courses.

Specific points

(Outstanding points)

The Graduate school has established the first international graduate course majoring in Soft Matter. It offers both Master's course and a Doctoral course.

(Suggestions for improvement)

Similar inter university program like Co-Tutelle program with France, would be useful for talented students from other countries.

III. Establishment of Framework

Are the necessary systems and frameworks being established in order to conduct international cooperative research and education?

Evaluation Results and Reasons

(Your Evaluation Results)

(S) / A / B / C / D (circle one)

(Reasons)
YES!
The GI-CoRE was established in 2014 as a faculty organization. It is an independent education and research organization managed by its director. Based on the success of GI-CoRE, the Global Station for Soft Matter was launched in 2016 to promote international collaborative research and education.

Specific points
(Outstanding points)
Organization and activities were driven by a faculty-led management system.

(Suggestions for Improvement)
According to future plans GSS will be internalized and absorbed into the Faculty of Advanced Life Science. GSS will maintain its independency, and the budget will be incorporated into the University ‘s ordinary budget. In order to carry on high-level research and education in the future, it is necessary to conserve the funding systems, which makes possible the world-class research and unique education system. Hokkaido University as well as GSS members need to make efforts to find sources in order to further strengthen and promote joint research and establish a word wide network on soft matter research and education.

IV. Overall Evaluation

(Your Evaluation Results)
(S) / A / B / C / D (circle one)

It was a good idea to establish GI-CoRE and GSS. The structure and activity of GSS clearly demonstrates the inevitable success of research and education in the rapidly growing field of soft matter science.

To summarize my evaluation: Outstanding
(Specific points)
The rapid development of life science with efforts to improve the quality of life, needs such an interdisciplinary knowledge, like soft matter science. It should be involved much more in the higher education. The future of GI-CoRE GSS serves this ambition.

Prof. Miklos Zrinyi

member of Hungarian Academy of Sciences

Global Station for Soft Matter
Global Institution for Collaborative Research and Education (GI-CoRE)
Hokkaido Univeristy

Research Progress Report
(Project Period: Academic Year 2016-2020)

Contents

I. Overview

1. Name of Global Station (GS)

Global Station for Soft Matter (GSS)

2. Project Period

2016-2020 academic years (5 years)

3. Aims and Goals

“Soft Matter” is a general term for research involving the conceptual development and utilization of soft substances and materials. Hokkaido University (HU) is a world leader in the research of Soft Matter, stemming originally from the research and development of mechanically tough double network hydrogels and their biomedical applications. Built on the strength of Hokkaido University’s previous achievements, GSS aims to establish a world-leading global hub for international research and education in Soft Matter. GSS aims to further strengthen our understanding of fundamental properties of hydrogels and accelerate the development of advanced hydrogel materials applications by bringing together world-leading experts on Soft Matter into one interdisciplinary group. Furthermore, GSS aims to establish the first international graduate school in Japan for the education of Soft Matter science, producing world-class graduates who will expand the global community of Soft Matter researchers. GSS will establish a cross-disciplinary educational curriculum in English to attract outstanding students from all over the world.

4. Necessity and Urgency

Soft Matter science is a broad, interdisciplinary field, cutting across the previously distinct boundaries of chemistry, physics, and biology to develop advanced new materials that aim to solve various modern societal challenges, including aging, environmental pollution, and resource shortages. Specifically, worldwide population aging is expected to progress rapidly in the next half century, and among the countries affected, Japan is advancing at an unprecedented rate. As society ages, the importance of artificial organs, such as artificial hearts and artificial joints, and reconstructive medical / nursing equipment such as endoscopes and robots, etc. is increasing. Existing “hard matter” materials such as metals, ceramics, and plastics, cannot act as fundamental materials for these biomedical purposes, as they possess significantly different mechanical properties from natural biomaterials, and often demonstrate poor biocompatibility. Developing new types of soft matter that possesses properties or functions closer to those of living organisms is urgently required. This requirement has been

recognized worldwide, and therefore the focus on Soft Matter research has been rapidly increasing. Because Soft Matter is interdisciplinary, spanning various academic (physics/chemistry/biology) and industrial (engineering /medical science/agricultural science) fields, it is urgently necessary to integrate interdisciplinary researchers into an organization for collaborative research and development and to establish a new knowledge system for the development of human resources in Soft Matter for the academic and industrial worlds. With the establishment of the Global Station for Soft Matter and International Graduate School, world-class research and education in the field of Soft Matter can be accelerated.

5. Originality and Novelty

Hydrogels, which are a type of soft matter, share many similarities with natural biological substances and are therefore expected to have a strong potential as artificial biomaterials. However, conventional hydrogels have been not of practical use because they are generally extremely brittle, breaking immediately when a slight force is applied. In 2003, Prof. Gong's research group at the HU Faculty of Advanced Life Science has developed, for the first time in history, a high-strength double network (DN) gel (patent applied for in Japan, China, South Korea, USA and EU) that achieves high toughness by taking advantage of the "softness" characteristics inherent to hydrogels, resulting in properties similar to cartilage or industrial rubbers (***Gong et al., Advanced Materials, 2003***). This research group has clarified the sacrificial bonding mechanism as the fundamental basis for the high toughness exhibited by DN gels (***Gong, Soft Matter, 2010***). Later, the group also developed reversible sacrificial bonds and succeeded in developing hydrogel materials that have not only high toughness but also self-healing properties (***Sun et al., Nature Materials, 2013***).
With the invention of double network hydrogels and discovery of the sacrificial bonding mechanism, we finally possess a strategy to produce materials with suitable properties for various modern applications, including biomedical applications such as muscles, cartilage, tendons, and ligaments, where high strength and toughness are indispensable. Since 2005, following the development of the DN gel, Prof. Yasuda's research group at the HU Faculty of Medicine, which ranks 8th (Web of Science) in the world for the study of soft tissues (ligaments), have been attempting to apply tough DN gels towards the development of artificial cartilage applications, in collaboration with Prof. Gong's materials research group. Many achievements have been made through this collaboration. One example is the discovery that natural regeneration of cartilage occurs *in vivo*, induced by the presence of DN gel (***Yasuda et al., Macromolecular Bioscience, 2009***). This discovery changed the common belief in the medical community that hyaline cartilage is not regenerable *in vivo* once damaged. This paper on the natural regeneration of cartilage *in vivo* by DN gel is ranked in the top 1% of all cited papers in the biomaterials field.

The original, cutting-edge research performed at HU has significantly impacted the general materials

science community and has inspired widespread international research on the development of novel tough soft matter (for example, ***Sun & Suo et al., Nature, 2012***, ***Ducrot & Creton et al., Science 2014***). Recently, the "sacrificial bonding principle" has been used in academia and industry in Japan and overseas as a design concept for producing high toughness materials. Based on the high citation rate of papers published by the research groups focused on hydrogels at HU (Total cited times 24,042; more than 1,000 times per year since 2011, and 2,840 times in 2019, as of July 6, 2020 google scholar), it is clear that Hokkaido University maintains a strong leadership position in this field.

GSS intends to combine the strength of HU in advanced hydrogels development and biomedical application and the strength of overseas universities on fundamentals of Soft Matter, by inviting top-class scientists to work together on the fundamental theories of Soft Matter and fracture mechanisms. Through this interdisciplinary collaboration, materials development and subsequent medical application (artificial cartilage, artificial ligament, etc.) will be accelerated.

II. Budget

Unit: 1,000 JPY

	Category	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020 (Projected)	Total
GI-CoRE Establishment of Framework	Personnel Cost (for Researchers from Overseas)	2,504	13,372	22,329	19,990	26,876	85,071
	Administrative Cost*	14,510	13,331	11,701	11,539	14,580	65,661
	Operating and Research Cost	161,472	151,783	144,456	135,524	129,048	722,283
Total		178,486	178,486	178,486	167,053	170,504	873,015

*Including travel expenses for invited researchers from overseas.

III. Detailed Results

1. Research in the Global Station for Soft Matter

1-1. Goals

The primary research objective of GSS is to create advanced polymer hydrogels with mechanical, physical, and biochemical functions close to those of biological tissues by introducing sophisticated structures inspired by living organisms. By this approach, GSS intends to create a material foundation for supporting advanced medical technologies such as biological tissue replacement and regenerative medicine. The followings are the specific tasks.

A. Bio-inspired Design and Development of Novel Functional Hydrogels

GSS aims to design multi-functional hydrogels following the structural essence of biological soft tissues, such as blood vessels, cartilage, and tendon. To create hydrogels with the required composite/ordered/hierarchical structures from nano- to macro-scale, GSS will develop various novel processes for gel synthesis, combining the bottom-up self-assembly and the top-down approach aided with the external energy input.

B. Revealing Physical Principles of Multi-functional Hydrogels

GSS will analyze the superb performance of hydrogels created in **t**ask **A**, including viscoelasticity, strength and toughness, fatigue, shock-absorbency, self-healing, anisotropy, adhesion, and friction, and reveal the mechanisms that allow for the emergence of soft, hydrated materials that are highly deformable yet possess sophisticated structures. By comparing the results of the obtained synthetic hydrogels with living tissues, GSS will provide a pathway through a soft matter materials science perspective to understanding the mechanisms that enable excellent biological functions in soft materials.

C. Applying Synthetic Hydrogels as Multi-functional Biomaterials

GSS will apply the multi-functional hydrogels developed in task **A** for various applications, mainly focusing on but not limited to biomedical applications. Specifically, GSS will focus on applications of tough hydrogels as artificial cartilage, on controlling and directing cell proliferation and differentiation, and on inducing spontaneous regeneration of soft tissues both *in vitro* and *in vivo*, using the dynamic stimulation effects of hydrogels. By integrating the above-described polymer science, cell engineering, and cell medicine, GSS will create multi-functional hydrogels that can serve as fundamental biomaterials for cutting-edge medicine.

D. Industry Collaboration

GSS will actively collaborate with industry to quickly convert the laboratory-scale materials into viable technologies for practical products. Specifically, GSS will establish a joint research laboratory with

the private sector, NGK Spark Plug Co.,Ltd., focusing on the development of tough double network hydrogels for joint disease treatment. GSS also participates in a Japanese cabinet-sponsored national project, the ImPACT Ito Kohzo program, that is aiming for fast transfer of academic knowledge on tough polymer designs to industry.

1-2. Construction of Base

1-2-1. Implementation System

Taking full advantage of GSS's budget and concentrated research center style, GSS has succeeded, from 2016 in total, in inviting 12 outstanding overseas researchers as cross-appointed professors, including 2 distinguished professors, 6 full professors, 3 associate professors, and 1 assistant professor from the US and France. These overseas faculty members are from top-class universities of the Soft Matter field. GSS also cross-appointed 33 domestic faculty members. Thus, GSS owns a group of faculty members with a broad research background, including polymer science, soft matter physics, fracture mechanics, cell biology, medicine, including both experimental and theoretical scientists.

GSS consists of three units. The Hokkaido University unit has 33 faculty members, 15 from Faculty of Advanced Life Science, 8 from Faculty of Medicine, 8 from the Research Institute for Electronic Science, and 2 from Hokkaido University Hospital. The US unit has 5 faculty members, 2 from the Duke University, 1 from Cornell University, 1 from North Carolina State University, and 1 from Iowa State University/Southern University of Science and Technology. The France unit has 7 faculty members, 3 from ESPCI Paris, 2 from Sorbonne University, 1 from University Paris Diderot, and 1 from University of Bordeaux. Several post-doctoral fellows are placed in the three units. The Hokkaido University members are strong in materials sciences, structure characterization, and medical sciences, while the French members and US members are strong in soft matter mechanics and theory.

List of GSS Members

Unit	Researchers	Research Field
Hokkaido University Unit 【Director】 Makoto Demura 【Unit Leader】 Jian Ping Gong	**Faculty of Advanced Life Science**	
	Distinguished Prof. Jian Ping Gong	Soft Materials, Hydrogels
	Prof. Takayuki Kurokawa	Polymers, Biomaterials
	Associ. Prof. Tasuku Nakajima	Polymer Science, Hydrogels
	Associ. Prof. Takayuki Nonoyama	Bio-Ceramics
	Assist. Prof. Daniel R. King	Soft Composites
	Visiting Prof. Kazunori Yasuda	Biomaterials
	Prof. Makoto Demura	NMR Spectroscopy
	Prof. Tomoyasu Aizawa	NMR Metabolomics,
	Lecturer Takashi Kikukawa	Photoactive Proteins
	Assist. Prof. Takashi Tsukamoto	Biophysics
	Prof. Hisashi Haga	Cell Mechanics
	Assist. Prof. Seiichiro Ishihara	Cell Mechanics
	Postdoctoral Fellow Hiroyuki Kumeta	NMR
	Assist. Prof. Taolin Sun (2016.4 - 2017.12)	Soft Materials
	Assist. Prof. Takeomi Mizutani (2016.6 - 2017.3)	Cell Mechanics
	Assist. Prof. Kazuya Furusawa (2016.6 - 2018.3)	Biomaterials
	Postdoctoral Fellow Tomáš Sedlačík (2017.4 - 2019.3)	Polymer Materials
	Postdoctoral Fellow Honglei Guo (2017.4 - 2019.3)	Physical Chemistry
	Research Institute for Electronic Science	
	Prof. Kuniharu Ijiro	Nanomaterials
	Associ. Prof. Hideyuki Mitomo	Nanomaterials
	Assist. Prof. Yusuke Yonamine	Nanomaterials
	Prof. Toshiyuki Nakagaki	Active Soft Matter
	Associ. Prof. Katsuhiko Sato	Active Soft Matter
	Assist. Prof. Yukinori Nishigami	Active Soft Matter
	Associ. Prof. Kenichi Niikura (2016.6 - 2017.3)	Bioengineering

	Assist. Prof. Shigeru Kuroda (2017.7 - 2018.3)	Active Matter
	Faculty of Medicine	
	Prof. Norimasa Iwasaki	Orthopedics, Biomaterials
	Associ. Prof. Masahiko Takahata	Orthopedics
	Assist. Prof. M. Alaa Terkawi	Immunology, Biomaterials
	Prof. Shinya Tanaka	Pathological Science
	Associ. Prof. Masumi Tsuda	Pathological Science
	Assist. Prof. Lei Wang	Pathological Science
	Assist. Prof. Jun Suzuka	Pathological Science
	Prof. Nobuto Kitamura (2016.6 - 2017.4)	Orthopedics, Biomaterials
	Hokkaido University Hospital	
	Prof. Eiji Kondo	Orthopedics
	Lecturer Tomohiro Onodera	Orthopedics
U.S. Unit 【Unit Leader】 Michael Rubinstein	Distinguished Prof. Michael Rubinstein (Duke University)	Polymer Physics Theory
	Prof. Stephen Craig (Duke University)	Mechanochemistry
	Prof. Jan Genzer (North Carolina State University)	Soft Matter Interface
	Prof. Wei Hong (Iowa State University/Southern University of Science and Technology)	Soft Mechanics Theory
	Prof. Chung-Yuen Hui (Cornell University)	Fracture Mechanics Theory
	Postdoctoral Fellow Tsutomu Indei	Polymer Physics, Rheology
France Unit 【Unit Leader】 Costantino Creton	Distinguished Prof. Costantino Creton (CNRS, ESPCI Paris)	Fracture Mechanics
	Prof. Dominique Hourdet (Sorbonne University)	Polymer Chemistry
	Prof. Anke Lindner (University Paris Diderot)	Microfluidics
	Associ. Prof. Tetsuharu Narita (CNRS, ESPCI Paris)	Polymer Dynamics

	Associ. Prof. Alba Marcellan (Sorbonne University)	Soft Matter Mechanics
	Associ. Prof. Cécile Monteux (CNRS, ESPCI Paris)	Surface and Interface
	Assist. Prof. Thomas Salez (CNRS, University of Bordeaux)	Soft Matter Physics
	Postdoctoral Fellow Xueyu Li	Fracture Mechanics
	Postdoctoral Fellow Yanan Ye	Polymer Science
	Postdoctoral Fellow Hui Guo (2017.4 - 2018.12)	Polymer Chemistry
	Postdoctoral Fellow Anaïs Giustiniani (2018.6 - 2019.9)	Soft Matter Physics

1-2-2. Role of Overseas Faculty Members

The overseas faculty members will focus on the fundamental theoretical and experimental studies on advanced soft matter in collaboration with the domestic faculty members. The research topic includes deformation, yielding, fracture, and fatigue of tough hydrogels, from single molecules to materials levels. The overseas faculty members will also contribute to the education of the newly established Division of Soft Matter, in the Graduate School of Life Science. They will give advice on researches to our graduate students and provide students with opportunities to study in their research laboratories. They will send students to GSS for collaboration. They will also give course lectures in the Graduate School of Life Science. In addition, they will provide seminars during their stay at Hokkaido University, giving students the opportunity to communicate frankly with them. The international faculty members will also participate in the organization of International Symposiums and International Soft Matter Summer Schools.

1-2-3. Role Sharing between Faculty Members at HU

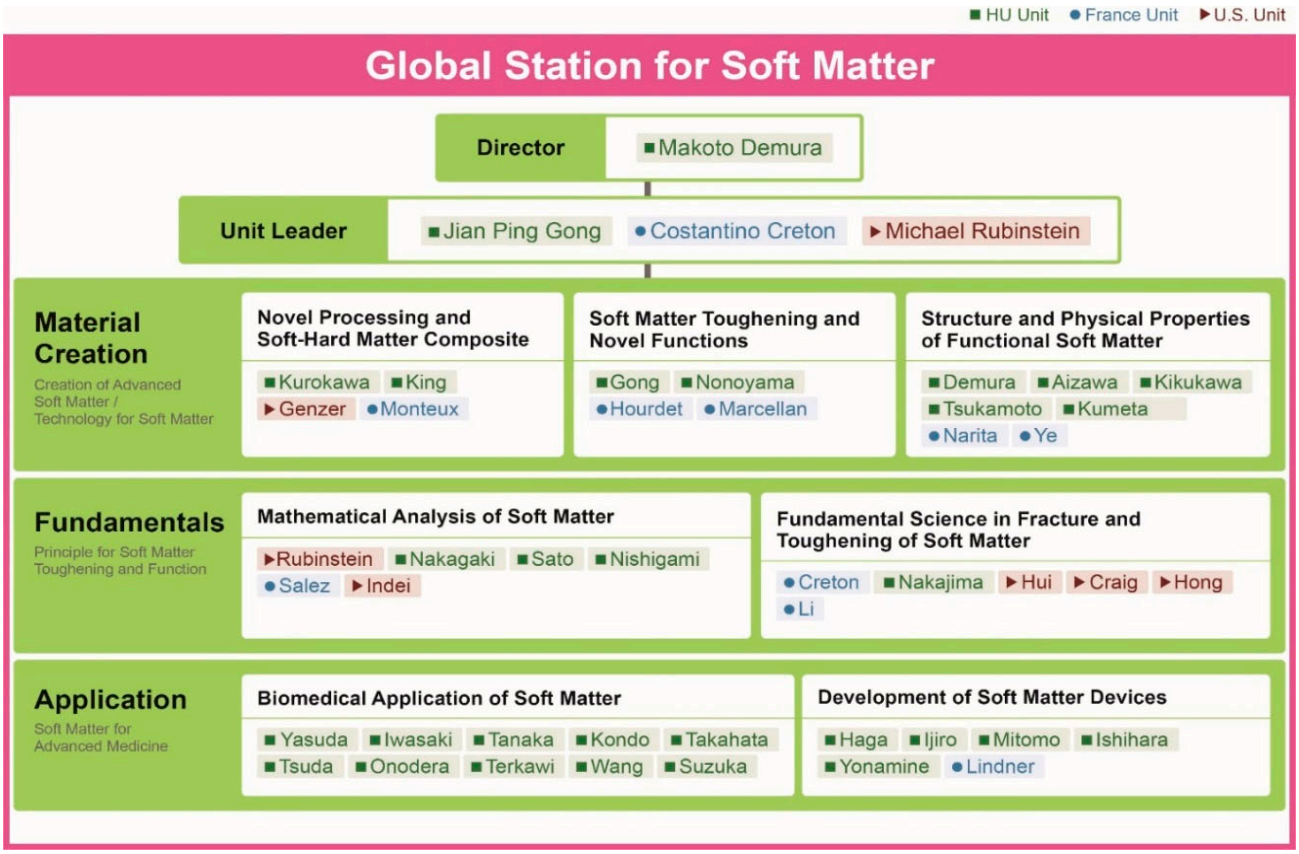
The members from the Faculty of Advanced Life Science will lead the development of novel hydrogels and its structural and functional characterization. The members from the Faculty of Medicine and from the University Hospital will lead the medical applications of hydrogels as artificial cartilage and as scaffolds for rapid reprogramming towards cancer stem cells materials for cancer treatment. Finally, the members from the Research Institute for Electronic Science will lead the research on the development of soft devices. Prior to the creation of this international collaborative project, some members from the Faculty of Advanced Life Science and the Medical School have collaborated for years, attempting to adopt tough double network hydrogels for cartilage treatment. This collaboration

will be continued during this project.

Faculty members of Hokkaido University will manage the international research projects, submit proposals for national grants, and prepare projects involving industry-academia collaborations. Faculty members will mainly educate the students in the Division of Soft Matter, Graduate School of Life Science and provide opportunities to work with major international researchers overseas. The faculty members at HU are distinguished into two groups; the hydrogel materials group will mainly engage in international collaborative researches with the overseas members, and the other group are primarily engaged in domestic collaborations and education within the Division of Soft Matter, Graduate School of Life Science.

1-2-4. Research Structure

The activities of GSS can be divided into three groups according to the three objectives of the project: the materials creation group, the fundamental science group, and the application group. In each group, both international faculty members and domestic faculty members are placed. Specifically, Professor Jian Ping Gong of HU unit will lead the research on design and development of novel soft materials with excellent function and its applications. Prof. Costantino Créton of the France unit will lead the research on fundamental science in fracture and toughening of soft matter. Prof. Michael Rubinstein of the US unit will lead the research on fundamental theories of soft matter deformation from the molecular to macroscopic levels.



1-2-5. Equipment and Facilities

For sharing equipment specialized for soft matter research, a Soft Matter Open Unit (SMOU) will be established in 2017 as a management and maintenance system based on the University Open Facility Platform. By such effort, the advanced equipment necessary for soft matter research is integrated. The SMOU facility provides an educational environment that can be used as a practical training facility for graduate education in the Division of Soft Matter (common graduate school subjects / international summer school).
http://aces.gfc.hokudai.ac.jp/future/sky/smou/english/

1-3. Current Progress of International Collaborative Research

Through collaborations between the three units, many prominent results have been achieved. These results demonstrate a significant advancement of the knowledge in the field of soft matter fundamentals and technology. Some of the results are highlighted in this progress report. For details, please see **Appendix A Highlighted Research Progress**.

Regarding **task A**, through investigating the structure of biosystems, from protein sequences to macroscopic geometries, novel bioinspired hydrogels with diverse functionalities have been fabricated. Inspired by the amino acid structure of adhesive foot proteins in Mussels, hydrogels from cationic and aromatic monomers with adjacent sequences have been synthesized and these poly(cation-adj-π) hydrogels exhibit prominent under sea water adhesion (***Fan et al., Nature Communications, 2019***), and the work has drawn great attention from the world. Inspired by thermally stable thermophile proteins, novel materials showing instant thermal switching from soft hydrogels to rigid plastics have been synthesized and the interplay mechanism between electrostatic interactions and hydrophobic interactions is proposed (***Nonoyama et al., Advanced Materials, 2019***).

To mimic order/disordered hybrid structures, double network physical hydrogels made from triblock copolymers have been synthesized, and these hydrogels show abnormally large linear deformation along with high toughness and self-healing (***Zhang et al., Advanced Materials, 2016***). These physical tough hydrogels allowed us to obtain ultra-thin (~μm) membranes for use as artificial biological membranes where toughness, semi-permeability and biocompatibility is required (***Ye et al., Advanced Functional Materials, 2018***). Inspired by the stretching/drying process that takes place during the formation of spider silk, a process of drying hydrogels from rigid biopolymers in confined conditions has been developed, which allows us to obtain perfectly aligned fibrous hydrogels with hierarchical superstructures, and these fibrous gels show ligament-like mechanical modulus and strength (***Mredha et al., Advanced Materials, 2018***).

The features of hard/soft composites found in natural materials also drives us to develop composite hydrogels. Combining viscoelastic and self-healing polyampholyte gels with woven fiber fabrics leads to the creation of extraordinarily tough soft hydrogel composites that exceeds the toughness of metals (***Huang et al., Advanced Functional Materials, 2017***). Recently, the design essence has been applied to viscoelastic elastomers as a soft matrix, and these new soft composites outperform the toughness of existing fiber reinforced polymer composites (***Cui et al., Advanced Materials, 2020***). The double network concept and the sacrificial bond principle is used to design and develop macro-scale composites (***King et al., ACS Applied Materials & Interfaces, 2019***). Composites made of soft matrices (hydrogels and elastomers) and hard grids (3D printed plastics and low melting alloys) with macroscopic double network structure show yielding and high toughness by preferential fracture of the rigid grid prior to the soft matrix, similar to that of a double network hydrogel. Such macro-scale composites allowed us to clarify the design criteria for optimizing strength and toughness. The

composite using low melting alloy enables self-healing, electrical conductivity, and controlled electrochemical reactions and channel-structure templating in hydrogel matrices (***Takahashi, et al., Advanced Materials, 2018***).

Inspired from the surface geometry of clingfish with a sucker for attachment to rocks and other surfaces, we designed millimeter-scale honeycomb-like channels on the surface of polyampholyte hydrogels. These hydrogels show fast, strong and reversible under water adhesion, since the honeycomb-like channels enable fast liquid drainage and resist crack propagation during debonding (***Rao et al., Advanced Materials, 2018***). Such fast attachment to surfaces while submerged in water should find applications, such as in bandaging bleeding tissues during surgery.

In biological systems, most structures are formed by dynamic, out-of-equilibrium processes. Furthermore, many functions are based on metabolic processes, accompanied by structure destruction and reconstruction, during which nutrition is required for mass and energy supply. Research mimicking such features has not yet been extensively explored. We are aiming to approach this challenge by building novel hydrogels based on out-of-equilibrium structures and mimicking metabolic processes. One successful example of out-of-equilibrium structure formation is the discovery of the abnormal swelling of hydrophobic gels in water, reaching water content as high as 99.6 wt%. The spontaneous skin layer formation and osmosis of water results in a skin-cell structure similar to the structure of an orange. Based on this mechanism, the gels can spontaneously separate pure water from sea water (***Guo et al., Advanced Materials, 2019***). Inspired by the memorizing-forgetting behavior of the brain, we proposed a principle to develop hydrogels that can memorize and then forget information spontaneously. Using polyampholyte hydrogels, we demonstrated that the forgetting time can be controlled by the thermal learning strength and learning time. The structure frustration transiently-induced by the large difference in the diffusion coefficient of heat and water, and the asymmetric swelling and shrinking kinetics of physical hydrogels at different temperatures, are two essential mechanisms for this memorizing-forgetting behavior of hydrogels (***Yu et al., PNAS, 2020***). Inspired by muscle training, we developed a double network hydrogel system that shows self-growing and self-strengthening by mechanical training. By deformation, the internal rupture of the brittle network occurs to generate mechanoradicals that initiate new network formation in the presence of monomers (nutrition). By such a mechanism, the double network hydrogels become stronger by mechanical training like muscle. This work is the first attempt to induce the metabolic-like process in a synthetic material (***Matsuda et al., Science, 2019***).

Regarding **task B**, we mainly focused on structure and mechanical behavior relationships and fracture mechanics of soft matter. We adopted three tough hydrogel systems (double network gels, polyampholyte gels, and the soft composites from polyampholyte/woven fiber fabrics) developed in **task A** as model systems for the study. Along with existing methodologies such as SAXS and TEM, we developed new methodologies to characterize the structures of hydrogels at the molecular- and meso-length scales. Specifically, a new microelectrode technique has been established to characterize

the spatial distribution of electric potential in hydrogels (***Guo, et al., Macromolecules, 2016***). Using this new technique, the internal fracture structure evolution of double network hydrogels during deformation has been elucidated on the micro-scale for the first time (***Guo et al., Macromolecules, 2019***). The molecular mechanism and criteria for yielding of double networks has been clarified by adopting Tetra-PEG hydrogels with well-controlled network structure for the first network (***Matsuda, et al., Macromolecules*****, 2016**). We are also establishing a theory and an experimental approach to extract single polymer chain force curves until its rupture from double network hydrogels. This work, for the first time, connects the molecular behavior with the macroscale properties of network polymers (***Indei et al., 68th Rheology Meeting, 2020***). We also clarified the mechanism for the elastic−plastic transformation found in double network physical hydrogels made from biopolymers chitosan and sodium hyaluronate. The role of chain rigidity and the polyelectrolyte complexation between the two biopolymers have been clarified (***Shi, et al., Macromolecules, 2018***).

For the tough and self-healing polyampholyte hydrogels, we revealed the existence of a meso-scale (~100 nm) network structure formed by local phase separation, and the high toughness of the gels is attributed to the multiscale energy dissipation mechanism (***Cui et al., Physical Review Letters, 2018***). Furthermore, the fatigue fracture of polyampholyte hydrogels has been studied and we observed a unique delayed fatigue fracture process in these hydrogels with hierarchical structures (***Li et al., PNAS, 2020***). For the deformation and fracture of fiber reinforced soft composites, theoretical analysis using a simplified composite model has been proposed, and this model describes the essential features of soft composites, such as the relationship between the modulus ratio of the components (fabric and matrix) and the width of the process zone. This model defines the design criteria for optimizing the properties of tough soft composites (***Hui et al., Extreme Mechanics Letters, 2020***).

Moreover, the surface sliding friction of hydrogels in concentrated polymer solutions, as a model system for cartilage lubrication, was studied and shearing-induced contact pattern formation has been discovered for the first time. The result gives insight into the lubrication mechanism of human joints (***Yashima et al., Soft Matter, 2019***).

Regarding **task C**, our main focus is on the application of strong and tough hydrogels as load-bearing biomaterials, including artificial cartilage and ligaments. A bottle neck of such applications is the difficulty to fix the hydrogels robustly to bone, with a non-toxic, surgically feasible approach. We have successfully developed a method to bond double network hydrogels to bone in vivo by mineralizing the surface layer of the hydrogels with the osteoconductive mineral HAp (***Nonoyama et al., Advanced Materials, 2016)***. This method is quite universal, also applicable to collagen-based tough double-network hydrogels (***Mredha et al., Biomaterials, 2017***). The method has been found feasible for fixing the gels on defected bones with various sizes ***(Wada et al., Acta Biomaterialia, 2016)***. Using isotope analysis at different implant times, the bonding mechanism has been clarified recently (***Nonoyama et al., submitted***). Using functional hydrogels to induce cell differentiation and proliferation is another aim of **target C**. We discovered that on some hydrogels, the cancer stem cell can be reprogrammed

back to the cancer stem cell (***Suzuka et al., Nature Biomedical Engineering, 2021***). This discovery is remarkable, since it has a great potential to permit the early stage diagnose of cancer diseases and fast drug screening. Besides, the soft composites are also used to build solvent-driven soft actuators (***Hubbard et al., Matter, 2019***), and a photonic hydrogel is successfully integrated into microfluidics devices for optical imaging of pressure distribution (***Ducloué et al., to be submitted***).

Regarding **task D**, we established a joint research laboratory at Hokkaido University with NGK Spark Plug Co., Ltd., devoted to the development of artificial cartilage using double network hydrogels. Application-oriented biomaterial properties of double network hydrogels, including biocompatibility, long term physical and chemical stability, implant geometry and dimension, surgery technique of implantation, and fabrication processes for large scale production in industry, are being studied. The progresses of these research areas have resulted in filed patents with NGK Spark Plug Co., Ltd. We also participated in the ImPACT Ito Kohzo program granted by the Cabinet of Japan, through which we had the opportunity to collaborate with the Bridgestone Corporation (one of the top 3 tire companies in the world) and succeeded in applying the double network concept to develop high performance industrial rubbers. In addition, we also collaborated with 12 other companies on novel materials research and development. The total research grant allowance from companies was 122 million Japanese Yen during FY2016-2020.

1-4. Future Research Perspective

Compared with natural hydrogels found in biological systems, the state-of-art synthetic hydrogels still lack the nano- to macro-scale complex hierarchical structures and are inferior in their functions. We are only scratching the surface of the possibilities in mimicking biological structures. A prerequisite for the formation of the elaborate structures seen in biological materials is the ability to precisely controlled monomer sequences. Therefore, one of the most important and fundamental problems in hydrogel material science is achieving precise control of monomer sequences within synthetic polymer networks. Although the development of synthetic polymers with controlled monomer sequences has seen some progress, it is still challenging to precisely control monomer sequences while using high-efficiency synthesis methods that allow for mass production to meet the commercial demand for these materials. GSS is starting the collaboration with groups in WPI-ICReDD (Institute for Chemical Reaction Design and Discovery, established by World Premier International Research Initiative) at Hokkaido University to tackle this challenge, and this collaboration will be strengthened over the next five years.

While achieving precise monomer sequence control is an important step, other requirements exist to create true synthetic hydrogels with properties similar to natural tissues. To build hierarchical structure

over many length scales (from micrometer to millimeter), a combination of bottom up approaches such as self-assembly and phase separation processes and top down approaches using external fields, such as tensile stress, shear flow, extrusion, and electric and magnetic fields, should be developed. To characterize the multiscale, order/disorder, composite structures, novel methodologies suitable for water-containing materials should also be developed.

Furthermore, the scientific understanding of the correlation of specific structures and properties of biological systems is still quite limited. High-performance hydrogels created through learning from nature can lead us to revealing the mechanism of *emergent functions* demonstrated in biological systems, thus answering the question of what special functions various structures have in living tissues. These studies will firmly establish a new subfield in soft matter that is characterized by molecular transportation, large deformation, non-linearity, relaxation, out-of-equilibrium processes, and mechanochemical reaction: *Soft & Wet Matter Science*.

We believe that the research achievements of bioinspired hydrogels will enable the next generation of artificial tissues and various soft artificial organs. These materials are vastly superior in both form and function to “hard” artificial organs such as artificial blood vessels and the artificial heart, which should improve their performance in real-world trials.

1-5. Activities and Outcomes (FY 2016-2020)

1-5-1. Summary of Research Achievements and Activities (FY 2016-2020)

1.International Collaborative Papers (peer reviewed)	Featured in Journals: #125 (Top 10% paper: # 6) Review #2
2. Other Publications	Featured in Journals: # 332 (Top 1% paper: # 3, Top 10% paper: # 5) Review/Others: #19 (Top 1% paper: # 1) Books Published: #3
3. Verbal Presentations	Plenary Lectures: #5 Keynote Speeches: #11 Invited Lectures: #99
4. Patent Applications	Pending Patents: #23 (# 17 in Japan, #6 overseas) Registered Patents (of the above number): # 2
5. Awards Received	#22
6. External Grants	National Grants: #29 Others: #29 Collaboration with Industry: # 12 Total Amount: 122,384,808JPY
7. Seminars	# 37
8. Science Outreach	Press Release: # 11 Media Reports: # 93 (Newspaper: # 43, Internet: # 26, TV Features: # 19, Magazines: #3, Radio: # 2)
9. International Symposiums & Workshops	# 5
10. Educations	#2 (Summer School, Summer Institute)

1-5-2. Publications in the High-Profile Journals

GSS has published many original papers related to hydrogel researches in the high-profile journals, from prominent science journals, top materials science journals, to top polymer science journals. Among them, 4 are ranked as top 1% papers, and 11 as top 10% papers, according to 2021.8.13 Percentile (from Essential Science Indicators).

The original papers directly related to the three goals of GSS are mainly published in the following journals.

General Science Journals

2 in Science (IF 41.037)
3 in Nature Communications (IF 11.800)
5 in PNAS (IF 9.580)
6 in Physical Review Letters (IF 9.227)

Material Science and Chemistry Journals

11 in Advanced Materials (IF 25.809)
3 in Advanced Functional Materials (IF 14.860)
2 in Journal of the American Chemical Society (IF 14.695)
2 in ACS Nano (IF 13.700)
2 in Journal of Materials Chemistry A (IF 10.733)
2 in Chemistry of Materials (IF 10.159)
6 in ACS Applied Materials & Interfaces (IF 8.456)
1 in Biomaterials (IF 10.250)
4 in Acta Biomaterialia (IF 6.638)
4 in Journal of Materials Chemistry B (IF 5.047)
1 in Advanced Materials Interface (IF 4.713)

Polymer Science Journals

22 in Macromolecules (IF 5.997)
3 in ACS Macro Letters (IF 5.775)
14 in Soft Matter (IF 3.330)
5 in Polymer (IF 3.164)

Bio Science and Engineering Journals

1 in Nature Biomedical Engineering (IF 17.135)

1-5-3. Publications Co-Affiliated with Other International and Domestic Institutions

GSS has performed very active international and domestic collaborations, not only among GSS international and domestic members but also with other international and domestic institutions (universities, research institutes, local government, companies, etc.). This can be seen from the publications of GSS members co-affiliated with other international and domestic institutions. Specifically, as shown in the following figure, 71 institutions that are co-affiliated, 14 are located in North America, 19 are in Europe universities, and 18 are in Asia and Oceania, 12 in Japanese, 8 with companies. A list of the co-affiliated international and domestic institutions of joint publication is shown in **Appendix B**.

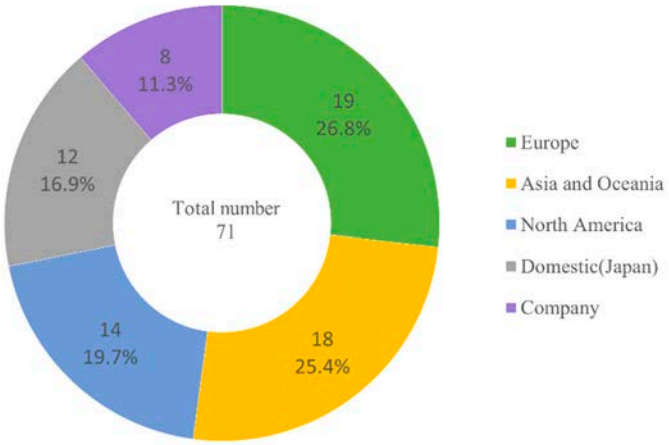


Figure: Regional distribution of co-affiliated international and domestic institutions (universities, research institutes, local government, companies, etc.) with joint publications with GSS members.

A full list of International collaborative publications, other publications by GSS members, verbal presentations, and patent, are shown in **Appendix C**. GSS members have received awards. A selected list of the awards is shown in **Appendix D**.

1-5-4. External Grants (FY2016-2020)

GSS members are quite successful in obtaining the competitive grants. GSS domestic members receive the grants of 1,000,494,808 JPY in total, mainly the Grant-in-Aid from the Japan Society for the Promotion of Science (JSPS) (74.9%). GSS also received grants from private companies and other organizations. The breakdown of grants received is shown in the following figure. A full list of the grants is shown in **Appendix E**.

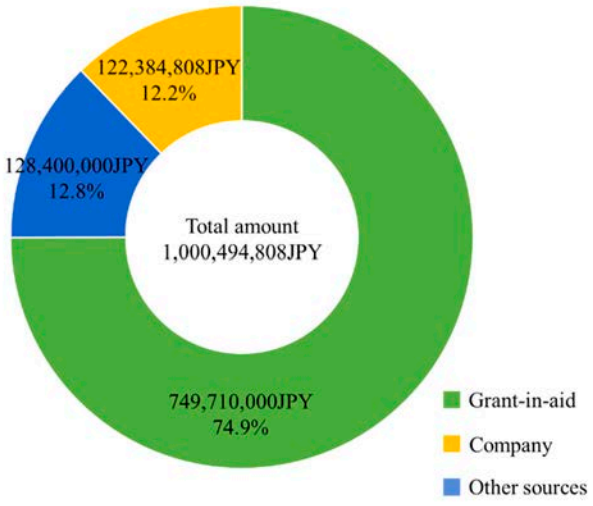


Figure: Total amount of grants and its breakdown obtained by domestic GSS members during FY 2016-2020.

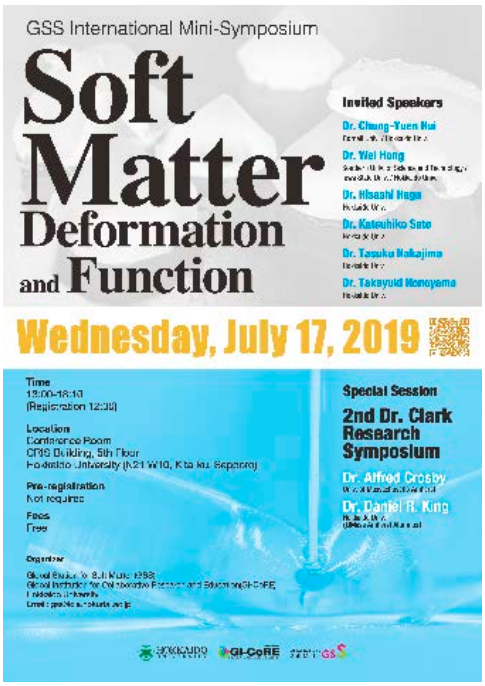
1-5-5. International Symposiums and Workshops

The following five international symposiums and workshops have been held during 2016-2020.

1. GSS International Mini-Symposium “Soft Matter Deformation and Function,” Hokkaido University, 2019.7.17
2. The 1st Dr. Clark Research Symposium, Hokkaido University, 2019.7.17
3. Hokkaido University-ImPACT Joint Symposium “International Symposium on Advanced Soft Matter: From Single Molecule to Tough Polymers”, Hokkaido University, 2017.8.7-8
4. International workshop on “Active Soft Matter and Ethology,” Hokkaido University, 2017.8.4
5. The First International Symposium on Advanced Soft Matter, “Celebrating the Kick-off of the Global Station for Soft Matter, GI-CoRE,” Hokkaido University, 2016.6.13-15

GSS International Mini-Symposium “Soft Matter Deformation and Function”, 2019.7.17

Global Station for Soft Matter held an international mini-Symposium “Soft Matter Deformation and Function” on July 17th, 2019 at the Creative Research Institution, Hokkaido University. The symposium gathered 52 attendees including invited speakers from overseas institutions: Prof. Chung-Yuen Hui from Cornel University, Prof. Wei Hong from Iowa State University and Sothern University of Science and Technology, and Prof. Alfred Crosby from the University of Massachusetts Amherst. Based on the symposium theme, the attendees exchanged opinions and had active discussion together with the students of newly established Division of Soft Matter.



- HU-ImPACT Joint Symposium

Hokkaido University-ImPACT Joint Symposium "International Symposium on Advanced Soft Matter: From Single Molecule to Tough Polymers" was held on August 7th and 8th, 2017 at Hokkaido University. This symposium was jointly organized by GSS and ImPACT's Ito Program, a research and development program by JST and the Cabinet Office, Government of Japan. The Joint Symposium was realized on the occasion of the "**International Soft Matter Summer School in Hokkaido**" in which many distinguished researchers, young investigators, and graduate students of soft matter studies from all over the world congregate in Hokkaido.

In the two-day program, 19 invited lectures on the advanced soft matter by the summer school lecturers and Ito Program academic members were delivered, followed by a fruitful Q&A session. Also, 82 posters were presented by young researchers and graduate students. A total of 165 people participated in this symposium, providing valuable research exchange opportunities for the attendees on the cutting-edge technologies and knowledge.

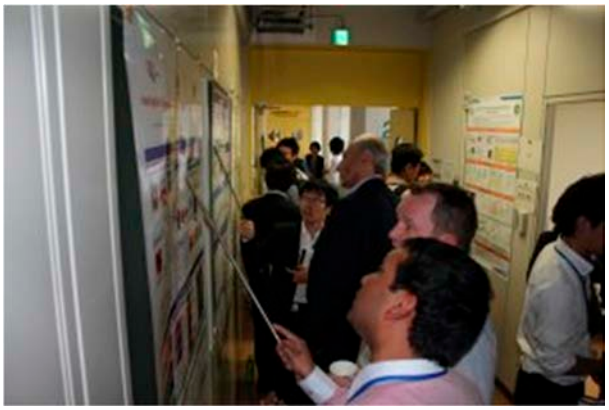
https://gi-core.oia.hokudai.ac.jp/gss/report-hokkaido-university-impact-joint-symposium/

Invited speakers and advisors of HU-ImPACT Joint Symposium

-The First International Symposium on Advanced Soft Matter

"The First International Symposium on Advanced Soft Matter: Celebrating the Kick-off of the Global Station for Soft Matter" was held on June 13th-15th, 2016 at Hokkaido University. The top researchers on soft matter from all over the world came to give lectures: from the U.S., the University of North Carolina at Chapel Hill, Duke University, North Carolina State University, and Iowa State University; from France, ESPCI Paris, Pierre and Marie Curie University, and University Paris Diderot; and from Japan, the University of Tokyo and Hokkaido University. After the lectures, there was an active discussion involving members in the audience. The poster session was held at the end of the symposium where students and young researchers had the opportunity to present their work and receive face to face comments from the world-leading researchers. Attended by nearly 150 people, the symposium was a successful kick-off event for Global Station for Soft Matter, and the station aims to continue more international collaborative work in the near future.

Honorary Guests and invited speakers.



Poster Session

1-5-6. Seminars

Seminars were held for our faculty and students with lectures given by GSS members, overseas and domestic visitors. Each international GSS member gave at least one GSS seminar during his/her stay each time. 37 GSS seminars were held. A full list of GSS Seminars is shown in **Appendix F**.

1-5-7. Science Outreach

GSS actively participates the science outreach activities, making effort to share the research achievements with the society. GSS has made 11 international and domestic press-release. Many of the press-releases receive great response from the international and domestic media, including newspapers (43 times), internet (26 times), TV features (19 times), magazine (3 times), and radio (2 times). Through the media reports, GSS has received many inquiries from the industry for collaborations.

Specifically, our research for "the tough, bendable fabric combines hydrogels" has been introduced on the CNN Digital Studios series, titled Vision: The Future of Japan (for details, see the link http://edition.cnn.com/style/article/hydrogel-steel-japan/index.html). Our paper "Double network hydrogels strongly bondable to bones by spontaneous osteogenesis penetration" (***Nonoyama et al., Advanced Materials 2016***) was in the top 5% of all research outputs with a score of 38 by Altmetric (https://www.altmetric.com/details/8372788). Our paper "Mechanoresponsive self-growing hydrogels inspired by muscle training" (***Matsuda et al., Science 2019***) was in the top 5% of all research outputs with a score of 325 by Altmetric (https://www.altmetric.com/details/54767155/news).

A full list of GSS science outreach is shown in **Appendix G**.

2. Education in the Division of Soft Matter, Graduate School of Life Science

2-1. Goals

The primary education objective of GSS is to establish the first international graduate course majoring in Soft Matter in Japan, by initiating a new Division of Soft Matter in the Graduate School of Life Sciences, Hokkaido University. The Division of Soft Matter offers both a Master's course and a Doctoral course that provide systematic education on basic knowledge related to scientific research of soft matter (physics, chemistry, biology) and its applied sciences (material science, life molecular science, biophysics, medicinal chemistry, and functional science). GSS aims to develop students who will be leaders in the research and development of soft matter globally.
Website for Division of Soft Matter: https://life.sci.hokudai.ac.jp/en/sm

2-2. Commencement History

Soft Matter is receiving broad attention as a growing field in the 21st century. Soft Matter science is interdisciplinary, spanning various academic (physics/chemistry/biology) and industrial (engineering /medical science/agricultural science) fields, and it is therefore necessary to establish a new knowledge system for the development of human resources in Soft Matter science for the academic and industrial worlds. However, there are few educational institutions that can systematically provide a cross-disciplinary educational curriculum in Soft Matter science in the world and there is none in Japan. For this reason, educational research institutions are required to carry out research and development while building a new academic system and developing human resources who can apply cutting-edge soft matter in parallel.

2-3. Necessity to Institute in Hokkaido University

Hokkaido University contains many leading researchers and good facilities in soft matter science, especially regarding soft matter materials development and collaborative biomedical applications. By inviting overseas researchers strong in the fundamental research of Soft Matter through the framework of GI-CoRE Global Station for Soft Matter, Hokkaido University is able to provide one of the best educational environments in the world, in which multi-disciplinary science of Soft Matter, span chemistry, material science, physics, mechanics, to life science and medicine, can be educated from both theoretical and experimental perspectives. Through such an education system, human resources capable of soft matter research and application will be developed.

2-4. Relationship with GI-CoRE

The Global Station for Soft Matter was established in April 2016 as a new base for GI-CoRE. By utilizing this educational and research organization system, it has become possible to further strengthen and develop the world's top-level soft matter research. As a result, the framework of GI-CoRE research centers can be effectively returned to soft matter-related education. As mentioned above, all members of the HU unit in GSS are full-time faculty members of the Division of Soft Matter. The overseas faculty members will also contribute toward education by giving course lectures, advising graduate students on research, and providing students with opportunities to study abroad in their research laboratories.

2-5. Construction of the Educational Implementation System

2-5-1. Outline and Practices of the Division of Soft Matter

- Division of Soft Matter was established on April 1st, 2018, two years after the establishment of GSS.
- It has a capacity of 16 seats for master course students and 6 seats for doctoral course students.
- It is an international education course and provides a curriculum in English.
- All faculty members in the HU unit of GSS are in charge of full-time education. Overseas unit members of GSS also conduct some lectures in normal courses and summer institute courses.
- It provides a curriculum where the students can learn the latest research in a wide range of soft matter, from fundamental sciences in chemistry and physics, material sciences and engineering, to life sciences and medicine.
- It also actively incorporates courses provided by or run jointly with other majors.
- It participates in the Hokkaido University Co-Tutelle Program, and has established an inter-university collaboration agreement with the French unit organization ESPCI Paris on collaborative research guidance for doctoral degrees.
- It has a field of cooperation with the National Institute for Materials Science (NIMS, Japan), and visiting faculty members from NIMS are in charge of research guidance for doctoral programs in the field of Soft Matter Functionality.
- A Soft Matter Open Unit (SMOU) that integrates the advanced equipment necessary for soft matter research is available for the students. The University Open Facility Platform is also available.
- The SMOU facility has an educational environment that can be used as a practical training facility for graduate education in soft matter majors (common graduate school subjects / international summer school).

2-5-2. Education Fields

The education fields of the Division of Soft Matter are shown in the following table, provided by full-time HU faculty members and visiting faculty members from NIMS.

Education Fields	Laboratories	Faculty Members
Soft Matter Materials Science	Laboratory of Soft & Wet Matter	**Faculty of Advanced Life Science** Prof. Jian Ping Gong Prof. Takayuki Kurokawa Associ. Prof. Tasuku Nakajima Associ. Prof. Takayuki Nonoyama Assist. Prof. Daniel R. King
	Laboratory of Molecular Device	**Research Institute forElectronic Science** Prof. Kuniharu Ijiro Associ. Prof. Hideyuki Mitomo Assist. Prof. Yusuke Yonamine

Biomolecular Soft Matter	Laboratory of Biological Information Analysis Science	**Faculty of Advanced Life Science** Prof. Makoto Demura Lecturer Takashi Kikukawa Assist. Prof. Takashi Tsukamoto
	Laboratory of Protein Science	**Faculty of Advanced Life Science** Prof. Tomoyasu Aizawa
Soft Matter Biophysics	Laboratory of Cell Dynamics	**Faculty of Advanced Life Science** Prof. Hisashi Haga Assist. Prof. Seiichiro Ishihara
	Laboratory of Physical Ethology	**Research Institute for Electronic Science** Prof. Toshiyuki Nakagaki Associ. Prof. Katsuhiko Sato Assist. Prof. Yukinori Nishigami
Soft Matter Medical Science	Laboratory of Pathology	**Faculty of Medicine** Associ. Prof. Masumi Tsuda
	Laboratory of Reconstructive Surgery & Rehabilitation Medicine	**Hokkaido University Hospital** Lecturer Tomohiro Onodera
Functional Soft Matter (MINS)	Laboratory of Functional Soft Matter	**Visiting Profs. from NIMS** Prof. Takashi Nakanishi Associ. Prof. Takeshi Ueki

2-5-3. Three Policies of International Graduate School

https://life.sci.hokudai.ac.jp/en/sm/three-policies

Admission Policy

The Division of Soft Matter seeks students interested in integrating materials science and a wide range of life sciences, developing soft matter science, understanding the structure and function of living matter from the viewpoint of materials science, designing and constructing advanced soft matter, and applying their findings to other fields.

Master's Program

The Division is especially seeking students who satisfy the following criteria:

1. Students who wish to learn basic physics, chemistry, and biology and develop analytical and manufactural techniques in the field of soft matter
2. Students who wish to acquire technical capabilities for advanced scientific research and have a strong intention to become educators, researchers, or research professionals in private firms.

Doctoral Program

The Division is especially seeking students who wish to acquire excellent analytical and discussion skills and conduct original research in topics such as the hierarchy understanding of soft matter from the microscopic to macroscopic scales and its association with the principle of dynamic emergent functions as well as designing and constructing advanced soft matter.

Curriculum Policy

The curriculum of the Division of Soft Matter reflects recent developments in soft matter research and its associated societal needs. The curriculum policy is stated below.

Master's Program

1. The Division offers an educational curriculum in which students can acquire both basic and advanced knowledge in soft matter science. Through the practical training offered in the Division, students should be able to contribute as researchers or technicians in the field of soft matter science.
2. The Division offers training through which students can improve their English presentation skills and global awareness.

Doctoral Program

1. The Division offers an educational curriculum in which students can acquire essential skills to conduct original and highly advanced research in the field of soft matter science.
2. Through the curriculum, students can gain a global perspective and become leaders in research and development activities in the field of soft matter science.

Diploma Policy

The Division confers a master's and doctor's degree on students who enroll in the graduate school for a designated period, receive appropriate research supervision, obtain required credits, and furthermore, have gained the knowledge and skills as stated below.

Master's Program

1. Comprehensive knowledge of soft matter science in general and its potential applications
2. Technical capability to conduct advanced scientific research
3. Communication and presentation skills of an international standard

Doctoral Program

1. Comprehensive knowledge of life sciences, research planning ability, analytical ability, and application development ability for conducting research independently
2. The ability to lead research and development in the field of advanced soft matter science

2-5-4. Implementation System for Selecting New Students

Division of Soft Matter, Faculty of Life Science

・**Enrollment Period:**

Two times each year: April and October

・**Type of Selection Test:**

Master's Program General Selection, Special Selection for International Students.

Doctoral Course General Selection, Special Selection for International Students, Special Selection for Working Adults.

When selecting international students, applications are made online and interviews are conducted by e-mail and video conferencing to make the process easier for overseas students.

・**Application Period:**

Master's Program First recruitment (August), Fall Recruitment (October), Second Recruitment (January)

Doctoral Program First Recruitment (August), Second Recruitment (January)

・**Student Acceptance Status:**

A two-step process is adopted for selecting students. In the first step, students contact the professors directly. The professors will make a prescreening according to their background, academic transcripts, and research achievements through e-mail and internet interview. Then, the professors will recommend the selected students to apply for the graduate school. In the second step, a selection committee consisting of at least three faculty members including members from different laboratories will select the applicants who passed the prescreening. The percentage of successfully enrolled students (2018 and 2019) in relative to the total pre-consulted students is approximately in the range of 28~64%.

Master's Course (capacity:16 students)

Academic Year	Pre-consulted Students	Applicants	Enrolled Students	Enrolled out of Pre-consulted
2018	48 (16)	32 (9)	31 (9)	64.5%
2019	43 (19)	24 (8)	21 (6)	48.8%
2020	37 (14)	26 (8)	22 (7)	48.6%

Doctor's Course (capacity: 6 students)

Academic Year	Pre-consulted Students	Applicants	Enrolled Students	Enrolled out of Pre-consulted
2018	35 (25)	10 (5)	10 (5)	28.5%
2019	23 (15)	8 (5)	8 (5)	34.8%
2020	42 (36)	10 (6)	10 (6)	14.3%

*: Parentheses indicate international students.

In the master's program, for a maximum capacity of 16 students, the average sufficiency rate for the last three years was 146% and the rate of international students was 25%. In the doctoral program, for a maximum capacity of 6 students, the average sufficiency rate for the past three years was 133% and the rate of international students was 48%. In this way, as an international graduate school, it has become an educational environment where both international students and Japanese can study together. In the entrance examination selection frame "Special selection for international students," the government-sponsored foreign student priority allocation program (MEXT scholarship) is used to select excellent international students.

2-5-5. Class Subject

Master's Program

Specialized Subject

Soft Matter Science Research
Soft Matter Science Paper Reading I (Reading)
Soft Matter Science Paper Reading II (Writing)
Soft Matter Science Training

Introduction to Soft Matter Science
Advanced Theory of Soft Matter Physics (Continuum Mechanics)
Special Lecture on Soft Matter Physics (Polymer Physics)
Soft Matter Physics (Non-Linear Phenomenon)
Special Lecture on Soft Matter Analysis (Soft Matter Structural Analysis)
Special Lecture on Soft Matter Analysis (Spectroscopy)
Soft Matter Molecular Science (Polymer Chemistry)
Soft Matter Molecular Science (Supramolecular Chemistry)
Special Course on Soft Matter Design (Biological Engineering)
Advanced Soft Matter Design (Informatics)
Special Course on Soft Matter Medical Engineering (Introduction to Soft Matter Basic Medicine)
Soft Matter Medical Engineering Special Course (Introduction to Regenerative Medicine and Clinical Medicine)
Soft Matter Medical Engineering (Mechanobiology)

Doctoral Program

Specialized Subject

Soft Matter Science Special Research

・**Research Subjects**

Soft Matter Science Paper Reading
International Joint Research Proposal Exercise
Small-Group Discussion-Type Training Program

・**Internationalization Subjects**

Doctoral Students' Overseas Research
Oral Presentation at International Conference
International Research Meeting Planning Program

・**Career practice Subjects**

Step-up Career Development for Graduate Students
Researches for Doctoral Students' Career Development

2-5-6. International Education Activities

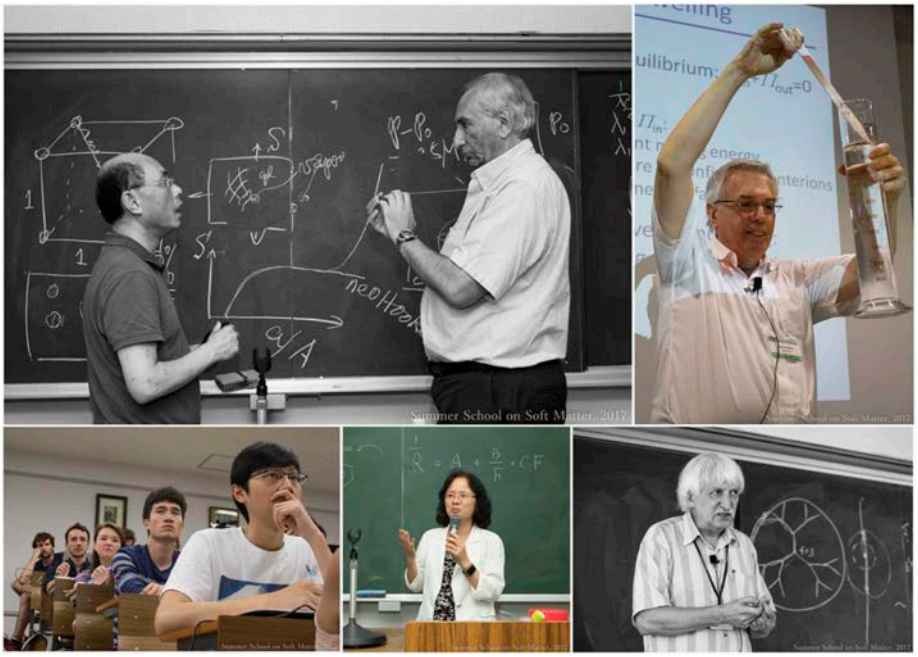
International Soft Matter Summer School 2017

The International Soft Matter Summer School "From single molecules to materials" was held for two weeks from July 30th to August 11th. The first week was in Otaki Seminar House, and the second week was in Sapporo campus. The summer school was organized by GSS in conjunction with the Hokkaido Summer Institute (HSI). The program was coordinated by three GSS members, Dr. Michael Rubinstein

from the University of Duke, Dr. Costantino Creton from ESPCI Paris, and Dr. Jian Ping Gong from Hokkaido University. 13 world-leading scientists were invited as lecturers to give 32 interdisciplinary lectures, covering chemistry & materials, dynamics & rheology, polymer physics, mechanics, and lipid membranes, were provided. Beside All of the 32 lectures were archived for sharing with other students. 57 graduate students and 19 young researchers, including 3 from USA, 19 from Europe, 15 from Asia, 2 from Oceania and 15 from other universities of Japan participated the summer school. Active learning is adopted. Specifically, students are divided into 8 groups, and each group was assigned a small project. 2-3 young researchers as mentors and several lecturers as consultants helped the students for the projects. Students presented their project at the presentation session on the last day of the school. Through the project, students could discuss and think deeper about concepts related to different subjects presented in the lectures.

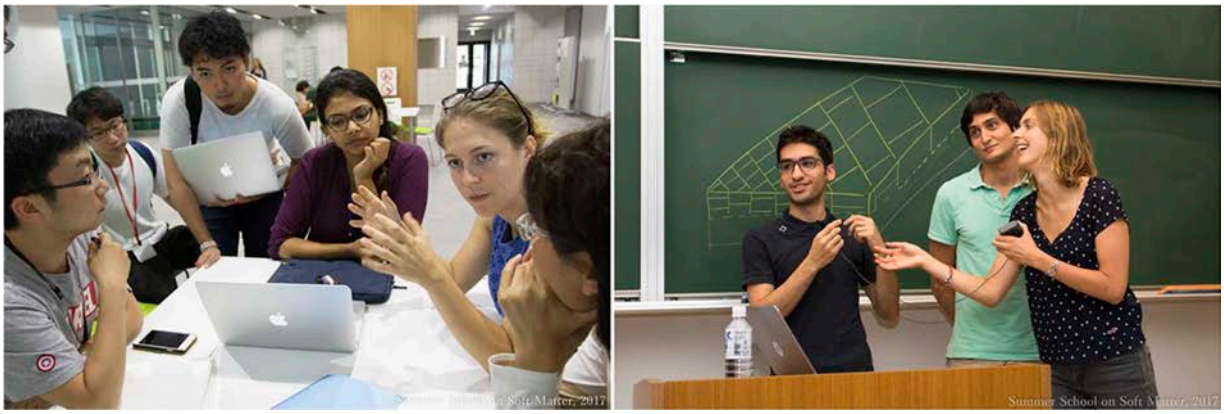
Besides, poster sessions were held, and two poster prizes were awarded by the Soft Matter, Royal Society of Chemistry.

https://gi-core.oia.hokudai.ac.jp/gss/wp-content/uploads/2017/09/Soft-Matter-Summer-School-edited-Kat.pdf



World-leading scientists lecturing the participants.

Poster sessions were held on July 30th and August 1st.



Students working on an assigned task (left) and giving a presentation (right).

Some of the attendees of the Soft Matter Summer School and the HSI course with Mt. Showa-shinzan in the background.

Summer Institute 2019

As a Hokkaido Summer Institute 2019 course, “Soft Interface & Soft Mechanics (Polymer Physics)” hosted 12 students including overseas students and a total of 17 audience members. The course was taught over two weeks by four members of GSS: Dr. Jian Ping Gong and Dr. Tasuku Nakajima (Hokkaido University), Dr. Wei Hong (Iowa State University/Southern University of Science and Technology), and Dr. Cécile Monteux (ESPCI Paris). The first week focused on physical properties of soft matter interface/surface and the second week deepened the knowledge on mechanics of soft matter. https://gi-core.oia.hokudai.ac.jp/gss/wp-content/uploads/HSI2019.pdf

Students International Exchange

Students international exchange have been actively performed. Students from HU are sent to universities of the France unit and US unit for collaboration. Students from universities of US unit members and other overseas universities are also actively accepted. Each year, one graduate student from ESPCI Paris is accepted.

List of HU Students Overseas Dispatch (excluding academic conference participation)

No.	Student	Host University	Period
1	Taiki Fukuda MC	ESPCI Paris, France	2017.2.20~3.19
2	Kohei Murakawa MC	ESPCI Paris, France	2018.1.10~2.10
3	Takahiro Matsuda DC	Duke University, USA	2018.2.15~24
4	Ye Zhang MC	Johnson Matthey Technology Centre, UK	2018.3.17~22
5	Takahiro Matsuda DC	DSM, Netherlands	2018.9.13~3.19
6	Martin Frauenlob DC	International Centre for Mechanical Sciences, Udine, Italy	2018.9.24~28
7	Tsuyoshi Okumura MC	Discover English, Melbourne, Australia	2019.2.25~3.8

List of Overseas Special Research Student

No.	Student	University	Period
1	Agathe Mocellin MC	ESPCI Paris, France	2017.5.1~8.31 (4 months)
2	Julie Brun MC	ESPCI Paris, France	2018.5.1~7.31 (3 months)
3	David Delgado DC	Northwestern University USA	2018.10.1~2019.1.31 (4 months)
4	Lei Wu MC	Zhejiang University, China	2018.10.1~2019.1.31 (4 months)
5	Yuki Meier MC	ETH Zürich, Swiss	2018.10.1~2019.3.31 (6 months)
6	Jiunn Hong Po MC	ESPCI Paris, France	2019.5.1~8.31 (4 months)
7	Vincent van der Doef MC	University of Wageningen, Netherlands	2019.9.1~2020.2.29 (6 months)

List of Overseas Visiting Student

No.	Student	University	Period
1	Christian Kessler DC	Dresden University of Technology, Germany	2016.5.30~8.6 (2 months)
2	Amber Marie Hubbard DC	North Carolina State University, USA	2017.7.5~12.4 (5 months)

List of Overseas Short-Visit Student

No.	Student	University	Period
1	Mingcong Liu DC	Cornell University, USA	2019.1.14~19
2	Mengdi Hou MC	Shaanxi University of Science & Technology, China	2019.8.4~7
3	Quyang Yue MC	Shaanxi University of Science & Technology, China	2019.8.4~7
4	Mingwei Jiang MC	Tsinghua University, China	2019.11.18~25
5	Jikun Wang DC	Cornell University, USA	2020.1.6~16

2-6. Future Developments in Education

Here, we will discuss the future of the Division of Soft Matter in the Graduate School of Life Science from three perspectives.

2-6-1. Admissions

We have enrolled students beyond the capacities of Master's course and Doctor's course for the past three years. However, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has a policy to strictly manage the admission capacity at the level of each division of the graduate school. This means that no matter how large the number and the quality of the applicants, we are unable to accept more students than the pre-determined capacity. As we have a quite high number of applicants for the master's course and doctor's course each year, we need to implement a stricter entrance examination and to admit the students within the pre-determined capacity.

2-6-2. Curriculum and Career Development

Education in the Division of Soft Matter is characterized by an emphasis on inter-disciplinary knowledge, with broad and international perspectives on academic studies and the application of soft matter. All classes are taught in English by faculties with a variety of backgrounds from different departments and by invited overseas faculties. We will maintain and enforce diversity in our curriculum. Furthermore, we will also

- encourage active learning and e-learning,
- encourage the doctor's course students to have more international collaborations,
- provide more opportunities for students to study in guest laboratories abroad,
- encourage overseas faculties to serve as sub-supervisors for doctor's course students,
- invite external reviewers for doctor degree defenses,
- improve the English proficiency of students, etc.

2-6-3. Recruitment of Excellent International Students

Since the inception of the Division of Soft Matter, we have been very successful in recruiting excellent international students. The percentage of international students was 25% for the master's program and 48% for the doctoral program. Some of the international students are supported by MEXT Scholarships through the International Graduate Program (IGP) in the Graduate School of Life Science. The current MEXT Scholarship will finish in 2021. To maintain such a high percentage of international students, we will need to apply for the MEXT scholarship after 2021.

2-6-4. International Summer Schools

Through the activities of the GI-CoRE Global Station for Soft Matter, joint research and education with overseas units in France and the United States has been steadily expanding. It has been agreed with the three unit-leaders of GSS, that large-scale international summer school will be conducted regularly in Japan, Europe, and the United States. The second International Soft Matter Summer School was planned in the summer of 2020 in Cargese, France. Due to the COVID-19 pandemic, this summer school has been rescheduled to July 11th-23rd, 2022 in the same place. Between every 2~3 years of large scale international soft matter summer school, GSS will provides international soft matter courses in Hokkaido Summer Institute (HSI).

3. Administrative Framework

3-1. Management System at the Global Station for Soft Matter

The Global Institution for Collaborative Research and Education (GI-CoRE) was established in April 2014 as a faculty organization with the aim of promoting international collaborative research and education that leverages Hokkaido University's strengths and distinctive character. The GI-CoRE is positioned as an independent educational and research organization managed by the President as its director. It brings together world-class researchers from around the world, within Japan, and within Hokkaido University (HU), based on a new idea to invite the world's highest-level research units.

Under the concept of GI-CoRE, the Global Station for Soft Matter (GSS) was launched in April 2016 as the fourth global station of the project. Under the supervision of GSS Director, GSS has promoted international collaborative research and education systematically together with leading research units invited from overseas, rather than individual researchers. To strengthen and promote the ongoing research network, GSS established the following three research project groups with the US unit (including Duke University, etc.), and France unit (including ESPCI Paris, etc.); the Materials Creation group, the Fundamentals group, and the Application group.

As such, activities are being driven successfully by a faculty-led management system.

3-2. Establishment and Improvement of Acceptance System/Environment

The uniqueness of the GI-CoRE framework has enabled GSS to invite 12 researchers from world-leading universities overseas to work jointly with the 33 HU faculties in fields related to soft matter, to promote international collaborative research and education. Especially in the management of GSS, the following acceptance system has been functional.

1) Cross-Appointment System with Overseas Universities and Institutions

GI-CoRE introduced its own cross-appointment system with overseas universities and institutions before the system implementation by the whole university. The cross-appointment system is to appoint top-class researchers from overseas and domestic institutions at Hokkaido University, while keeping their status at the host institutions and pay salaries to them on a pro rate basis in accordance with the actual number of days of the working period at Hokkaido University. This enables the world-wide recognition of Hokkaido University as one of the centers of Soft Matter research and education. As a result, GSS attracts many excellent students and young researchers from around the world.

2) Cross-Appointment System to Participating Researchers of Hokkaido University

To utilize the existing research resources in the university, GI-CoRE has also applied the cross-appointment system to participating researchers of Hokkaido University who conduct international collaborative research and education and appointed them to positions both in their original departments and in GI-CoRE. This enables collaborative research on biomedical applications based on the developed hydrogel materials. This also enables the Division of Soft Matter to provide a multi-disciplinary curriculum for graduate students.

3) Exemption from Administrative Tasks

To secure the academic environment and to allow for concentration on research, GI-CoRE overseas faculty members are exempt from administrative tasks such as faculty meetings and admissions related duties, etc.

Beyond these systems, GSS has also provided a good research environment and extensive educational experiences to young researchers, which also led to the fusion of different research fields/interdisciplinary collaboration with diversified departments through cooperation in the project. Given the proven cycle, the effectiveness of the pilot systems has been gradually expanded to the whole university and has begun to reinforce the university's administrative function.

3-3. Administrative System at the Global Station

The GI-CoRE head office distributes staff members with study/work abroad experiences and has established bilingual (English) administrative support systems. In order to support daily research and educational activities conducted in the Global Station, two bilingual administrative staff have been stationed in the station office. These on-site administrative staff are supervised by the GI-CoRE head office.

IV. Future Development of GSS

1. Structural Change of GSS from FY 2021

- GSS will be internalized and absorbed into the Faculty of Advanced Life Science from FY2021. Despite such a change to the structure, GSS will maintain its function as a highly independent research-based hub through the collaborative research activities between the cross-appointed overseas researchers and the Hokkaido University faculties.
- On this occasion, GSS needs to further strengthen the collaborative research activities and its financial basis. The members of GSS from both overseas units and the Hokkaido University unit need to be carefully re-selected as those who can promote joint research, obtain external research funds, and publish their research achievements in leading journals.
- To run a sustainable high-level research and education system for the next 10 years, GSS requires a mechanism to stimulate more young faculty members to act as the core of the collaborative research. Furthermore, as the current core members and PIs of GSS are approaching retirement, GSS will need to seek young, talented faculty members as directors to lead the project within the next several years.
- From FY2021, the two administrative staff in GSS office will be internalized into the administrative office of the Faculty of Advanced Life Science. This will strengthen their capabilities to handle educational affairs, and to collaborate with other administrative staff within the department.

2. Budget and Research Funds

- As the first phase of the project period for GSS will end by FY2020 and the management of GSS will be passed on to the Faculty of Advanced Life Science, it affects GSS's budget.
- Upon the internalization, the budget will be incorporated as the university’s ordinary budget, therefore, it will be funded constantly, but the amount may be decreased by approximately 50% of the former amount.
- To maintain the ongoing activities, besides the grant from the Japanese government, GSS members need to make efforts to obtain external funds from various sources. It is essential to obtain competitive grants constantly not only from national sources such as grants-in-aid for scientific research but also from other sources including private sectors through active collaboration with industry, donations, etc.

3. Detailed Activities Planned

- To further strengthen and promote joint research with overseas universities and institutes, GSS has the following plans as core areas of research to be developed in the near future.
  - Stimulating young faculties to be the core of joint collaborations,
  - Promoting more collaborations with industries and contribute to society,
  - Organize international symposiums on soft matter,
  - Establish a world-wide network on soft matter research and education,
  - Participating international collaborative projects for research and education. DoDeNet (sponsored by EU Horizon 2020 program) and Monet (https://monet.duke.edu/the-team/, sponsored by NSF, USA) are two undergoing international projects that GSS members are participating. GSS will continue to actively organize and participate in such international projects.
  - Organizing international summer schools regularly in Japan, Europe and US. The next two-weeks large summer school (seats: ~100) will be held in 2022 in France.
  - Three GSS members are participating as PIs in the WPI-ICReDD project at Hokkaido University established in 2018, focusing on "Chemical Reaction Design and Discovery". GSS will actively attract members in these PIs' groups in WPI-ICReDD for collaborative research, which will greatly enrich the activities of GSS.
  - GSS will also actively collaborate with WPI-ICReDD on education through the MANABIYA system. The MANABIYA system aims to foster a new generation of researchers proficient in the three fields of computational, information and experimental science and to develop the new interdisciplinary academic field of "Chemical Reaction Design and Discovery" worldwide.

Appendices

Appendix A Highlighted Research Progress

Contents

Target A Bio-inspired Design and Development of Novel Functional Hydrogels

For practical application of hydrogels, along with the high strength and toughness of hydrogels, other functions, like self-healing, fatigue resistance, anisotropic function, adhesion, lubrication, etc., are also required. Our strategy to integrating these functions is to learn from the nature. Compared with natural hydrogels seen in biological soft tissues, synthetic hydrogels remain relatively simple in structure and inferior in function (***Fan et al, Macromolecules, 2020).***). After hundreds of millions of years of evolution, biological soft tissues achieved structures with two unique characteristics. One is their water-containing structure. Most soft tissues contain 50-85% of water by weight. Hydrated structures enable biological soft tissues to serve as a medium for dynamic biological processes. The other is their elaborate structure, integrating features of multi-component, order-disorder, and hierarchical structures ranging from the molecular to macroscopic scale. The fact that biological soft tissues contain a suitable amount of water to ensure molecular mobility and, at the same time, have elaborate structures is the key differentiator that enables biological tissues to have sophisticated functions. In contrast, synthetic hydrogels usually have an amorphous and isotropic structure. Therefore, there are great opportunities to develop innovative synthetic hydrogels with superb functions by inducing super-structures analogous to those present in natural hydrogels.

The strategy of this project is to design and develop new hydrogels based on features inspired by biological systems. At the molecular level, we design monomers with specific functions to mimic biomolecules like amino acids. At the nanometer scale, controlling the monomer sequence results in synthetic polymers that mimic biomacromolecules. At the submicron to micrometer scale, we can control the network topological structure and self-assembled structure by intermolecular interactions, as in DNA or protein folding. Finally, at the macroscopic level, we design hydrogels with functional geometries or morphologies, inspired by biological systems (**Figure A-1**).

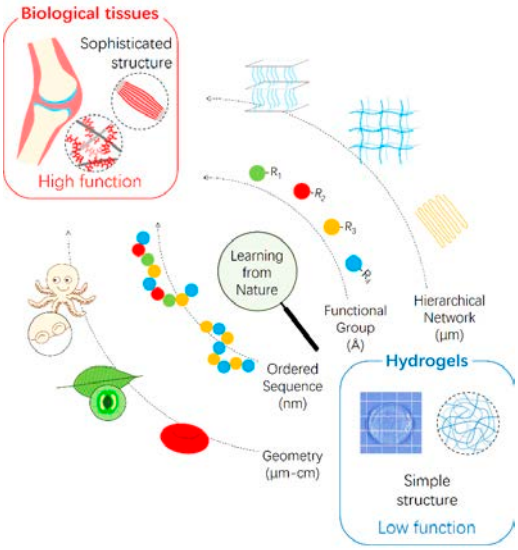


Figure A-1. Challenges and opportunities in the fabrication of bioinspired hydrogels at different length-scales and their physical functions. ***Fan et al, Macromolecules, 2020***.

A-1. Building Block Design and Polymer Sequence Control

Biological functions of proteins depend on their amino acid type and sequences. Specific amino-acid type and sequences, even as short as two or three residues, can enable specific functions in the proteins. Therefore, protein data provides a rich source for the molecular design of functional polymer materials. For instance, adjacently located amino acids of cationic and aromatic residues have been found to play critical roles in various physiological activities, including protein folding and binding of peptides to bilayer membranes. Such cohesion and adhesion caused by cationic–aromatic sequences provide an attractive molecular design model to develop adhesive hydrogels or glues for application in saline solutions or even marine environments.

However, there is a wide knowledge gap between the molecular design and development of materials, as sequence-controlled polymer synthesis is still a central challenge and there are few efficient, scalable, and cheap methods. For example, free-radical polymerization is a highly scalable and cost-effective method, but this traditional one-pot technique usually does not permit precise monomer sequence control, except for a few specific monomer combinations. In contrast, state-of-the-art polymerization methods for precise control of monomer sequences are generally multi-step, have low product yield, and are expensive.

1. Poly(cation-*adj*-π) Hydrogels with Precisely Controlled Sequence for Marine Adhesives

We discovered that a series of copolymers bearing adjacently located cationic and aromatic residuals, hereinafter referred to as poly(cation-*adj*-π) (*adj* is short for adjacent and π for aromatic monomer), can be synthesized in abundance by a traditional one-pot free radical polymerization of cationic and aromatic monomers at an equimolar ratio (***Fan et al., Nature Communications, 2019***). There are two prerequisites for the formation of such poly(cation-*adj*-π)s with precisely controlled sequences: a strong cation–π interaction between cationic and aromatic monomers to form a complex in the precursor solution, and the same reactive vinyl head ($R_1 = R_2$) of cationic and aromatic monomer pairs (**Figure A-2**). The application of this rule to diverse pairs of cation and aromatic monomers is studied in this work. The poly(cation-*adj*-π) series with adjacently located cationic and aromatic residuals is water soluble and can form physical hydrogels in seawater. The gels are strong and self-recoverable, exhibiting strong adhesion on various surfaces, especially on negatively charged surfaces, in seawater. The aromatic groups are found to enhance the electrostatic interactions of their adjacent cationic residues with the counter surfaces in a high ionic-strength medium that usually screens the electrostatic interaction completely for common polyelectrolytes. This work opens a pathway to develop adhesives for use in saline conditions.

Cation–π complex-aided copolymerization provides a new route for the synthesis of sequence-controlled polymers by simple free-radical polymerization. The synthesized polymers with adjacent cationic–aromatic sequences not only provide the foundation for the development of next-generation underwater adhesives, but also give rise to new opportunities to study fundamental chemistry, such as the electrostatic interactions under high ionic-strength conditions.

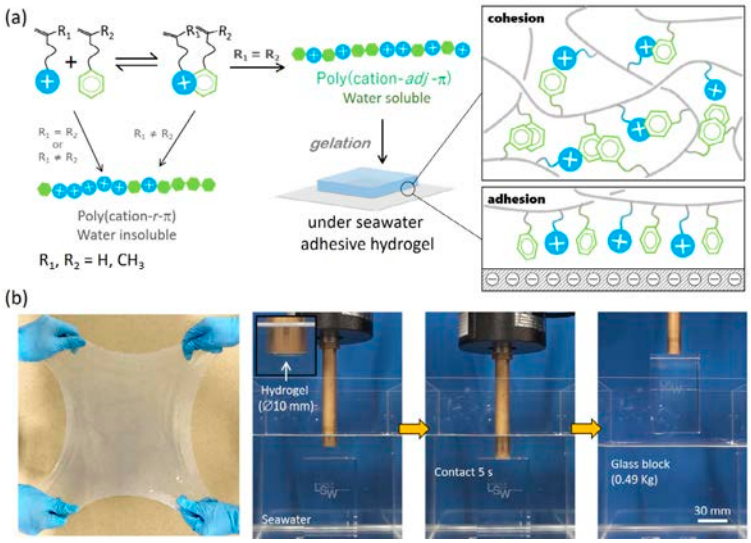


Figure A-2. Under sea water adhesion through bioinspired monomer design and polymer sequence control. Adhesive hydrogels with an adjacent cationic-aromatic sequence. (a) Cation–π complex-aided free-radical polymerization to synthesize poly(cation-adj-π) with adjacent cationic–aromatic sequences and its supramolecular hydrogel showing electrostatic adhesion in seawater. (b) Photos of a

poly(cation-adj-π) hydrogel and its under seawater adhesion. ***Fan et al., Nature Communications, 2019***.

2. Instant Thermal Stiffening Hydrogels Inspired by Protein of Thermophiles

Conventional polymer materials soften or even flow above their glass transition temperature, T_g. In contrast, many proteins form stable structures at elevated temperatures. For example, thermophiles and hyperthermophiles, kinds of extremophiles, can live in high-temperature environments (up to ~120 °C) such as hot springs and deep-sea hydrothermal vents, owing to the thermal stability of their constitutive proteins. These proteins are found to possess more charged amino acid residues, compared with those of animals living in normal environments. Nature uses the cooperative effects of hydrophobic interactions and ionic interactions to gain thermal stability, since the strength of ionic interactions increases with decreasing dielectric constant. Inspired by thermophile proteins, we developed novel materials that undergo ultra-rapid, isochoric, and reversible switching from soft hydrogels to rigid plastics at an elevated temperature by using poly (acrylic acid) gel containing calcium acetate (**Figure A-3**) (***Nonoyama et al., Advanced Materials, 2019***). By enhancing the electrostatic interaction in hydrophobic media at high temperatures, the hydrogels undergo significant spinodal decomposition and subsequent rubbery-to-glassy transition when heated to an elevated temperature without volume change. Based on this thermal hardening mechanism, novel thermal- hardening materials can be developed. This will substantially broaden the range of applications for polymeric materials, such as thermo-activated protector.

This work is a collaboration with members of the US unit.

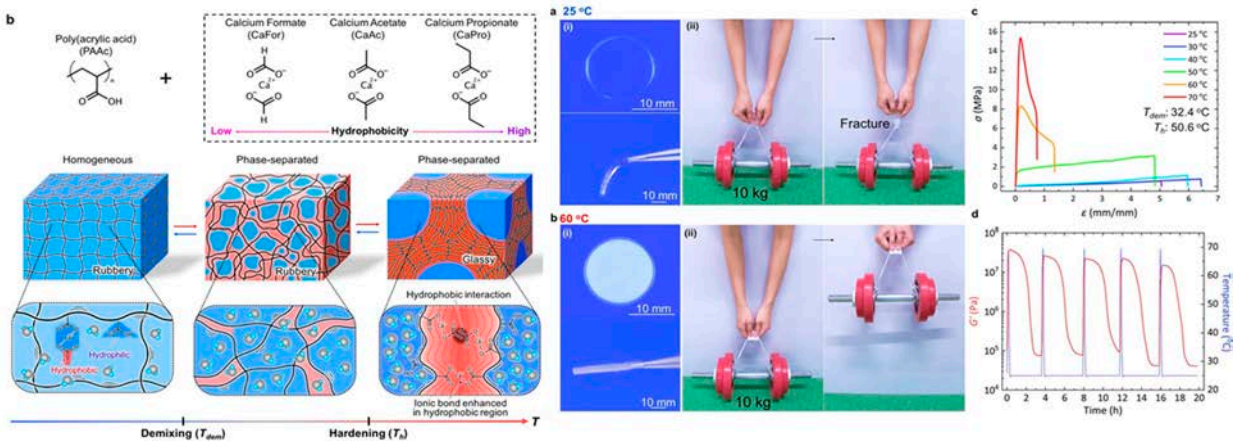


Figure A-3. Functions through bio-inspired monomer control. Thermophile protein-inspired hydrogels that are thermally stiffened using cooperative effects of hydrophobic interactions and ionic interactions. ***Nonoyama et al., Advanced Materials 2019.***

A-2. Design of Supramolecular Structures

With a precisely controlled sequence, biomacromolecules can assemble into ordered aggregate structures, for example, the double helix structure of DNA and β-folding of proteins. In hydrogels, polymer aggregation can be used as a physical crosslinker to connect the polymers into a network. Biomacromolecule-based hydrogels are typically crosslinked by the association of their well-defined biopolymer segments. In contrast, the associated structures in synthetic physical polymers usually have a disordered structure. Efforts have been made to synthesize hydrogels with well-defined associated structures.

Supramolecular Double-Network Hydrogels

We developed supramolecular double-network hydrogels with high toughness, abnormally large linear deformation, and self-recovery properties (***Zhang et al., Advanced Materials, 2016***). As the first network, an amphiphilic triblock copolymer was employed to form a physical hydrogel (B gel) which is hyper cross-linked by strong hydrophobic associations (micelles). As the second network, linear polymers that form hydrogen bonding with the middle block of the amphiphilic triblock copolymers were chosen. Specifically, the amphiphilic triblock copolymer consists of the hydrophobic end blocks of poly (butyl methacrylate) (PBMA) and a hydrophilic mid-block of poly (methacrylic acid) (PMAA), PBMA-*b*-PMAA-*b*-PBMA, with weight-average degree of polymerization of 134-273-129. The second network was linear polyacrylamide (PAAm). The amide groups on PAAm form hydrogen bonds with the carboxylic acid groups on the hydrophilic mid-block (PMAA). The hydrogen bonds between the first and second network act as sacrificial bonds for energy dissipation. Such DN gels, having no chemical cross-linking, are named as B-DN gels (**Figure A-4)**. This supramolecular double-network hydrogel based on hydrophobic domains and sacrificial hydrogen bonds exhibits high mechanical performance in concentrated saline solution, making it a good candidate as a load bearing material.

Stretchable and tough soft materials usually show non-linear deformation, while double network hydrogels made from triblock copolymers as the first network (B-DN gels) exhibit an extra-ordinarily large linear deformation up to sample failure in uniaxial tensile tests. We studied the underlying molecular mechanism of such a unique behavior of the B-DN gels by *in situ* characterization of the nano-scale structure during tensile deformation. We found that regardless of the irreversible first network rupture, the nano-scale deformation of B-DN gels keeps affine to the bulk deformation up to sample failure, resulting in a linear stress-strain relation. This result reveals that the internal rupture of the first network does not induce any local strain amplification, and the suppression of stress concentration is due to the interplay of the hyper connectivity of the first network and the stress transfer between the two networks by physical bonding. This result provides a path to design tough double network gels with large linear mechanical responses (***Ye et al, PNAS 2021***).

By combining non-covalent DN properties and spin-coating, we successfully fabricated thin (thickness: 5-100 μm), yet tough (work of extension at fracture: 10^5-10^7 J/m^3) and 100% self-recoverable hydrogel

membranes with high water content (62-97 wt%) at large sizes (~100 cm^2). The excellent mechanical properties of these tough and thin gel membranes are comparable, or even superior to many biological membranes. The *in vitro* and *in vivo* tests show that these hydrogel membranes are biocompatible, and postoperative non-adhesive to neighboring organs. The excellent mechanical and biocompatible properties make these thin hydrogel membranes potentially suitable for use as biological or postoperative anti-adhesive membranes (***Ye et al., Advanced Functional Materials, 2018***).

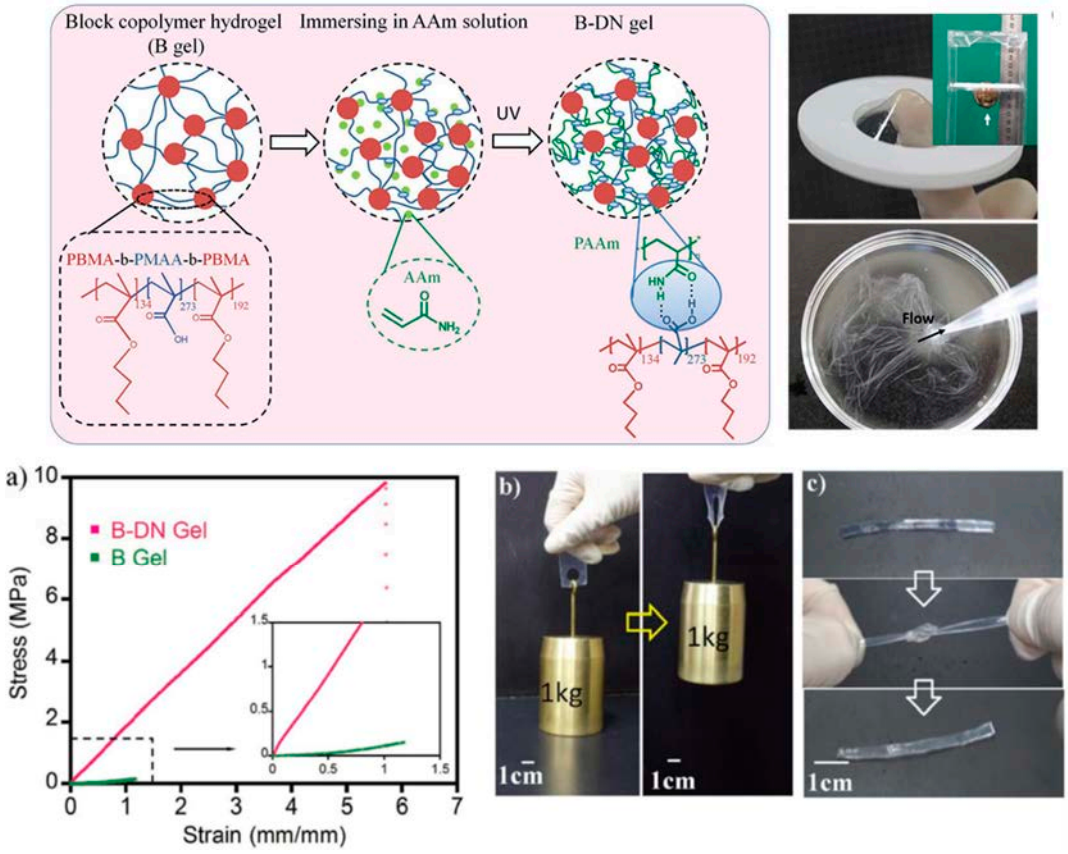


Figure A-4. Structure and mechanical performance of double network hydrogel utilizing amphiphilic triblock copolymer as the first network (B-DN gel). Upper left: Molecular structure and preparation process of B-DN gel. Upper right: Demonstration of a thin B-DN gel membrane in deformation and flowing into a narrow capillary by sucking. Lower left: Abnormally large linear deformation of the high strength B-DN gel. Lower right: Demonstration of the excellent mechanical performance of B-DN gel. ***Zhang et al., Advanced Materials 2016, Ye et al., Advanced Functional Materials, 2018.***

A-3. Hydrogels with Hierarchical Structures

Natural structural materials (such as tendons and ligaments) are comprised of multiscale hierarchical architectures, with dimensions ranging from the nano to macroscale, which are difficult to mimic synthetically. We developed a bioinspired, facile method to fabricate anisotropic hydrogels with perfectly aligned multiscale hierarchical fibrous structures similar to those of tendons and ligaments (**Figure A-5**) ***(Mredha et al., Advanced Materials, 2018***). The method includes drying a diluted physical hydrogel in air by confining its length direction. During this process, sufficiently high tensile stress is built along the length direction to align the polymer chains and multiscale fibrous structures (from nano- to submicro- to microscale) are spontaneously formed in the bulk material, which are well-retained in the reswollen gel. The method is useful for relatively rigid polymers (such as alginate and cellulose), which are susceptible to mechanical signals. By controlling the drying with or without pre-stretching, the degree of alignment, size of superstructures, and the strength of supramolecular interactions can be tuned, which sensitively influences the strength and toughness of the hydrogels. The mechanical properties are comparable with those of natural ligaments. This study provides a general strategy for designing hydrogels with highly ordered hierarchical structures, which opens routes for the development of many functional biomimetic materials for biomedical applications.

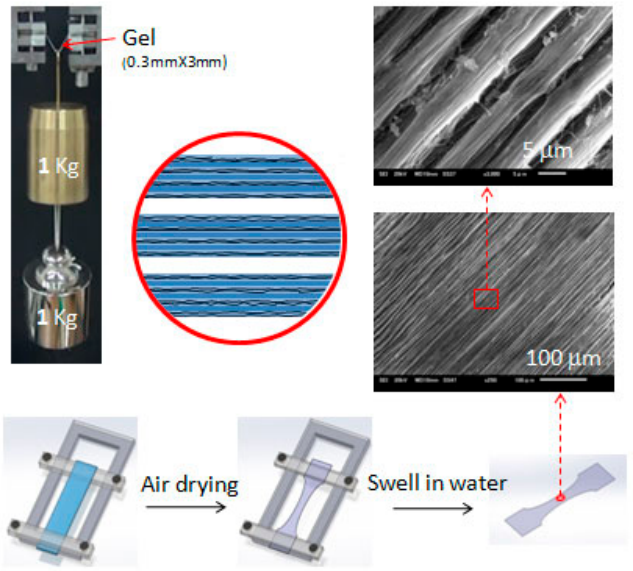


Figure A-5. Schematic illustration of DCC (drying in confined conditions) method for creating perfectly aligned fibrous alginate hydrogels with hierarchical superstructures. ***Mredha et al., Advanced Materials, 2018.***

A-4. Composite Hydrogels

1. Fiber Reinforced Soft Composites

Tough hydrogels have shown strong potential as structural biomaterials. These hydrogels alone, however, possess limited mechanical properties (such as low modulus) when compared to some load-bearing tissues, e.g., ligaments and tendons. Ligaments are unique wet biological tissues with high tensile modulus and fracture stress, yet high bending flexibility. Developing hydrogel composites with high stiffness fabrics is a strategy to develop ligament-like biomaterials. The most challenging issue to produce such hydrogel composites is how to form a structure that can transfer the force from the fabric to the hydrogel matrix, as common hydrogels swell in water and interact poorly with solid components. We succeeded to produce extraordinarily tough ligament-like hydrogel composites by strategically utilizing polyampholyte hydrogels (PA gels) (***Huang et al., Advanced Functional Materials, 2017***). The PA gels, developed by our group several years ago (***Sun et al., Nature Materials, 2013***), are not only very soft and tough, but also adhesive to glass surface. In addition, PA gels de-swell in water. Owing to these unique properties of PA gels, the new ligament-like composites, consisting of polyampholyte hydrogels and glass fiber woven fabrics, exhibit extremely high toughness (250,000 J/m^2), high tear strength (~65 N/mm), high tensile modulus (606 MPa), and low bending modulus (4.7 MPa), while being composed of water-containing biocompatible materials. These excellent mechanical performances are obtained for the first time for water-containing materials, comparable to high toughness Kevlar/polyurethane blends and fiber-reinforced polymers. Importantly, the mechanical properties of these composites greatly outperform the properties of either individual component.

The unique combination of soft, adhesive and tough properties of the matrices ensures a strong component interface, which consequently maximizes the energy dissipation density and gives rise to a large force transfer length enabled by the extremely high fiber/matrix modulus ratio. We have found that this design principle of combining adhesive, soft and tough matrix with rigid fiber is general for develop soft composites with extraordinary fracture toughness. In fact, recently we further developed novel soft composites from the combination of viscoelastic polymers that are adhesive, soft, and tough as matrices and various rigid fiber (carbon fiber, Aramid fiber, glass fiber) fabrics. These soft composites achieve toughness of up to 2500 kJ m^{-2} (***Cui et al., Advanced Materials, 2020***), even outperforming the toughness of PA gel/fiber composites.

Figure A-6 plots the specific fracture energy of materials as a function of specific strength. The fiber reinforced soft composites are located in the upper-right corner of the plot, indicating an excellent combination of high toughness and strength with low weight. The performances of the soft composites, both the tough PA gel/fiber composites and viscoelastomer/fiber composites, are superior to all best-in-class industrial materials at present. These results demonstrate that fiber reinforced soft composites made from adhesive, tough viscoelastic matrix could overcome the conflict between toughness and weight.

This work is a collaboration with members of the US unit.

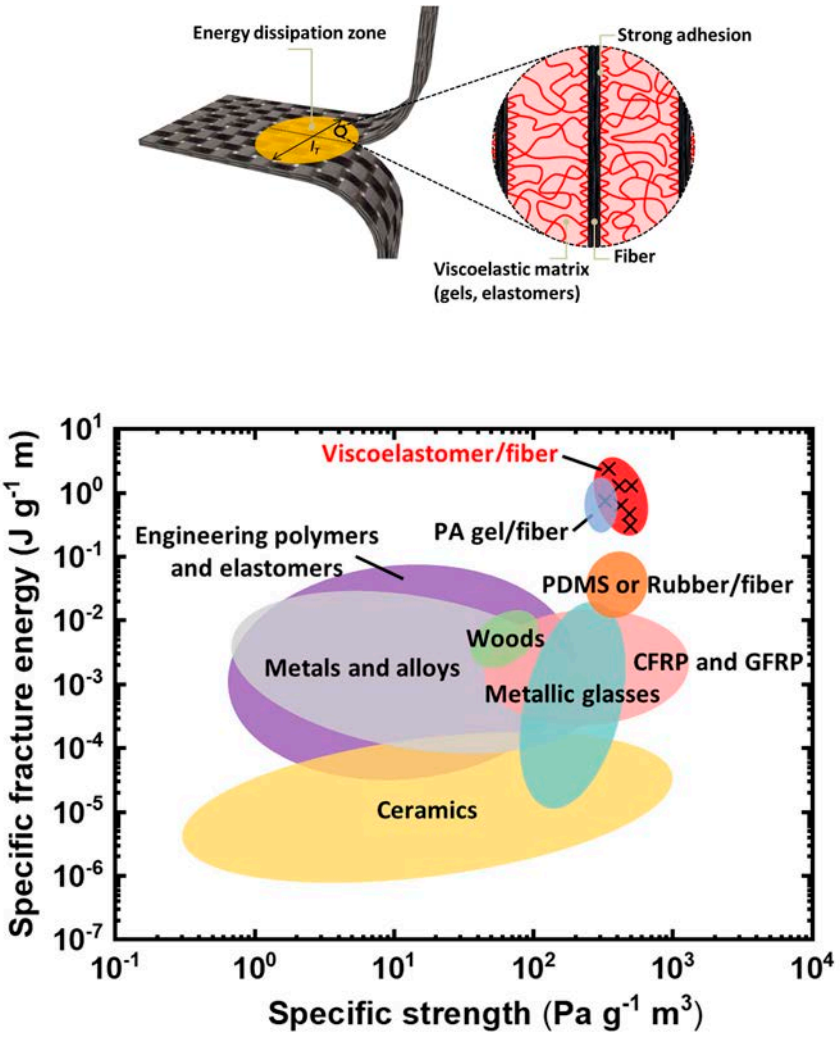


Figure A-6. Soft composites made from tough soft matrix (PA gels or viscoelastomers) and woven fibers show higher specific strength and toughness than any existing materials. ***Huang et al., Advanced Functional Materials, 2017, Cui et al., Advanced Materials, 2020.***

2. Macroscale Double Networks

Based on the essence of double network hydrogels, macroscale double networks have been fabricated by combining a rigid 3D printed grid within soft elastomer matrices. During deformation of a DN gel, the first network fractures sacrificially to dissipate energy, while the second network maintains the integrity of the bulk sample. As shown in **Figure A-7** (***King et al., ACS Applied Materials & Interfaces, 2019)***, we can achieve these same responses at macroscopic length scales. We find that the important criteria guiding this process is the ratio of fracture strength of the reinforcing grid to the matrix. When this ratio is nearly 1, the matrix possesses sufficient strength to break the sacrificial network without prematurely rupturing the stretchable matrix. Internal fracture achieved through this process greatly increases toughness. By utilizing this method, we were able to increase the work of extension by up to

51%. Importantly, this method does not depend on material chemistry, and can be considered a universal technique for improving the strength and toughness of soft materials.

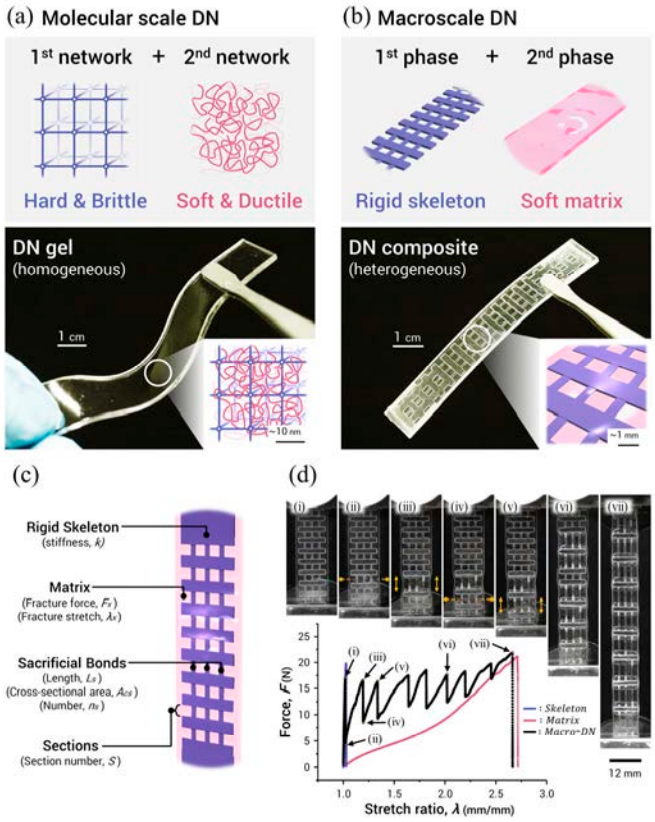


Figure A-7. (a) Example of molecular scale networks, and (b) their analogous networks at the macroscale. (c) A schematic of a macroscale DN composite, with the important criteria defined. (d) Force versus stretch ratio curve of a macroscale DN composite, along with its neat components. Insets (i) through (vii) show the internal fracture process, and the corresponding location on the force versus stretch ratio curve. ***King et al., ACS Applied Materials & Interfaces, 2019.***

3. Hydrogel/Metal Alloy Composites with Macroscopic Double Network Structure

Reinforcing hydrogels with a rigid scaffold is a promising method to greatly expand the mechanical and physical properties of hydrogels. One of the challenges of creating hydrogel composites is the significant stress that occurs due to swelling mismatch between the water-swollen hydrogel matrix and the rigid skeleton in aqueous media. This stress can cause physical deformation (wrinkling, buckling, or fracture), preventing the fabrication of robust composites. We introduced a simple yet versatile method to create hydrogel composites with a macroscale double network structure, by utilizing a rigid reinforcing phase that can relieve stress-induced deformation (**Figure A-8**) (***Takahashi et al., Advanced Materials, 2018***). A low-melting-point alloy that can transform from a load-bearing solid state to a free-deformable liquid state at relatively low temperature is used as a reinforcing skeleton, which enables the release of any swelling mismatch, regardless of the matrix swelling degree in liquid

media. This design can generally provide hydrogels with hybridized functions, including excellent mechanical properties, shape memory, and thermal healing, which are often difficult or impossible to achieve with single component hydrogel systems. Furthermore, this technique enables controlled electrochemical reactions and channel-structure templating in hydrogel matrices. This work may play an important role in the future design of soft robots, wearable electronics, and biocompatible functional materials.

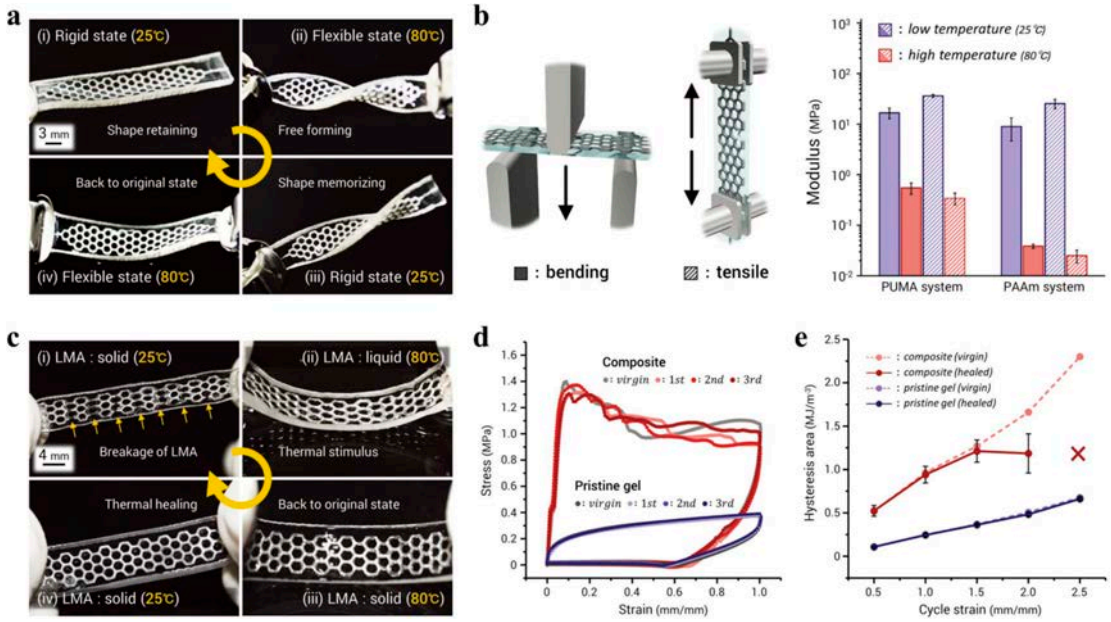


Figure A-8. Thermal response and thermal healing of composites from hydrogel-low melting point alloy, the PUMA–LMA composites. a) Demonstration of shape memory based on the solid–liquid phase transition of the LMA skeleton. b) Bending (solid shade) and tensile (hashed) moduli of the composite at low (25 °C, blue) and high (80 °C, red) temperature. c) Demonstration of thermal healing ability at a strain ratio of ≈1.5. Inset arrows in (i) represent the broken points of the internal LMA skeleton. d) Cyclic test curves of composite and pristine PUMA gels. e) Mechanical hysteresis loss during loading and unloading testing at various strains. ***Takahashi et al., Advanced Materials, 2018.***

A-5 Geometry and Morphology Design Inspired from Clingfish

Looking beyond the microscale of biological systems, the structures in organisms also have complex macro geometry and morphology, which affect their biophysical characteristics and enable specific biological functions. Learning the relationship between such macroscale structures and corresponding functions also provides us with design ideas and inspiration when designing functional materials.

Developing adhesives that work well on wet surfaces or underwater is a challenge, due to the existence of hydration layers on surfaces. In nature, the endoparasite *Pomphorhynchus laevis* can swell its proboscis to attach to the intestinal walls of its host. Inspired by the geometry of the adhesive discs of clingfish, we presented a design strategy to obtain hydrogels with fast, strong, and reversible adhesion underwater (**Figure A-9**) (***Rao et al., Advanced Materials, 2018***). We patterned hexagonal structures on the surface of a polyampholyte hydrogel, resulting in surface grooves that not only accelerate water drainage and prevent water trapping but also delay crack propagation during detachment. Furthermore, at the nanoscale, the dynamic bonds of the gel form reversible bridges at the interface, as well as dissipate energy in bulk during deformation. As a result, the patterned hydrogels exhibited excellent underwater adhesion on diverse substrates, including hard glasses, soft hydrogels, and biological tissues. This strategy of combining macroscale surface engineering and microscale dynamic bonds is applicable to various tough hydrogels.

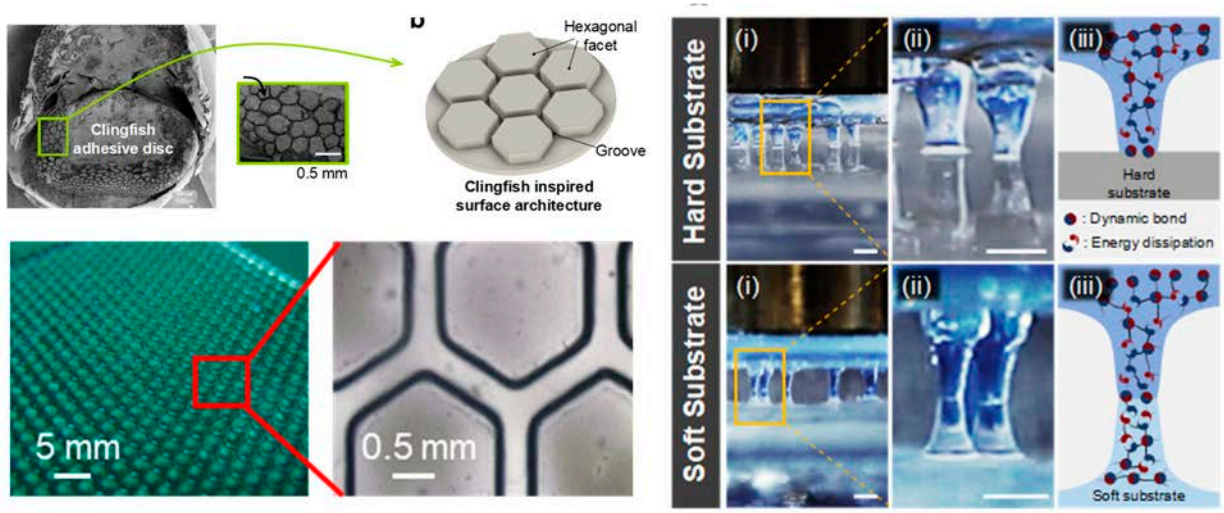


Figure A-9. Functions through macroscopic geometry and morphology control. (b) Photograph and optical microscopy image of the surface structures on a polyampholyte (PA) hydrogel, and photograph of patterned gels during debonding from a glass plate under water. ***Rao et al., Advanced Materials, 2018.***

A-6. Out-of-Equilibrium Hydrogels

1. Hydrophobic Hydrogels with Fruit-Like Structure and Functions

Normally, a polymer network swells in a good solvent to form a gel, but the gel will shrink if placed in a poor solvent. We discovered an abnormal phenomenon: some hydrophobic gels significantly swell in water, reaching water content as high as 99.6 wt% (**Figure A-10**) (***Guo et al., Advanced Materials, 2019***). Such abnormal swelling behaviors in the nonsolvent water are observed universally for various hydrophobic organogels containing omniphilic organic solvents that have a higher affinity to water than to the hydrophobic polymers. The formation of a semipermeable skin layer due to rapid phase separation, and the asymmetric diffusion of water molecules into the gel driven by the high osmotic pressure of the organic solvent–water mixing, are found to be the reasons. As a result, the hydrophobic hydrogels have a fruit-like structure, consisting of a hydrophobic skin and water-trapped micropores, to display various unique properties, such as significantly enhanced strength, surface hydrophobicity, and anti-drying, despite their extremely high water content. Furthermore, the hydrophobic hydrogels exhibit selective water absorption from concentrated saline solutions and rapid water release at low pressure, like squeezing juices from fruits. These novel functions of hydrophobic hydrogels will find promising applications, e.g., as materials that can automatically take fresh water from seawater.
This work is a collaboration with members of the France unit.

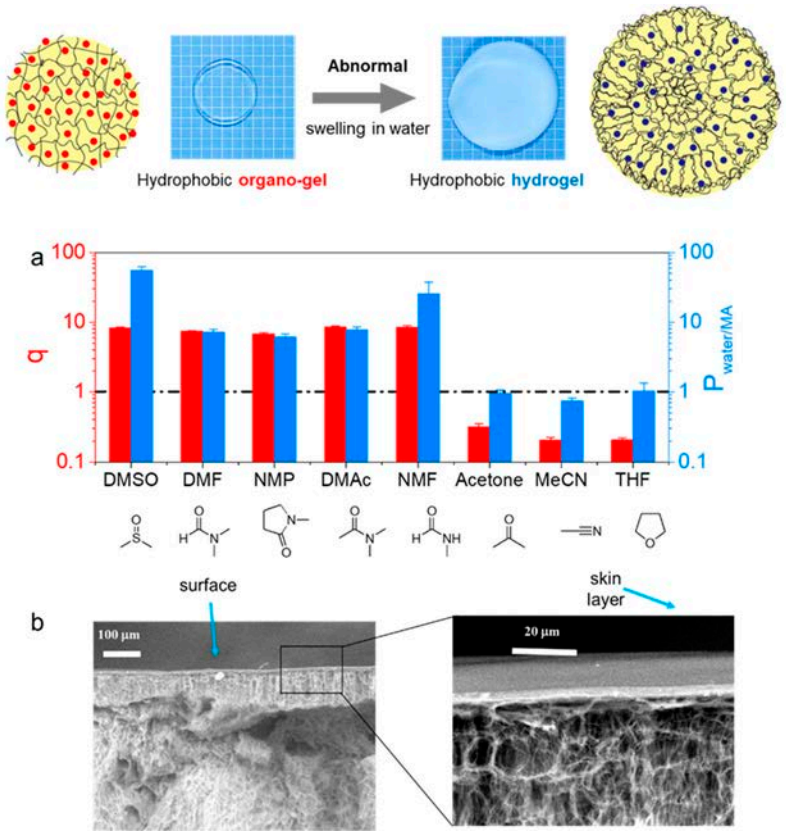


Figure A-10. Abnormal swelling of hydrophobic gels in water by formation of fruit-like structures. ***Guo et al., Advanced Materials, 2019.***

2. Memorizing-Forgetting Hydrogels

The ability for our brain to store memories is a dynamic process: unimportant details are spontaneously separated and forgotten. By contrast, technologies developed throughout history to record information usually depend on permanently modifying hard materials, such as inscriptions in stone or ink on paper. This information cannot be erased without the use of a subsequent energy-intensive process. Creating dynamic memory based on out-of-equilibrium processes of soft matter, similar to biological memory storage, has never been realized.

We proposed a principle for developing dynamic memory from soft hydrogels with temperature-sensitive dynamic bonds (**Figure A-11**) (***Yu et al., PNAS, 2020***). The memorizing-forgetting behavior is achieved through fast water uptake and slow water release upon thermal stimulus of polyampholyte hydrogels. The forgetting time is proportional to the thermal learning time, in analogy to the behavior of the brain, with an amplification coefficient determined by the ratio of cooperative diffusion coefficients of the gel for shrinking at low temperature and for swelling at high temperature. The memory is stable against temperature fluctuations and large stretching; moreover, the forgetting process is programmable. This novel principle may inspire future research on dynamic memory based on the nonequilibrium processes of soft matter.

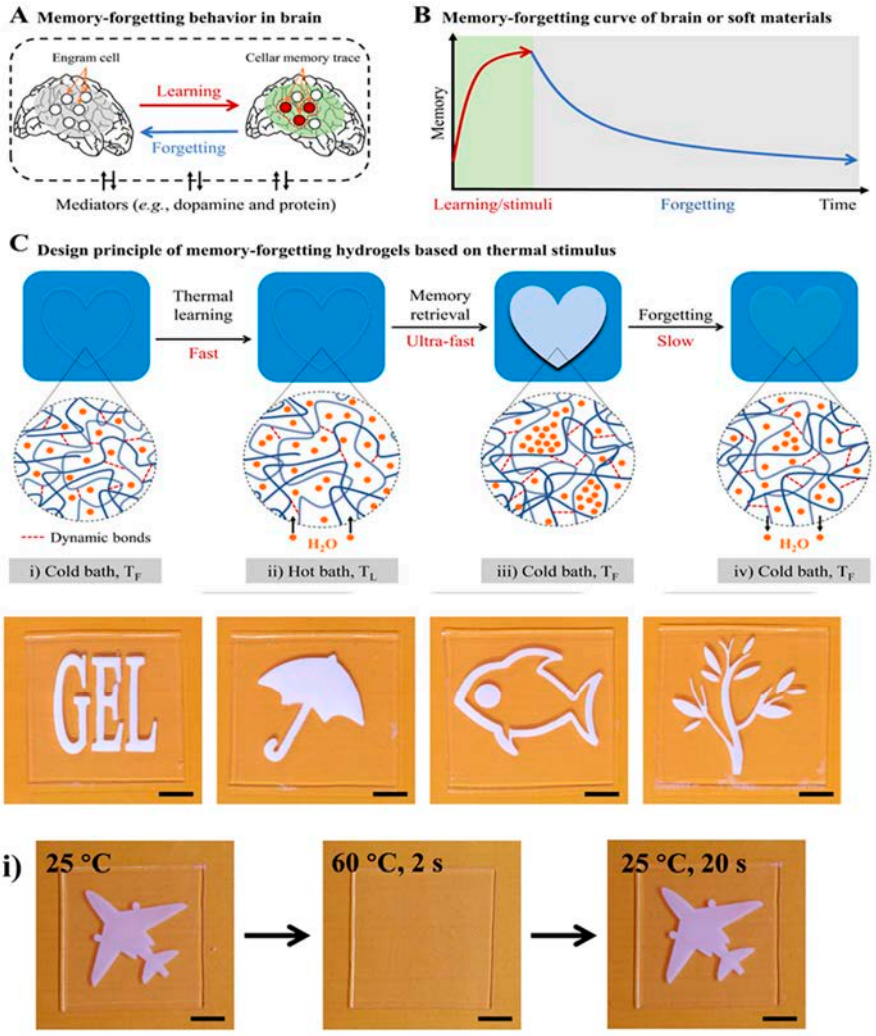


Figure A-11. Upper: Conceptual scheme of the dynamic memorizing-forgetting behavior from humans to soft materials. Lower: Thermal learning and memory of PA gels. ***Yu et al., PNAS, 2020.***

3. Self-Growing Hydrogels Inspired by Muscle Training

Today's hydrogels can show different responses to diverse kinds of external stimuli; however, such processes are related to transitions from one equilibrium state to another. In contrast, biological systems utilize a different way to update themselves to adapt to environmental changes while in the out-of-equilibrium state. For example, muscles can autonomously grow or atrophy to adapt to their surrounding mechanical environment through metabolic processes. The development of real out-of-equilibrium hydrogels that possess adaptivity using metabolic-like processes is also a direction for the next generation of bioinspired hydrogels. Recently, we have made significant progress on imitating a "metabolic" process in a synthetic hydrogel (**Figure A-12**) (***Matsuda et al., Science, 2019***). We show that double-network hydrogels can be healed and even strengthened after repeated mechanical training. In this system, the breakage of the network by mechanical stress is analogous to muscle damage, and the monomers supplied from the external environment are analogous to nutrients in a biosystem used

for the formation of a new network. This work is the first example of realizing continuous upgrades of a polymer network under external stimuli with a muscle metabolism-like mechanism. Although this approach is still in its infancy, lacking the ability to remove waste as a biological metabolic process does, it will motivate further research on fabricating more complex systems analogous to living matter.

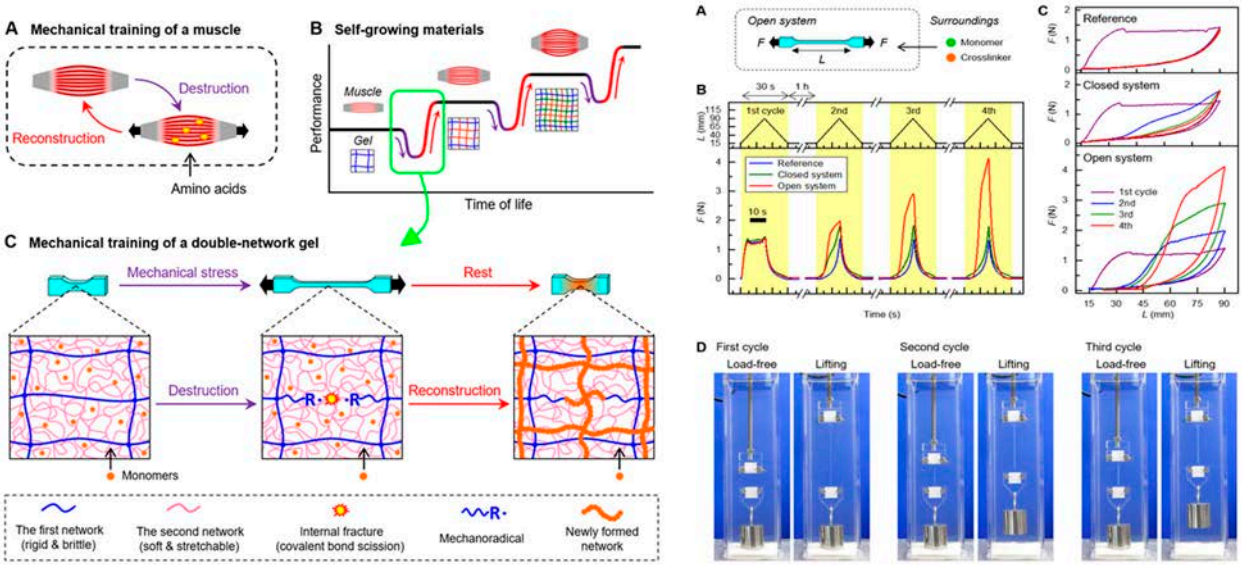


Figure A-12. Functions inspired by muscle training. Self-growing materials based on mechanical training of DN gels. Mechanical stress leads to covalent bond breakage that generates mechanoradicals, and the mechanoradicals subsequently react with monomers supplied from the external environment to form a new network and strengthen the gel. ***Matsuda et al., Science, 2019.***

Selected Publications for Target A

GSS members are indicated in bold.

1. Zhang HJ, **Sun TL**, Zhang AK, Ikura Y, **Nakajima T**, **Nonoyama T**, **Kurokawa T**, Ito O, Ishitobi H, **Gong JP**, "Tough Physical Double-Network Hydrogels Based on Amphiphilic Triblock Copolymers," ***Advanced Materials***, 28(24), 4884-4890 (2016).
2. Huang YW, **King DR**, **Sun TL**, **Nonoyama T, Kurokawa**, **Nakajima T**, **Gong JP**, "Energy-Dissipative Matrices Enable Synergistic Toughening in Fiber Reinforced Soft Composites," ***Advanced Functional Materials,*** 27(9), 1605350 (2017).
3. Takahashi R, **Sun TL**, Saruwatari Y, **Kurokawa T**, **King DR**, **Gong JP**, "Creating Stiff, Tough, and Functional Hydrogel Composites with Low Melting Point Alloys," ***Advanced Materials***, 30(16), 1706885 (2018).
4. **Ye YN**, Frauenlob M, **Wang L**, **Tsuda M**, **Sun TL**, Cui KP, Takahashi R, Zhang HJ, **Nakajima T**, **Nonoyama T**, **Kurokawa T**, **Tanaka S**, **Gong JP**, "Tough and Self-Recoverable Thin Hydrogel Membranes for Biological Applications," ***Advanced Functional Materials***, 28(31), 1801489 (2018).
5. Mredha MTI, Guo YZ, **Nonoyama T**, **Nakajima T**, **Kurokawa T**, **Gong JP**, "A Facile Method to Fabricate Anisotropic Hydrogels with Perfectly Aligned Hierarchical Fibrous Structures," ***Advanced Materials***, 30(9), 1704937 (2018).
6. Rao P, **Sun TL**, Chen L, Takahashi R, Shinohara G, Guo H, **King DR**, **Kurokawa T**, **Gong JP**, "Tough Hydrogels with Fast, Strong, and Reversible Underwater Adhesion Based on a Multiscale Design," ***Advanced Materials***, 30(32), 1801884 (2018).
7. Fan HL, Wang JH, Tao Z, Huang JC, Rao P, **Kurokawa T**, **Gong JP**, "Adjacent Cationic-Aromatic Sequences Yield Strong Electrostatic Adhesion of Hydrogels in Seawater," ***Nature Communications***, 10, 5127 (2019).
8. **Nonoyama T**, Lee YW, Ota K, Fujioka K, **Hong W**, **Gong JP**, "Instant Thermal Switching from Soft Hydrogel to Rigid Plastics Inspired by Thermophile Proteins," ***Advanced Materials***, 32(4), 1905878 (7 pages) (2019).
9. **Guo H**, **Nakajima T**, **Hourdet D**, **Marcellan A**, **Creton C**, **Hong W**, **Kurokawa T**, **Gong JP**, "Hydrophobic Hydrogels with Fruit-like Structure and Functions," ***Advanced Materials***, 31(25), 1900702 (2019).
10. **King DR**, Okumura T, Takahashi R, **Kurokawa T**, **Gong JP**, "Macroscale Double Networks: Design Criteria for Optimizing Strength and Toughness," ***ACS Applied Materials & Interfaces***, 11(38), 35343-35353 (2019).
11. Matsuda T, Kawakami R, Namba R, **Nakajima T**, **Gong JP**, "Mechanoresponsive Self-Growing Hydrogels Inspired by Muscle Training," ***Science***, 363(6426), 504-508 (2019).
12. Matsuda T, **Nakajima T**, **Gong JP**, "Fabrication of Tough and Stretchable Hybrid Double-Network Elastomers Using Ionic Dissociation of Polyelectrolyte in Nonaqueous Media," ***Chemistry of Materials***, 31(10), 3766-3776 (2019).
13. Yu CT, Guo HL, Cui KP, **Li XY**, **Ye YN**, **Kurokawa T**, **Gong JP**, "Hydrogels as Dynamic Memory with Forgetting Ability," ***PNAS***, 117 (32), 18962-18968 (2020).
14. Cui W, **King DR**, Huang YW, **Sun TL**, Guo YZ, Saruwatari Y, **Hui CY**, **Kurokawa T**, **Gong JP**, "Fiber-Reinforced Viscoelastomers Show Extraordinary Crack Resistance that Exceeds Metals," ***Advanced Materials***, 32(31), 1907180 (2020).
15. Fan HL, **Gong JP**, "Fabrication of Bioinspired Hydrogels: Challenges and Opportunities," ***Macromolecules***, 53(8), 2769-2782 (2020). (Invited review paper)
16. **Ye YN,** Cui KP, **Hong W**, **Li XY**, Yu CT, **Hourdet D**, **Nakajima T**, **Kurokawa T**, **Gong JP**, "Molecular Mechanism of Abnormally Large Nonsoftening Deformation in a Tough Hydrogel," ***PNAS***, 118(14), e2014694118 (2021)

Target B Revealing Physical Principles of Multi-functional Hydrogels

B-1. Microelectrode Technique for Observation of Electric Potential Distribution in Hydrogels

The spatial distribution of electric potential reveals important structural information of polyelectrolyte hydrogels. We report, for the first time, the quantitative measurement of the local electric potential of brittle polyelectrolyte hydrogels using the microelectrode technique (MET) (**Figure B-1**) (***Guo, et al., Macromolecules, 2016***). Given the solid-like nature of the hydrogels, the primary difficulty in applying MET is making good contact between the microelectrode to the hydrogel. Poor local contact substantially underestimates the potential. We found that by using microelectrodes with a tip wall thickness less than the local Debye length, the Donnan potential of polyelectrolyte gel could be accurately measured. Using a micromanipulator, the insertion process of the microelectrode is precisely controlled, and the depth profile of electric potential in the hydrogels can be measured with a spatial resolution down to ~100 nm. From the spatial distribution of potential, the microstructure of hydrogels both in the bulk and near the surface can be determined accurately, for samples ranging from ultra-thin hydrogels to heterogeneous layered structure composite gels. The MET established in this work provides a powerful tool for direct characterization of the spatial distribution of electric potential of hydrogels.

This work is a collaboration with members of the US unit.

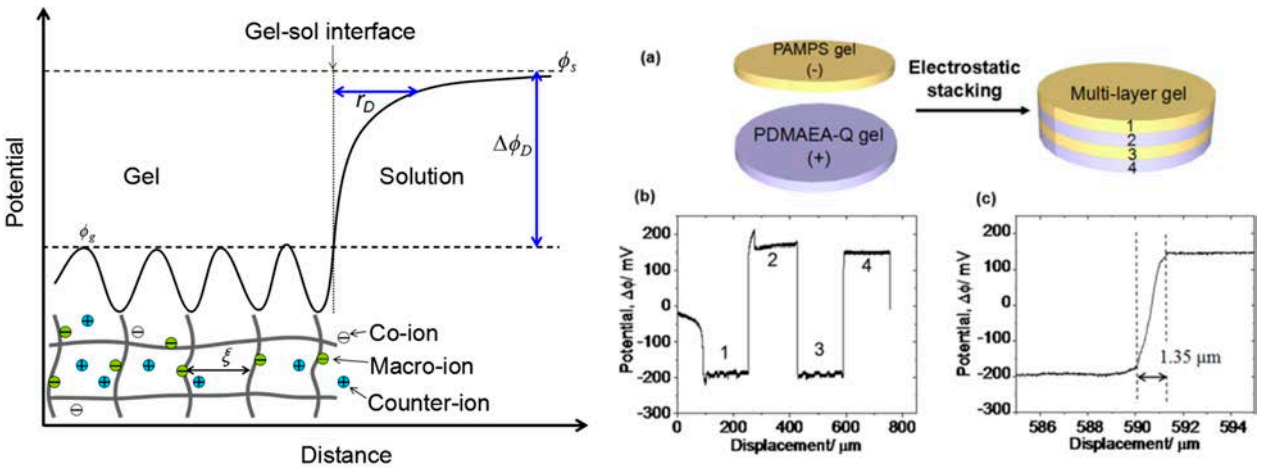


Figure B-1. Measurement of the electric potential distribution in a hydrogel and its application to a multilayer gel. ***Guo, et al., Macromolecules, 2016.***

B-2. Internal Damage in Double-Network Hydrogels Studied by Microelectrode Technique

Double-network (DN) hydrogels have attracted considerable attention owing to their unique mechanism that enables extraordinary mechanical strength and toughness. Although the toughening mechanism of DN gels, based on breaking the relatively stiff and brittle first network as sacrificial bonds, is widely accepted, the microstructure and morphology evolution of the internal damage has not yet been elucidated.

We employed the MET to study the internal fracture behavior of a pre-stretched DN gel under uniaxial deformation (**Figure B-2**) (***Guo et al., Macromolecules, 2019***). This method gives structure information at a scale larger than the probe size of ~200 nm in this study. The measured electric potential distributions in re-swollen DN gels reveals stretch-induced anisotropy: the material is softened more significantly along the tensile direction, possibly related to the coalescence of the internal cracks in the first network. With increasing pre-stretch, the statistical distribution of potential values changes from unimodal to bimodal, indicating the coexistence of minor damaged regions and the major damaged regions. The volume fraction of the minor damaged region is predicted to decrease with increasing pre-stretch, while the volume fraction of the major damaged region increases with stretch and reaches 0.72 in the hardening regime. The average distance between neighboring major (or minor) damaged regions along the tensile direction are almost constant at ~2 μm for the un-swollen sample, independent of pre-stretch. Additionally, the microstructure of the transition region between the necked and un-necked zones suggests that the damage initiates from the gel surface and then propagates into the depth.

This work is a collaboration with members of the US unit.

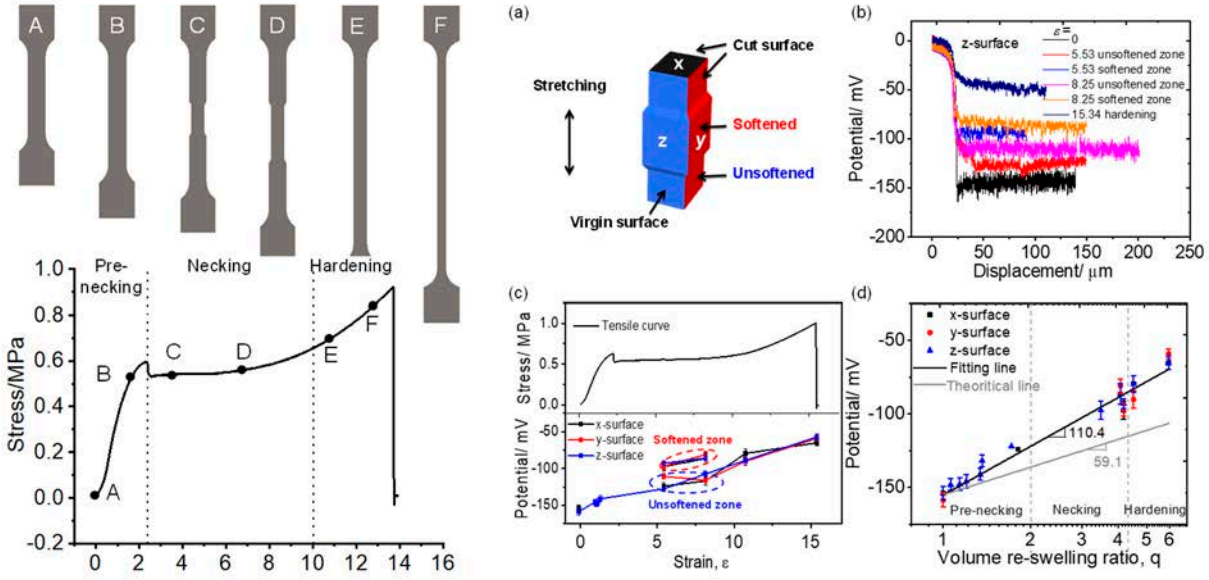


Figure B-2. Loading curve of a typical DN gel under uniaxial elongation. Electric potentials measured from different directions in reswollen DN gels after pre-stretching. ***Guo et al., Macromolecules, 2019.***

B-3. Yielding Criteria of Double Network Hydrogels

Double network (DN) gels, consisting of interpenetrating brittle first and flexible second networks, are known to be extremely tough and functional hydrogels. In a DN gel subjected to force, the brittle first network widely breaks prior to the flexible network breakage. This process, called internal fracture, dissipates much energy and increases the energy required to fracture DN gels. Such internal fracture macroscopically appears as yielding-like behavior. We investigated the relationship between the yield point and the first network molecular structure of DN gels to deepen the understanding of the internal fracture mechanism (**Figure B-3**) (***Matsuda, et al., Macromolecules, 2016)***. To achieve this goal, we synthesized DN gels with a tetra-PEG first network, which is known as a nearly ideal and well-defined network gel. We have found the following yielding criteria: 1) the yield point of DN gels is determined by the extension limit of the first network chains; 2) the yield stress (along the stretching direction) is determined by the area density of the first network; and 3) the effect of the second network on the yield point is negligible. This study gives us clear insight into the yielding and toughening mechanism of DN gels. Additionally, the yield point is sometimes considered as the maximum allowable deformation of materials for practical use since materials undergo irreversible deformation at this point. Thus, clarification of the yield point of DN gels, done by this work, helps in designing DN gels suitable for various applications.

This work is a collaboration with members of the US unit.

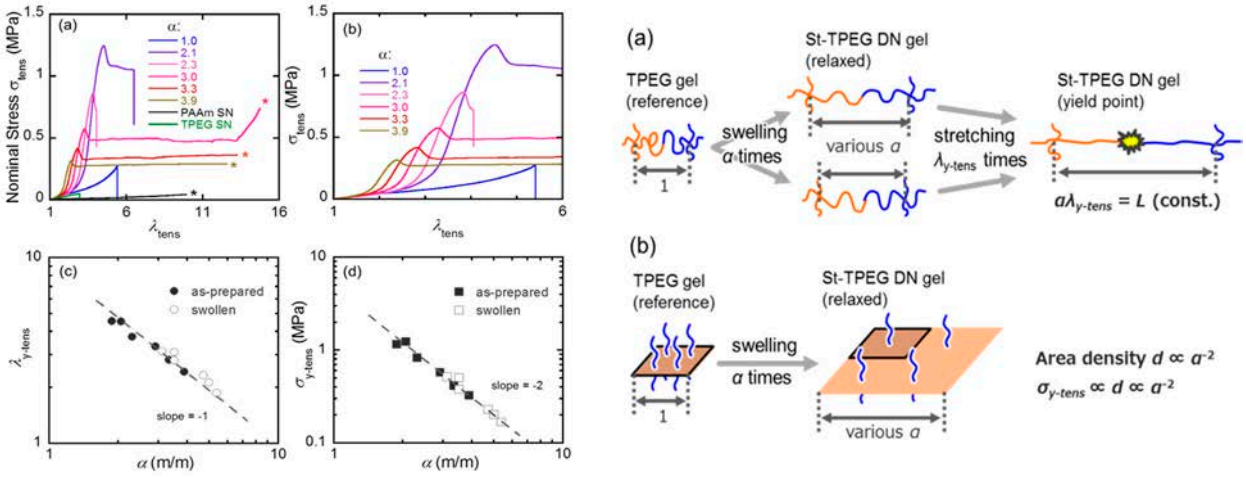


Figure B-3. Left: (a) Tensile stress-deformation ratio curves of the as-prepared St-TPEG/PAAm DN gels with various pre-swelling ratio of the first network α. (b) Highlight of the small deformation region of (a). (c, d) Yield deformation ratio $\lambda_{y\text{-tens}}$ and yield stress $\sigma_{y\text{-tens}}$ dependence on α of the St-TPEG/PAAm DN gels. Dashed lines are observed power-law relationships. Right: Schematic illustrations for determination factors of (a) yield deformation ratio and (b) yield stress of DN gels. ***Matsuda, et al., Macromolecules, 2016.***

B-4. Single-Chain Force Spectroscopy by Double Network Deformation

Understanding the force-extension relation of a single polymer chain is one of the most fundamental issues in polymer science. The behavior of a chain near the stretching limit is poorly understood due to the experimental difficulty of reaching this state. We proposed a macroscopic method, termed "network force spectroscopy", to extract a single macromolecule force-extension relationship from the stress-elongation dependence of the corresponding network (**Figure B-4**) (***Indei et al., 68th Rheology Meeting, 2020***). The key to applying this principle is to have the corresponding network strands strongly stretched without causing macroscopic failure, which is achieved by using the double-network concept. The network force spectroscopy reaches single-chain tension significantly higher than the tension measured by atomic force microscopy. The macroscopic approach can thus be a facile and powerful technique complementary to the nanoscale method.

This work is a collaboration with members of the US unit.

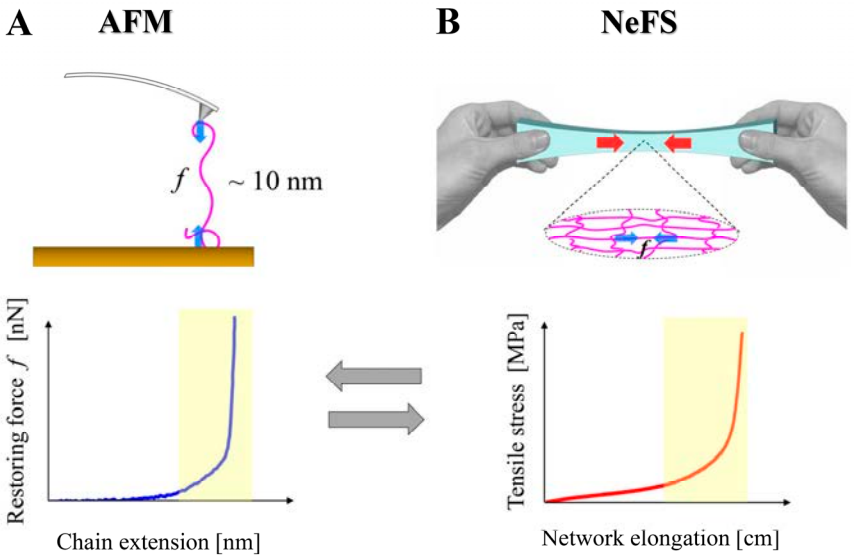


Figure B-4. Extraction of force-extension relation of a single polymer chain (A) from stress-elongation relation of the polymer network (B). The strong non-linear regime is indicated in yellow. ***Indei et al., 68th Rheology Meeting, 2020.***

B-5. Elastic−Plastic Transformation of Polyelectrolyte Complex Hydrogels from Biopolymers

Hydrogels formed by polyelectrolyte complexation (PEC) of oppositely charged biopolymers, free of any chemical additives, are promising biomaterials. We investigated the mechanical behavior of hydrogels consisting of positively charged chitosan and negatively charged sodium hyaluronate (HA) at the charge balanced composition (**Figure B-5**) (***Shi, et al., Macromolecules, 2018***). These hydrogels exhibit strong tensile strain and strain rate dependence. They are elastic-like, independent of the strain rate at small strain, but exhibit plastic-like behavior above the yield point by showing a monotonous decrease in stress. The cyclic tensile test demonstrates that these hydrogels exhibit small and quickly recoverable hysteresis in the elastic-like region but large and partially recoverable hysteresis above the yield point. The stress relaxation experiment shows a plateau in the reduced stress followed by abrupt fracture, and the time to failure decreases exponentially with increasing applied step strain. Such elastic-to-plastic-like transformation of the biopolymer PEC gels is quite different from the behavior of PEC hydrogels formed by oppositely charged vinyl-type synthetic polyelectrolytes due to the difference in flexibility, charge density, and ionic bond strength of these polymers.
This work is a collaboration with members of the US unit.

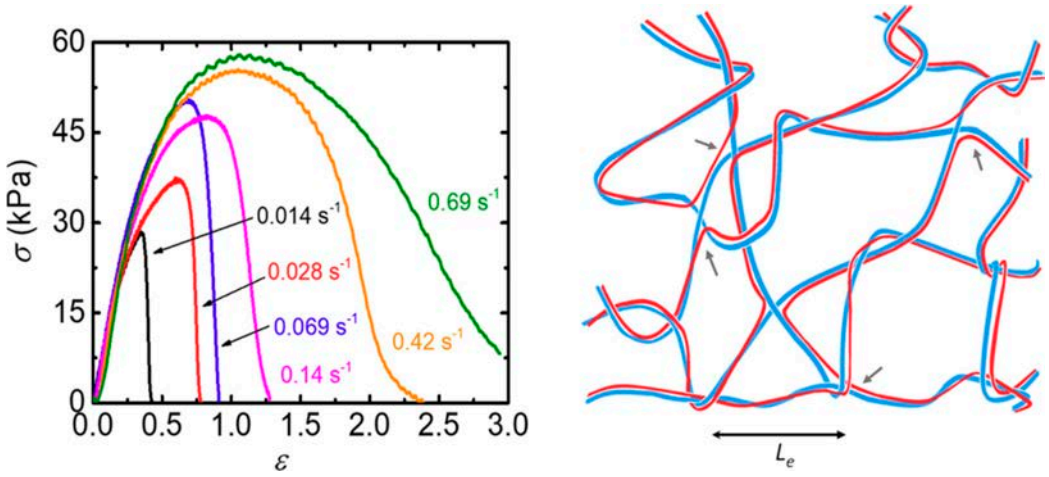


Figure B-5. Left: Mechanical behavior of HA/chitosan polyelectrolyte complex (PEC) hydrogels at the nominal charge ratio of HA/chitosan of 1.09. Right: A simplified illustration representing the molecular structure of a HA/chitosan hydrogel: a double-stranded network of oppositely charged biopolymers. The entanglements between double strands and chain exchanges (bridges indicated by gray arrows) serve as crosslinks, contributing to the modulus of the hydrogel. The blue and red lines represent oppositely charged chains. ***Shi, et al., Macromolecules, 2018.***

B-6. Multiscale Energy Dissipation Mechanism in Tough and Self-Healing Hydrogels

Understanding the energy dissipation mechanism that occurs during deformation is essential for the design and application of tough soft materials. We show that, in a class of tough and self-healing polyampholyte hydrogels, a bicontinuous network structure, consisting of a hard network and a soft network, is formed, independently of the chemical details of the hydrogels (**Figure B-6**) (***Cui et al., Physical Review Letters, 2018; Cui et al., Macromolecules 2020***). Multiscale internal rupture processes, in which the double-network effect plays an important role, are found to be responsible for the large energy dissipation of these hydrogels. Specifically, we studied the strain-induced fracture in tough and self-healing supramolecular gels, focusing on the underlying energy dissipation mechanism and its relation to the structure. Supramolecular hydrogels composed of polyampholytes (PA) display viscoelasticity and excellent mechanical properties, such as high toughness, high fatigue resistance, and self-healing, making them perfect candidates for this study. By combining a customized extensional rheometer and time-resolved synchrotron radiation small-angle x-ray scattering (SAXS), we elucidate that these PA gels have a multiscale structure and the toughening results from a synergistic effect involving multiscale energy dissipation.

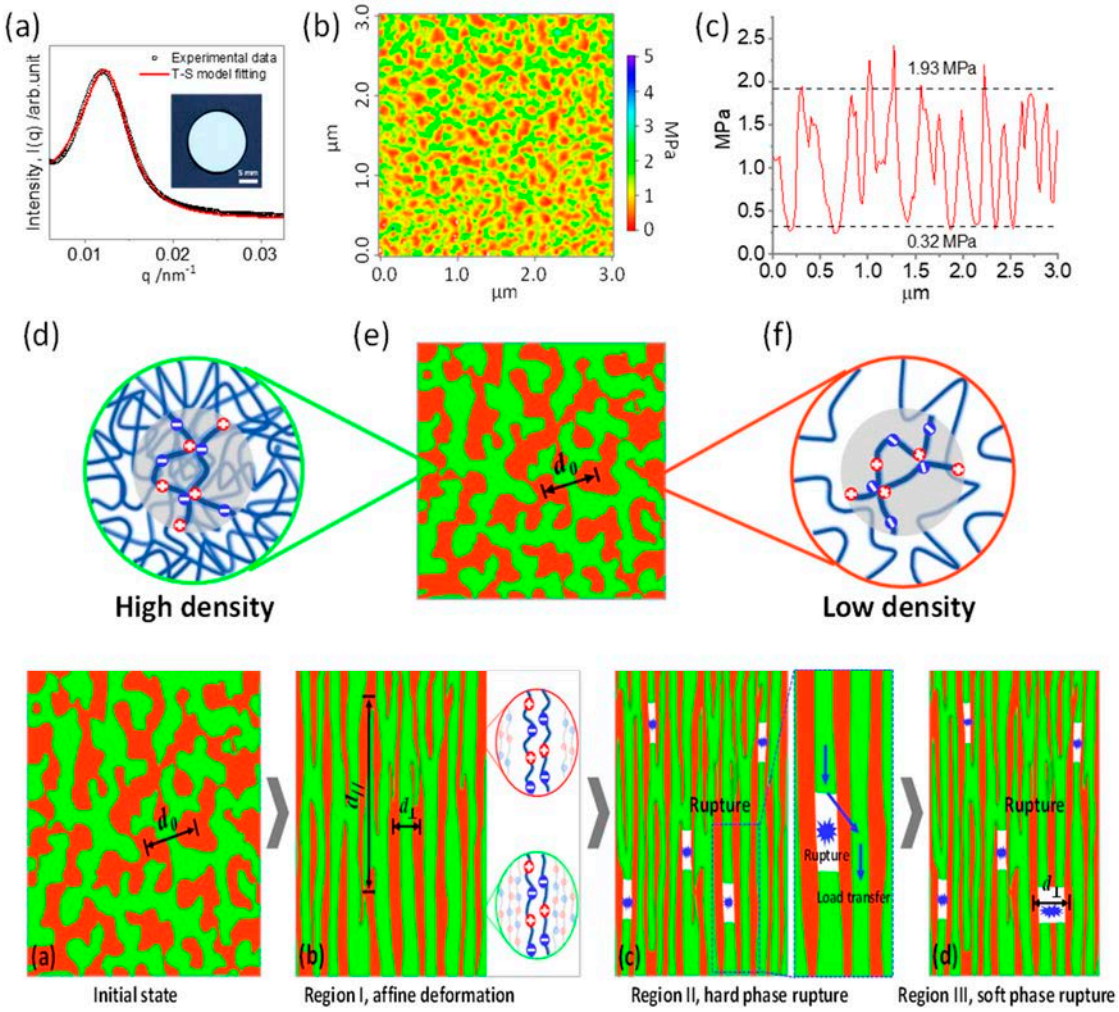


Figure B-6. Multi-scale structure of polyampholyte (PA) hydrogels and illustrations of the multi-scale fracture process of phase-separated gels that results in high toughness. ***Cui et al., Physical Review Letters, 2018; Cui et al., Macromolecules, 2020.***

B-7. Delayed Fatigue Fracture in Self-healing Hydrogels with Hierarchical Structure

Load-bearing biological tissues, such as muscles, are highly fatigue resistant, but how the exquisite hierarchical structures of biological tissues contribute to their excellent fatigue resistance is not well understood. We studied antifatigue properties of soft materials with hierarchical structures using polyampholyte hydrogels (PA gels) as a simple model system (**Figure B-7**) (***Li et al., PNAS, 2020, Li et al., Science Advances, 2021***). PA gels are tough and self-healing, consisting of reversible ionic bonds at the 1-nm scale, a cross-linked polymer network at the 10-nm scale, and bicontinuous hard/soft phase networks at the 100-nm scale. We find that the polymer network at the 10-nm scale determines the threshold of the energy release rate G_0 above which the crack grows, while the bicontinuous phase networks at the 100-nm scale significantly decelerate the crack advance until a transition G_{tran} far above G_0. *In situ* small-angle X-ray scattering analysis reveals that the hard phase network suppresses the

crack advance to show decelerated fatigue fracture, and G_{tran}. Such an antifatigue mechanism based on hierarchical structures not only gives important hints to understand fatigue-resistant behavior of bio-tissues with complex hierarchical structures, but also provides a design strategy for tough and fatigue-resistant hydrogels, by forming multiscale network structures using noncovalent bonds as building blocks.

This work is a collaboration with members of the France unit.

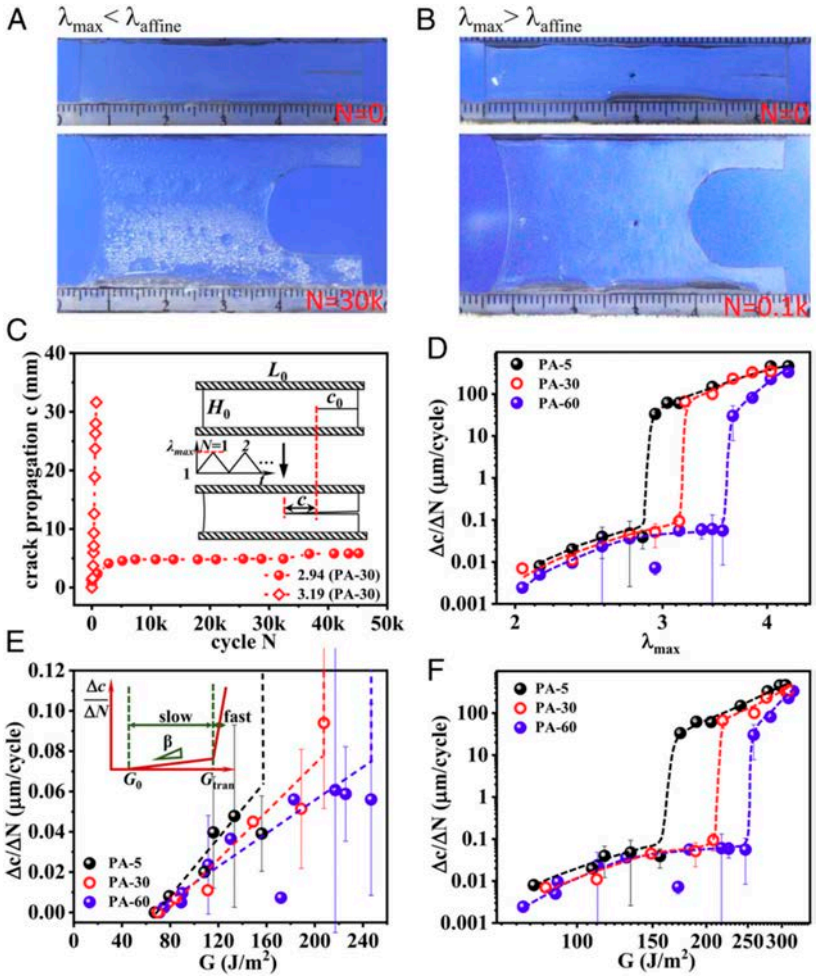


Figure B-7. Delayed fatigue fracture of self-healing PA gels with hierarchical structures.

(A and B) Shape of the crack tip for fatigue test under $\lambda_{max} = 2.94$ ($<\lambda_{affine}$) at 30,000 cycles (A) and $\lambda_{max} = 3.19$ ($>\lambda_{affine}$) at 100 cycles (B) for PA-30 as a representative. (C) Crack propagation length c as a function of cycle N at elongation ratio $\lambda_{max} = 2.94$ and 3.19 for PA-30. (Inset) The geometry of the sample applied in the fatigue test. (D) $\Delta c/\Delta N$ as a function of λ_{max} for gels dialyzed at various temperatures T_{dial}. A transition for crack propagation from slow to fast mode is observed universally at $\lambda_{tran} \sim \lambda_{affine}$ for all of the samples. The comparison of λ_{tran} and λ_{affine} is shown in Fig. 2D. (E) The enlarged slow mode regime for $\Delta c/\Delta N$ as a function of energy release rate G. A linear relation $\Delta c/\Delta N = \beta (G - G_0)$ at $G_0 < G < G_{tran}$, is observed (as schemed in Inset). (F) $\Delta c/\Delta N$ as a function of G in a log-log plot. ***Li et al., PNAS, 2020; Li et al., Science Advances, 2021***

B-8. Theoretical Study on Fracture of Fiber Reinforced Soft Composites

Through collaborations with the US unit, a mechanism describing the extraordinarily large force transfer zone of hydrogel/fiber composites is proposed based on established fabric tearing theory, which will enable the development of a new generation of mechanically robust composites based on fabric (**Figure B-8**) (***Hui et al., Extreme Mechanics Letters, 2020***).

An upper-bound estimate for fiber/matrix modulus ratio in traditional fiber reinforced polymer (FRP) composites is 100. Matrices made from tough elastic gels can have modulus approaching kilopascals and increase this ratio to 10^7. We study how this extremely high modulus ratio affects the mechanical behavior of such fiber reinforced "soft" composites (FRSCs). We focus on unidirectional FRSCs with parallel fibers perfectly bonded to a soft elastic matrix. We show such composites exhibit the Mullins effect typically observed in rubbers and double network (DN) gels. We quantify the size effect on the mechanical properties by studying unidirectional composites consisting of finite length fibers. We determine the stress concentration factors (SCFs) for a cluster of fiber breaks in this geometry and show that there is a transition from equal load sharing (ELS) to local load sharing (LLS). We also determine the mean strength and work of extension assuming fibers obey Weibull statistics. We discuss the application of fracture mechanics to this emerging class of composites. We highlight similarities and differences between FRSCs and DN gels. Based on our model, we propose the following design criteria:

(a) Use high strength fibers to increase energy dissipation.

(b) Fibers in short composites do not reach their maximum load bearing capability and toughness can be compromised due to pull-out.

(c) Good interfacial adhesion to ensure effective load transfer.

(d) An ideal elastic matrix should be soft in small strains, but strain hardens rapidly at large strains.

These results will be important in the field of soft biological prosthetics, and more generally for commercial applications such as tear-resistant gloves and bullet-proof vests.

These design criteria have been verified recently by tough composites made from viscoelastomers and fiber fabrics (***Cui et al., Advanced Materials, 2020***).

This work is a collaboration between members of the US unit and HU unit.

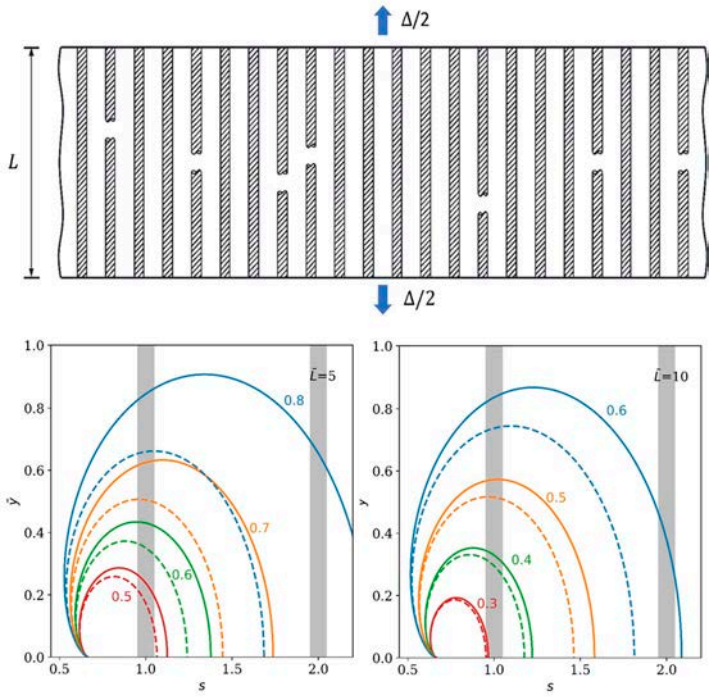


Figure B-8. Upper: A composite of N parallel fibers (shaded) with length L bonded to a soft matrix (white) in a displacement-controlled tension test. Lower: Shapes of damage zone at different nominal stress levels for different normalized fiber lengths. Solids lines are the closed-form solution and dotted lines are the asymptotic solution. ***Hui et al., Extreme Mechanics Letters, 2020.***

B-9. Shearing-Induced Contact Pattern Formation in Hydrogels Sliding

Biological systems display fascinating low friction properties, as found in human joints and eyes. Friction-reducing processes in biological systems take place between water-containing soft tissues intermediated by viscoelastic synovial fluid or mucus. Hydrogels are a class of material similar to biological soft tissues, in terms of their water containing structure and softness. Hydrogels are therefore useful as model substances to elucidate the low friction mechanisms of soft tissues as well as biomaterials such as artificial cartilage and meniscus. Previous research has shown that hydrogels exhibit very rich friction behaviors, in which solid friction and fluid dissipation coexist. The surface chemistry, surface topology, bulk mechanical properties of the hydrogels, and the polymer lubricants all play intertwined roles in the friction-reducing processes.

To elucidate the role of synovial fluid in these systems, hydrogel friction in polymer solutions have been studied previously. It has been found that the friction at low sliding velocity, at which the interfacial interaction is the dominant mechanism, decreases with the polymer concentration in the dilute and semi-dilute regimes, reaching a minimum value for a concentration around 10C*, and then the friction increases with the polymer concentration in the concentrated region. Here, C* is the overlap concentration of the polymer solution.

In situ observations of the contact of a hydrogel during the rotational shearing on a glass surface in concentrated sodium hyaluronate (HA) solution was performed using a home-made optical system based on the principle of critical refraction (**Figure B-9**) (***Yashima et al., Soft Matter, 2019***). Dynamic contact patterns are observed for the first time and the patterns display periodicity in the circumferential direction. The appearance time and character of the contact patterns are dependent on the polymer concentration, the sliding velocity, the normal pressure, and the modulus of the gel. More concentrated polymer solutions and higher sliding velocities produce contact patterns with finer characters. Higher pressures and lower moduli lead to a quicker pattern formation. The results suggest that the instability is related to the shear thinning of the HA solutions as lubricants of the soft hydrogels under rotational shearing.

This work is a collaboration with the members of France unit and US unit.

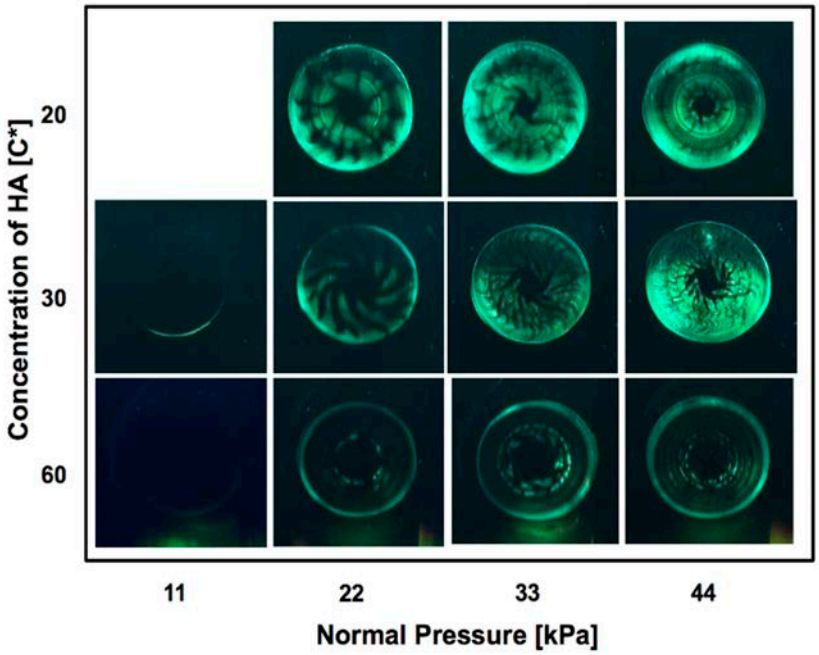


Fig. B-9. HA concentration and normal pressure effects on the contact pattern at the hydrogel/glass interface, observed 90 seconds after the beginning of the sliding motion. Gel modulus: 40 kPa; angular velocity: 5.3 rad/s. ***Yashima et al., Soft Matter, 2019***.

Selected Publications for Target B

GSS members are indicated in bold.

1. Matsuda T, **Nakajima T**, Fukuda Y, **Hong W**, Sakai T, **Kurokawa T**, Chung, U, **Gong JP**, "Yielding Criteria of Double Network Hydrogels," ***Macromolecules***, 49(5), 1865-1872 (2016).
2. Guo HL, **Kurokawa T**, Takahata M, **Hong W**, Katsuyama Y, Luo F, Ahmed J, **Nakajima T**, **Nonoyama T**, **Gong JP**, "Quantitative Observation of Electric Potential Distribution of Brittle Polyelectrolyte Hydrogels Using Microelectrode Technique," ***Macromolecules***, 49(8), 3100-3108 (2016).
3. Shi R, **Sun TL**, Luo F, **Nakajima T**, **Kurokawa T**, Bin YZ, **Rubinstein M**, **Gong JP**, "Elastic–Plastic Transformation of Polyelectrolyte Complex Hydrogels from Chitosan and Sodium Hyaluronate," ***Macromolecules***, 51(21), 8887-8898 (2018).
4. Cui KP, **Sun TL**, Liang XB, Nakajima K, Ye YN, Chen L, **Kurokawa T**, **Gong JP**, "Multiscale Energy Dissipation Mechanism in Tough and Self-Healing Hydrogels," ***Physical Review Letters***, 121(18), 185501 (2018).
5. Mai TT, Matsuda T, **Nakajima T**, **Gong JP**, Urayama, K, "Distinctive Characteristics of Internal Fracture in Tough Double Network Hydrogels Revealed by Various Modes of Stretching," ***Macromolecules***, 51(14), 5245-5257 (2018).
6. Yashima S, Hirayama S, **Kurokawa T**, **Salez T**, Takefuji H, **Hong W**, **Gong JP**, "Shearing-induced Contact Pattern Formation in Hydrogels Sliding in Polymer Solution," ***Soft Matter***, 15(9), 1953-1959 (2019).
7. **Guo HL**, **Hong W**, **Kurokawa T**, Matsuda T, Wu ZL, **Nakajima T**, Takahata M, **Sun TL**, Rao P, **Gong JP**, "Internal Damage Evolution in Double-Network Hydrogels Studied by Microelectrode Technique," ***Macromolecules***, 52(18), 7114-7122 (2019).
8. **Li XY,** Cui KP, **Sun TL**, Meng LP, Yu CT, Li LB, **Creton C**, **Kurokawa T**, **Gong JP**, "Mesoscale Bicontinuous Networks in Self-healing Hydrogels Delay Fatigue Fracture," ***PNAS***, 117(14), 7606-7612 (2020).
9. **Hui CY**, Liu ZZ, Phoenix SL, **King DR**, Cui W, Huang YW, **Gong JP**, "Mechanical Behavior of Unidirectional Fiber Reinforced Soft Composites," ***Extreme Mechanics Letters***, 35, 100642, (2020).
10. Cui W, **King DR**, Huang YW, Chen L, Sun TL, Guo YZ, Saruwatari Y, **Hui CY**, **Kurokawa T**, **Gong JP**, "Fiber-Reinforced Viscoelastomers Show Extraordinary Crack Resistance that Exceeds Metals," ***Advanced Materials***, 32(31), 1907180, (2020).
11. Haque MA, Cui KP, Ilyas M, **Kurokawa T**, **Marcellan A**, Brulet A, Takahashi R, **Nakajima T**, **Gong JP**, "Lamellar Bilayer to Fibril Structure Transformation of Tough Photonic Hydrogel under Elongation," ***Macromolecules***, 53(12), 4711-4721, (2020).
12. Cui KP, **Ye YN**, **Sun TL**, Yu CT, **Li XY**, **Kurokawa T**, **Gong JP**, "Phase Separation Behavior in Tough and Self-Healing Polyampholyte Hydrogels," ***Macromolecules***, 53(13), 5116-5126 (2020).
13. **Indei T**, Matsuda T, **Nakajima T**, Takahashi Y, Kouznetsova TB, **Rubinstein M**, **Craig SL**, **Gong JP**, "Extraction of Polymer Chain's Force-Extension Relation from Stress-Strain Relation of Polymer Network," ***68th Rheology Meeting***, Oct. 21~23, 2020, Iwate University
14. **Li XY**, Cui KP, **Kurokawa T**, **Ye YN**, **Sun TL**, Yu CT, **Creton C**, **Gong JP**, "Effect of Mesoscale Phase Contrast on Fatigue-Delaying Behavior of Self-Healing Hydrogels," ***Science Advances***, 7(16), eabe8210 (2021)

Target C Applying Gels as Multi-functional Biomaterials

C-1. Tough Double Network Hydrogels as Artificial Cartilages

Recent progress in developing tough hydrogels has made these highly water-containing materials promising substitutes for soft supporting tissues such as cartilage and ligaments. However, bonding of tough hydrogels to bone is a great challenge for such potential applications.

Double-Network Hydrogels Strongly Bondable to Bones by Spontaneous Osteogenesis Penetration

Through collaborations in the Hokkaido University unit, we have developed a novel tough double-network hydrogel that spontaneously bonds to defected bones robustly *in vivo* (**Figure C-1**) (***Nonoyama et al., Advanced. Materials, 2016)***. The osteointegration of the hydrogel is realized by mineralizing calcium-phosphate-hydroxide salt hydroxyapatite (HAp) nanospheres in the surface layer of the hydrogel. We discovered that the presence of HAp on the surface layer of the hydrogel induces spontaneous osteogenesis penetration into the semipermeable hydrogel. A gel/bone hybrid layer of around 40 μm thickness was observed to give the robust bonding. The strong osteointegration of the HAp/DN gel was due to the formation of a gel/bone hybrid layer at the interface with a gradient structure. This study demonstrated that the HAp/DN gel enhanced osteointegration in the early stage after implantation. The presence of nanoscale structures in addition to the osteointegration ability of HAp promoted osteoblast adhesion onto the surface of the HAp/DN gel (***Wada et al., Acta Biomaterialia, 2016***).

A recent study on using the isotope microscopy revealed that the mineralized HAp nanoparticles are reutilized in the new bone formation (***Nonoyama et al., submitted***). This method to strongly bind the hydrogels to bones is simple and feasible for practical medical use. This work is groundbreaking for the application of tough hydrogels as substitutes of soft supporting tissues connecting to bones, such as cartilage, tendon, and ligament. Indeed, we have also applied this method to fix the anisotropic tough double network hydrogel from fish collagen that have ligament-like properties, and we confirmed the same spontaneous *in vivo* bonding to bone (***Mredha et al., Biomaterials, 2017***).

This work is a collaboration between inter-department members of HU unit.

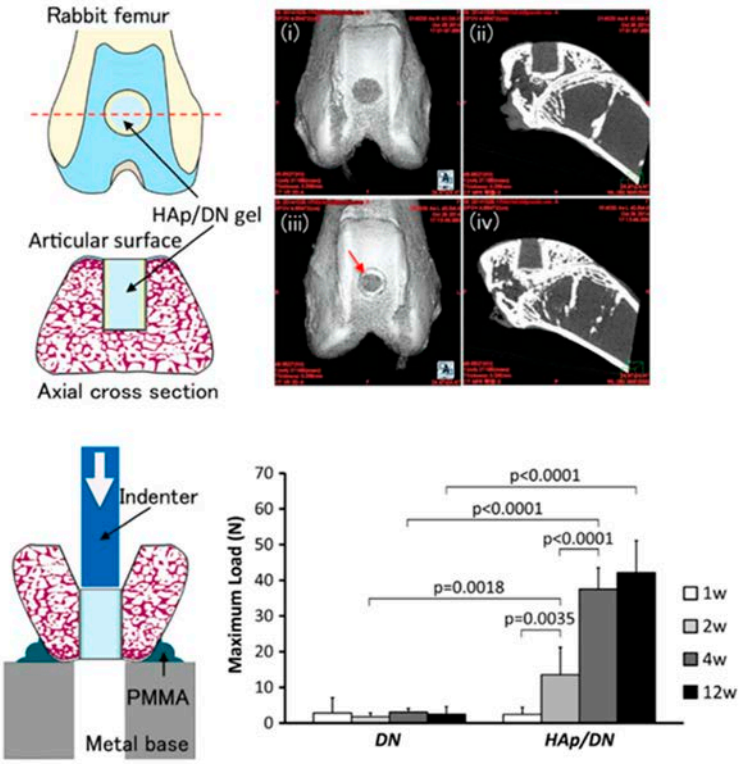


Figure C-1. Implantation and push-out test of HAp/DN gel on rabbit bone defect. ***Nonoyama et al., Advanced. Materials, 2016.***

C-2. Hydrogels as Scaffolds for Rapid Reprogramming Towards Cancer Stem Cells

Cancer is the leading cause of death in developed countries, and more than 8.6 million people die from cancer annually worldwide. Cancer tissues are composed of heterogeneous populations with some cancer stem cells (CSCs) and a majority of differentiated non-CSCs. CSCs have potential for self-renewal, and they also give rise to differentiated non-CSCs in tumor masses. As CSCs are therapy-resistant because of their slow growth rate, thus exhibiting dormancy, their ability to excrete chemotherapeutic reagents outside the cells, and their enhanced protection against reactive oxygen species (ROS), CSCs are therefore a priority as therapeutic targets.

Despite the importance of targeting CSCs, identifying these cells is extremely difficult, because they are present only in small numbers in cancer tissue (reportedly comprising less than 0.0001% of cells in melanoma). Several membrane proteins or cytoplasmic enzymes such as CD133, CD44, and ALDH have been reported to be highly expressed in CSCs. However, clinical identification of CSCs in an individual patient is not available to date because single expression of these proteins does not strictly define CSCs. Thus, establishment of a rapid detection method of CSCs is required for further analysis.

Depending on the character of the obtained CSCs, specific molecular targeted therapeutics can be used for complete eradication of CSCs in practice.

Through collaborations in the Hokkaido University unit, we discovered that double-network (DN) hydrogels have the potential to rapidly generate CSCs (***Suzuka et al., Nature Biomedical Engineering***, ***published online, 2021***). By placing six human cancer cells onto DN hydrogels, sphere formations were observed within 24 hours that expressed stemness markers including *Sox2*, *Oct3/4*, and *Nanog*. These DN hydrogel-induced CSCs were highly tumorigenic in SCID mice. The DN hydrogels rapidly modulated cellular gene expression and facilitated reprogramming of differentiated cancer cells towards CSCs. In this process, hydrogel/calcium channel TRP/osteopontin axis played an essential role in the induction of cancer stemness. The DN hydrogels could reveal CSC-specific expression of the tyrosine kinase (TK) receptor, therefore suggesting possible eradication of CSCs by a TK inhibitor. Thus, DN hydrogels are a powerful tool for detecting CSCs when analysing the molecular mechanism of cancer cell reprogramming, and they may importantly contribute to the discovery of reagents to eradicate CSCs.

We are now developing a rapid diagnostic system for cancer stem cells using DN hydrogels (**Figure C-2**). Cancer stem cells are therapy resistant and a main source of cancer recurrence. By using the hydrogels we developed, medical doctors can rapidly identify the cancer stem cells and determine the drugs that can completely eradicate cancer cells, leading to better prognosis of the patients.

This work is a collaboration between inter-department members of HU unit.

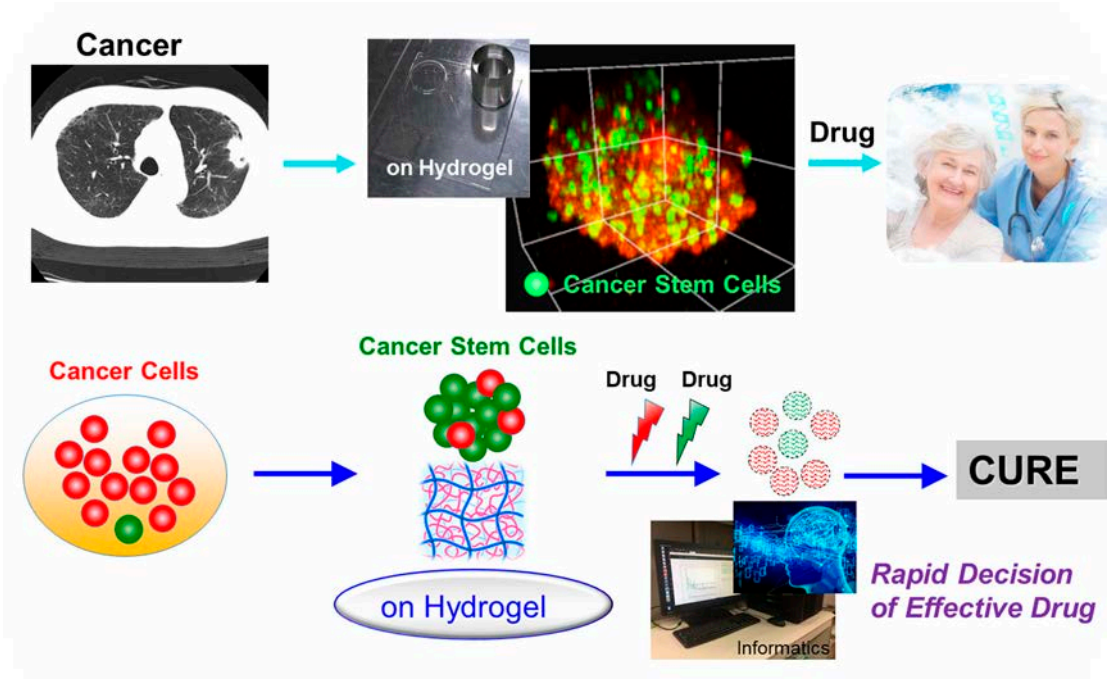


Figure C-2. Rapid induction of reprogramming towards cancer stem cells on hydrogels and its application for cancer diagnose at early stage and complete eradication of cancers. ***Suzuka et al., Nature Biomedical Engineering, published online, 2021***.

C-3. Hydrogel/Elastomer Laminates for Stimuli-Responsive Actuators

The human body is composed of composite structures comprising water-rich hydrophilic domains and hydrophobic barriers. Similar in concept, combining hydrogels with elastomers has resulted in applications ranging from stretchable electronics to actuators. We report a new method to combine hydrogels with elastomers through the use of a glass fiber (GF) fabric interphase (**Figure C-3**) (***Hubbard et al., Matter, 2019***). The interphase plays two roles: it enables two chemically different materials to be robustly bound, and it also dramatically increases the mechanical strength and toughness of the composite. This general method enables the combination of hydrogels and elastomers into one composite structure, with strong adhesion between phases without the need for specialty chemical approaches. Maximum interfacial adhesion energies of ~1050 N m^{-1} between the polyampholyte hydrogel and fabric and ~330 N m^{-1} between the elastomer and fabric were achieved, approaching adhesion values in chemically bound soft materials. Due to the GF fabric interphase, the composite tearing toughness (143 kJ m^{-2}) vastly exceeds the toughness of either neat soft component. Furthermore, the Young's modulus of the composite is high (~1.2 GPa) while the bending modulus of the composite is low (~7 MPa), indicating a preference for bending rather than stretching. Through controlled solvent exposure, these composites serve as actuators where the bending behavior can cycle repeatedly, without delamination, while achieving curvature predicted by the Timoshenko theory. The actuation stress reaches ~40% of human skeletal muscle, demonstrating that this mechanism has applicability towards artificial muscles. The method presented in this paper will facilitate the simple fabrication of robust soft materials by merging the benefits of fabric-reinforced composites with those of hydrogel/elastomer composites.
This is a collaborative work between the HU unit and US Unit.

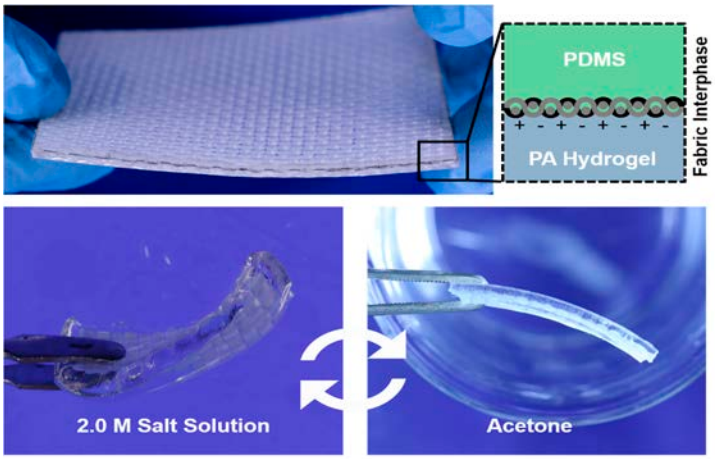


Figure C-3. Photographs of the composite prepared with the PDMS elastomeric layer facing upward and the PA hydrogel layer facing downward. The glass fibers are perpendicular to one another based on the weave of the fabric. The composite exhibits reversible but opposite bending when exchange between salt solution and acetone. ***Hubbard et al., Matter, 2019.***

C-4. Microfluidic Pressure Sensing Using Color Switching Hydrogels

The widening applications of microfluidic devices have increased the need for reliable pressure sensing in those systems. Pressure sensing in such small fluidic circuits, however, is complicated by specific challenges stemming from the design of microfluidic chips. The lab-on-a-chip layout, first, requires that the sensor be fully integrable to the chip, and so most commonly to PDMS architectures. The sensitivity of the sensor is a second challenge, given that the pressure changes along short fluid sections can be minute.

Several methods have been proposed to overcome these difficulties, which rely on soft sensing elements that deform under pressure. This deformation is then usually measured via electric methods (piezoelectric pillars, conductive liquid circuits, conductive inflating membrane). Such methods require that the microfluidic chip is wired to external electrical apparatus, which may not be convenient. We propose a fully chip-integrated optofluidic pressure sensor that enables local pressure measurements along any microfluidic fluid path (**Figure C-4**) (***Ducloué et al., in preparation***). The sensor itself is based on the compression of an underlying slab of photonic hydrogel, which changes colour in response to the compression.

This is a collaborative work between the HU unit and France Unit. An international patent is filed.

Selected Publications for Target C

GSS members are indicated in bold.

1. **Kitamura N**, Yokota M**, Kurokawa T**, **Gong JP**, **Yasuda K**, "In Vivo Cartilage Regeneration Induced by a Double-Network Hydrogel: Evaluation of a Novel Therapeutic Strategy for Femoral Articular Cartilage Defects in a Sheep Model," ***Journal of Biomedical Materials Research Part A***, 104(9), 2159-2165 (2016).

2. **Nonoyama T**, Wada S, Kiyama R, **Kitamura N**, Mredha MTI, Zhang X, **Kurokawa T**, **Nakajima T**, Takagi Y, **Yasuda K**, **Gong JP**, "Double-Network Hydrogels Strongly Bondable to Bones by Spontaneous Osteogenesis Penetration," ***Advanced Materials***, 28(31), 6740-6745 (2016).

3. Wada S, **Kitamura N**, **Nonoyama T**, Kiyama R, **Kurokawa T**, **Gong JP**, **Yasuda K**, "Hydroxyapatite-Coated Double Network Hydrogel Directly Bondable to the Bone: Biological and Biomechanical Evaluations of the Bonding Property in an Osteochondral Defect," ***Acta Biomaterialia***, 44, 125-134 (2016).

4. Mredha MTI, Kitamura N, **Nonoyama T**, Wada S, Goto K, Zhang X, **Nakajima T**, **Kurokawa T**, Takagi Y, **Yasuda K**, **Gong JP**, "Anisotropic Tough Double Network Hydrogel from Fish Collagen and Its Spontaneous in Vivo Bonding to Bone," ***Biomaterials***, 132, 85-95 (2017).

5. **Suzuka J**, **Tsuda M**, **Wang L**, Kohsaka S, Kishida K, Semba S, Sugino H, Aburatani S, Frauenlob M, **Kurokawa T**, Kojima S, Ueno T, Ohmiya Y, Mano H, **Yasuda K**, **Gong JP**, **Tanaka S**, "Rapid Reprogramming of Tumour Cells into Cancer Stem Cells on Double-Network Hydrogels," ***Nature Biomedical Engineering***, published online (2021).

6. Hubbard AM, Cui W, Huang YW, Takahashi R, Dickey MD, **Genzer J**, **King DR**, **Gong JP**, "Hydrogel/Elastomer Laminates Bonded via Fabric Interphases for Stimuli-Responsive Actuators," ***Matter*,** 4, 674-689 (2019).

Appendix B List of International and Domestic Institutions with Joint Publications

Total 71 institutions (universities, research institutes, local government, companies, etc.)

North America (14)

Iowa State University, USA
University of Massachusetts, USA
University of North Carolina, USA
UC Santa Barbara, USA
Duke University, USA
Cornell University, USA
North Carolina State University, USA
University of Colorado Boulder, USA
National Institutes of Health, USA
University of California, USA
Oak Ridge National Laboratory, USA
State University of New York, USA
University of Calgary, Canada
Lehigh University, USA

Europe (19)

ESPCI Paris, France
PSL Research University, France
Sorbonne University, France
Paris-Saclay University, France
Pasteur Institute, France
Armand Trousseau Children Hospital, France
Assistance Publique – Hôpitaux de Paris, France
University of Bordeaux, France
Aix-Marseille University, France
Beckman Coulter France, France
Eurofins-Biomnis, Lyon, France
Newcastle University, UK
University of Stuttgart, German
Aachen University, German
University of Chemistry and Technology, Prague, Czech
University of Innsbruck, Austria
Swiss Federal Institute of Technology in Lausanne, Swiss
The Hebrew University of Jerusalem, Israel
Weizmann Institute of Science, Israel

Asia and Oceania (18)

Zhejiang University, China
University of Science and Technology of China
Xi'an Jiaotong University, China
Southeast University, China
South China University of Technology, China
Dalian University of Technology, China
Southern University of Science and Technology, China
Southwest University, China
Northwestern Polytechnical University, China
Chinese Academy of Sciences, China
Huazhong University of Science and Technology, China
Beijing Institute of Technology, China
Inner Mongolia Normal University, China
Sogang University, Korea
Chiang Mai University, Thailand
University of Dhaka, Bangladesh
University of Wollongong, Australia
The University of Sydney, Australia

Domestic Collaborations (total 12 universities and institutes)

The University of Tokyo, Japan
Osaka University, Japan
Kyushu University, Japan
Tohoku University, Japan
Tokyo Institute of Technology, Japan
Kyoto Institute of Technology, Japan
University of the Ryukyus, Japan
Kobe University, Japan
Gunma University, Japan
National Institute of Advanced Industrial Science and Technology, Japan
Japan Science and Technology Agency (JST), Japan
National Museum of Nature and Science, Japan

Industry Collaborations (total 8)

Otsuka Chemical Co. Ltd., Japan
Osaka Organic Chemical Industry Ltd., Japan
Bridgestone Corporation, Japan
OmniSeq Inc., USA
Epizyme Inc. USA
Roswell Park Cancer Institute, USA
Roswell Park Comprehensive Cancer Center, USA
Razi Vaccine and Serum Research Institutz, Iran

Appendix C List of Publications, Verbal Presentations, Patents

(Project Period: April 2016- March 2021)
As of August 23rd, 2021

Contents

1) International Collaborative Papers

(peer reviewed original papers)

- Among the papers with "* (asterisk)", papers where "GI-CoRE" is stated as an affiliated institution are marked with "(1)", and papers which mention "Hokkaido University" in the acknowledgements are marked with "(2)".

1. Li XY, Cui KP, Kurokawa T, Ye YN, Sun TL, Chengtao Yu, Creton C, Gong JP, "Effect of Mesoscale Phase Contrast on Fatigue-Delaying Behavior of Self-Healing Hydrogels," Science Advances, 14;7(16):eabe8210 (2021). DOI: 10.1126/sciadv.abe8210 *(1)
2. Cui KP, Ye YN, Sun TL, Yu CT, Li XY, Kurokawa T, Gong JP, "Phase Separation Behavior in Tough and Self-Healing Polyampholyte Hydrogels," Macromolecules, 53(13), 5116-5126, (2020). DOI: 10.1021/acs.macromol.0c00577 *(1)
3. Cui W, King DR, Huang YW, Chen L, Sun TL, Guo YZ, Saruwatari Y, Hui CY, Kurokawa T, Gong JP, "Fiber-reinforced Viscoelastomers Show Extraordinary Crack Resistance that Exceeds Metals," Advanced Materials, 32(31), 1907180, (2020). DOI: 10.1002/adma.201907180 *(1)
4. Delgado DE, King DR, Cui KP, Gong JP, Shull KR, "High-Fidelity Hydrogel Thin-Films Processed from Deep Eutectic Solvents," ACS Applied Materials & Interfaces, 12(38), 43191-43200, (2020). DOI: 10.1021/acsami.0c09618 *(1)(2)
5. Yin HY, King DR, Sun TL, Saruwatari Y, Nakajima T, Kurokawa T, Gong JP, "Polyzwitterions as a Versatile Building Block of Tough Hydrogels: From Polyelectrolyte Complex Gels to Double-Network Gels," ACS Applied Materials & Interfaces, 12(44), 50068-50076, (2020). DOI: 10.1021/acsami.0c15269 *(1)
6. Venkata SP, Cui KP, Guo JG, Zehnder AT, Gong JP, Hui CY, "Constitutive Modeling of Bond Breaking and Healing Kinetics of Physical Polyampholyte (PA) Gel," Extreme Mechanics Letters, (2021). DOI: 10.1016/j.eml.2021.101184 *(1)
7. Kimura T, Suzuki A, Yang Y, Niida Y, Nishioka A, Takei M, Wei J, Mitomo H, Matsuo Y, Niikura K, Ijiro K, Tono K, Yabashi M, Ishikawa T, Oshima T, Bessho Y, Joti Y, Nishino Y, "Micro-Liquid Enclosure Array and Its Semi-Automated Assembling System for X-Ray Free-Electron Laser Diffractive Imaging of Samples in Solution," Review of Scientific Instruments, 91, 083706, (2020). DOI: 10.1063/5.0008398 *(1)(2)
8. Irie T, Orias AAE, Irie TY, Nho SJ, Takahashi D, Iwasaki N, Inoue N, "Three-Dimensional Curvature Mismatch of the Acetabular Radius to the Femoral Head Radius Is Increased in Borderline Dysplastic Hips," PLOS ONE, 15, 4, e0231001, (2020). DOI: 10.1371/journal.pone.0231001
9. Irie T, Orias AAE, Irie TY, Nho SJ, Takahashi D, Iwasaki N, Inoue N, "Computed Tomography–Based Three-Dimensional Analyses Show Similarities in Anterosuperior Acetabular Coverage Between Acetabular Dysplasia and Borderline Dysplasia," Arthroscopy, 36(10), 2623-2632, (2020). DOI: 10.1016/j.arthro.2020.05.049
10. Hui CY, Liu ZZ, Bain N, Jagota A, Dufresne ER, Style RW, Kiyama R, Gong JP, "How Surface Stress Transforms Surface Profiles and Adhesion of Rough Elastic Bodies," Proceedings of the Royal Society A, 476(2243), 20200477, (2020). DOI: 10.1098/rspa.2020.0477 *(1)(2)
11. Xiao R, Mai TT, Urayama K, Gong JP, Qu SX, "Micromechanical Modeling of the Multi-Axial Deformation Behavior in Double Network Hydrogels," International Journal of Plasticity, published online, (2020). DOI: 10.1016/j.ijplas.2020.102901 *(1)
12. Ye YN, Cui KP, Hong W, Li XY, Yu CT, Hourdet D, Nakajima T, Kurokawa T, Gong JP, "Molecular Mechanism of Abnormally Large Nonsoftening Deformation in a Tough Hydrogel," PNAS, 118(14), e2014694118, (2021). DOI: 10.1073/pnas.2014694118 *(1)
13. Nakajima T, Hoshino K, Guo HL, Kurokawa T, Gong JP, "Experimental Verification of the Balance

between Elastic Pressure and Ionic Osmotic Pressure of Highly Swollen Charged Gels," Gels, Special Issue: Stimuli-Responsive Gels 2.0, 7(2), 39, (2021). DOI: 10.3390/gels7020039 *(1)

14. Venkata SP, Cui KP, Guo J, Zehnder AT, Gong JP, Hui CY, "Constitutive Modeling of Strain-Dependent Bond Breaking and Healing Kinetics of Chemical Polyampholyte (PA) Gel," Soft Matter, 17(15), 4161-4169, (2021). DOI: 10.1039/D1SM00110H *(1)
15. Shi YL, Li Q, Zhang Y, Wang GQ, Matsuo Y, Liang XG, Takarada T, Ijiro K, Maeda M, "Hierarchical Growth of Au Nanograss With Intense Built-in Hotspots for Plasmonic Applications," Journal of Materials Chemistry C, 8(45), 16073-16082, (2020), DOI: 10.1039/d0tc04294c *(1)
16. Oettmeier C, Nakagaki T, Döbereiner HG, "Slime Mold on the Rise: The Physics of Physarum Polycephalum," Journal of Physics D-Applied Physics," 53(31), 310201, (2020), DOI: 10.1088/1361-6463/ab866c
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3) Review/Others

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4) Books

1. Riku Takahashi, Jian Ping Gong: "Stimulus-Responsive Polymer Handbook, Chapter 3, Material Desig, Section 3 New Design of High-Strength/High-Toughness Gel Developed by Sacrificial Bonds," Supervised by Takashi Miyata, NS, pp. 195-202, (2018). ISBN: 978-4-86043-535-6 C3043
2. Takayuki Murosaki, Jian Ping Gong: "Next-Generation Biomimetic Research Frontline-Learn from Biodiversity, Chapter 2, Functional Elucidation, 7 Why Barnacles Do Not Attach to Seaweeds-Development of Antibiotic Adhesive Gels Learned From Seaweeds-," supervised by Masatsugu Shimomura, edited by Biomimetics Research Society, Si-Mushi-Publishing, pp.99-109, (2017). ISBN: 978-4-47813-1217-0
3. Takayuki Nonoyama, Takayuki Kurokawa, Kazunori Yasuda, Jian Ping Gong: "Chapter 12 Application of Gels to Other Medical Materials and Gelation Technology, Section 2 Development of Double Network Gel That Is Hard, Soft and Stretches Well, "How to Use Gelling/Thickening Agent, How to Choose, Casebook," Planning and Editing: Technical Information Association, Technical Information Association, pp.596–604, (2018). ISBN: 978-4-86104-691-9-3043

5) Verbal Presentations

Plenary Lectures

1. Takahiro Matsuda, Ryo Namba, Tasuku Nakajima, Jian Ping Gong: "Self-Growing Double Network Hydrogels by Repetitive Mechanical Training," Frontiers in Polymer Science2019, Novotel Budapest Congress Centre, Budapest, Hungary, 2019.5.8 [International conference]
2. Takahiro Matsuda, Tasuku Nakajima, Jian Ping Gong: "Self-Growing Hydrogels by Mechanical Training," 7th Asian Symposium on Advanced Materials (ASAM-7), Beijing Institute of Petrochemical Technology, China, 2019.9.5[International conference]
3. Jian Ping Gong: "Hydrogels with Reversible Sacrificial Bonds-From Toughness to Bioadhesion to Soft Composites," The Adhesion Society 41st Annual Meeting and 6th World Congress on Adhesion and Related Phenomena (WCARP), Catamaran Resort Hotel, San Diego, CA, USA, 2018.3.1[International conference]
4. Jian Ping Gong: "Tough Soft Composites Based on Sacrificial Bond Mechanism," The 2nd International Symposium for Advanced Gel Materials & Soft Matters (ISAGMSM), Renaissance Guiyang Hotel, Guiyang, Guizhou, China, 2017.8.21[International conference]
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Keynote Speeches

1. Jian Ping Gong: “Fiber Reinforced Hydrogels with Extra-Ordinarily High Toughness,” Materials Research Meeting 2019 (MRM2019), Yokohama Symposia, Yokohama, Kanagawa, 2019.12.12 [International conference]
2. Kuniharu Ijiro: “Self-Assembly of Rod-Shaped Au Nanoparticles and those Plasmonic Functions,” 15th IUPAC International Conference on Novel Materials and their Synthesis (NMS-XV), Renaissance Shenyang West Hotel, Shenyang, China, 2019.9.8[International conference]
3. Kenji Urayama, Thanh-Tam Mai, Hiroki Koike, Akira Tanaka, Takahiro Matsuda, Tasuku Nakajima, Jian Ping Gong: “Nonlinear Elasticity and Internal Fracture of Double Network Hydrogels Characterized by Multiaxial Stretching,” The 7th Pacific Rim Conference on Rheology (PRCR2018), Phoenix Jeju, Jeju, Korea, 2018.6.13[International conference]
4. Jian Ping Gong: “Deformation of 1D Photonic Hydrogels with Lipid Bilayers,” The 4th International Workshop on Soft Machines and Mechanics, Wyndham Grand Hotel, Xi’an City, Shaanxi Province, China, 2018.6.16[International conference]
5. Takahiro Matsuda, Ryo Namba, Runa Kawakami, Tasuku Nakajima, Jian Ping Gong: “Autonomous Mechanical Remodelling of Double Network Hydrogels,” 82nd Prague Meeting on Macromolecules - Polymer Networks and Gels 2018 and 24th Polymer Network Group Meeting (PNG2018), Institute of Macromolecular Chemistry, Prague, Czech, 2018.6.18[International conference]
6. Toshiyuki Nakagaki: “Transport Network Designed by Current-Reinforcement Rule,” Annual Meeting of Society of Mathematical Biology, University of Sydney, Sydney, Australia, 2018.7.9 [International conference]
7. Kuniharu Ijiro: “Development of Stimuli-Responsive Gold Nanostructure Assembly and those Applications,” 14th IUPAC International Conference on Novel Materials and their Synthesis (NMS-XIV), South China Normal University, Guangzhou, China, 2018.10.23[International conference]
8. Toshiyuki Nakagaki: “Ethology of the Plasmodium of Physarum Polycepharum,” 9th International Congress of Systematics and Ecology of Myxomycetes, Kinan Cultural Hall, Wakayama, Japan, 2017.8.19[International conference]
9. Katsuhiko Sato: “Direction-Dependent Contraction Forces on Cell Boundaries Induce Collective Migration of Epithelial Cells within their Sheet,” 17th International Conference CoMFoS17: Mathematical Analysis of Continuum Mechanics, Okinawa Institute of Science and Technology Graduate University (OIST), Okinawa, Japan, 2017.9.20[International conference]
10. Kuniharu Ijiro: “Self-assembled Nanoparticles as Photonic and Biological Nanomaterials,” International Symposium on Materials for Chemistry and Engineering (IMCE 2017), Kyushu University, Fukuoka, Japan, 2017.2.3[International conference]
11. Jian Ping Gong: “Self-healing and Self-Adjustable Adhesion of Polyampholyte Hydrogels,” The 11th International Gel Symposium (GelSympo2017), Nihon University Tsudanuma Campus, Chiba, Japan, 2017.3.7[International conference]

Invited Lectures

1. Takayuki Kurokawa: “Friction of Polymer gel,” 69th The Society of Polymer Science Japan (SPSJ) Annual Meeting, (Cancelled due to COVID-19, the Presentation is Valid), 2020.5.27[International conference]
2. Takayuki Kurokawa: “Polymer Gel Research Tutorial,” 69th Symposium on Macromolecules, Online, Oral, 2020.9.16
3. Takayuki Kurokawa: “Hydrogel Surface Friction Dynamics,” 10th CSJ Chemistry Festa, Online,

2020.10.21

4. Daniel R. King: “There and Back Again: How an Internship in Japan Sparked a New Journey,” 10th CSJ Chemistry Festa, “Let’s Enjoy Chemistry in Japan! / Enjoy chemistry in Japan!” Session, Online, 2020.10.22
5. Jian Ping Gong: “Dynamic Hydrogels Inspired from Nature,” 95th Young Polymer Scientists, Online, 2020.11.14
6. Jian Ping Gong: “Design and Creation of High Toughness Composite,” 29th Polymer Material Forum, Online, 2020.11.26
7. Tasuku Nakajima: “It’s Like a Living Thing! The World of High-Performance Composite gel,” 176th Symposium on Macromolecules, Online, 2020.12.5
8. Jian Ping Gong: “Self-Growing and Strengthening of Double Network Hydrogels by Mechanical Training,” Extreme Mechanics Letter (EML) Webinar, Online, 2020.12.9
9. Jian Ping Gong: “Polymer Physics/Physical Chemistry,” ACS Macro Letters 10th Anniversary Lecture/Webinar Series, Online, January-March, 2021.3.3
10. Takahiro Matsuda, Ryo Namba, Tasuku Nakajima, Jian Ping Gong: “Self-Growing Hydrogels by Repetitive Mechanical Training,” The 3rd International Symposium for Advanced Gel Materials & Soft Matters, Academic Lecture Hall, Shaanxi University of Science and Technology, Xi'an, China, 2019.6.16[International Conference]
11. Daniel R. King, Tsuyoshi Okumura, Riku Takahashi, Takayuki Kurokawa, Jian Ping Gong: “Macroscale Double Networks: Design Criteria for Optimizing Strength and Toughness,” Joint Meeting of the 5th International Symposium of Flexible and Stretchable Electronics 2019 (ISFSE 2019) and the 5th International Workshop on Soft Machines and Mechanics 2019 (IWSMM 2019), Southern University of Science and Technology Research Building 1 Lecture Hall, Shenzhen, Guandong, China, 2019.6.29[International Conference]
12. Takayuki Nonoyama, Ryuji Kiyama, Kazuki Fukao, Kazuki Tanaka, Naohiro Kashimura, Jian Ping Gong: “Bone-Inspired Soft Composite Possessing Osteo-Activity,” Joint Meeting of the 5th International Symposium of Flexible and Stretchable Electronics 2019 (ISFSE 2019) and the 5th International Workshop on Soft Machines and Mechanics 2019 (IWSMM 2019), Southern University of Science and Technology Research Building 1 Lecture Hall, Shenzhen, Guandong, China, 2019.6.29[International conference]
13. Daniel R. King: “Macroscale Double Networks: A Universal Method for Improving the Strength and Toughness of Soft Materials,” Seminar at South China University of Technology, South China University of Technology, Guangzhou, China, 2019.7.1[International conference]
14. Takayuki Nonoyama: “Bone-Inspired Soft Ceramics Possessing Osteo-Activity,” Seminar at South China University of Technology, South China University of Technology, Guangzhou, China, 2019.7.1 [International conference]
15. Daniel R. King: “Macroscale Double Networks: Extending the “Double Network Concept” to Large Length-Scales,” Seminar at the University of Tokyo, The University of Tokyo Kashiwa Campus, Kashiwa, 2019.7.8
16. Daniel R. King: “Macroscale Double Networks: Expanding the “Sacrificial Bond Concept” to Large Length-Scales,” ECI Colloidal, Macromolecular and Biological Gels II, Maryborough Hotel and Spa, Cork, Ireland, 2019.7.22[International conference]
17. Takayuki Nonoyama: “Quick & Reversible Thermo-Robustizing Hydrogels Exhibiting 1000 Times Modulus Jump,” International Symposium on Biopolymer Synthesis and Degradation, Hokkaido University, Sapporo, 2019.7.29 [International conference]

18. Takayuki Kurokawa: “Activity Measurement of Polyelectrolyte in Hydrogels by Microelectrode Technique,” International Congress on Pure & Applied Chemistry (ICPAC Yangon 2019), Rose Garden Hotel, Yangon, Myanmar, 2019.8.7[International conference]
19. Jian Ping Gong: “Self-Growing Materials under Mechanical Training,” JST CREST International Workshop: New Developments toward Wearable Photonics: From Materials to Devices CREST, Akibaplaza, Tokyo, 2019.10.7 [International conference]
20. Takayuki Nonoyama, Yong Woo Lee, Kumi Ota, Keigo Fujioka, Jian Ping Gong: “Hydrogel Possessing Rubbery-to-Glassy Transition at Elevated Temperature,” 2019 National Polymer Congress of CHINA / China Japan Joint Symposium for Young Polymer Scientists, Northwestern Polytechnical University, Xi’an, China, 2019.10.18 [International conference]
21. Takayuki Nonoyama: “Robust Phase-Separation Induced Rubbery-to-Glassy Transition at Elevated Temperature,” Seminar at Shaanxi University of Science & Technology, Shaanxi University of Science & Technology, Xi’an, China, 2019.10.20 [International conference]
22. Jian Ping Gong: “Strengthening materials using weak bonds-A novel strategy,” Millennium Science Forum (MSF), British Embassy, Japan, 2019.11.22[International conference]
23. Jian Ping Gong: “Self-Growing Hydrogels by Mechanical Training,” Seminar at ESPCI, Paris, France,2019.11.27[International conference]
24. Md Anamul Haque, Most Laboni Begum, Sobuj Roy, Mehedi Hasan, Ajadur Rahman Sakil, Md Aftab Ali Shaikh, Jian Ping Gong: “Fabrication of Hydrogel Composite for Removal of Dyes and Heavy Metals from Water,” Conference for Enviromental Solutions and Sustainable Development: Towards Developed Bangladesh (CESSD 2019), Nawab Ali Chowdhury Senate Building, University of Dhaka, Dhaka, Bangladesh, 2019.11.27-29[International conference]
25. Takahiro Matsuda, Tasuku Nakajima, Jian Ping Gong: “Self-growing hydrogels by repetitive mechanical training,” CEMS International Symposium on Supramolecular Chemistry and Functional Materials 2019 (CEMSupra2019), Tokyo University, 2019.12.10[International conference]
26. Daniel R. King: “Macroscale Double Networks: Extending the ‘Double Network Concept’ to Large Length-Scales,” Seminar at University of Pennsylvania, University of Pennsylvania, Philadelphia, PA, 2019.12.13[International conference]
27. Tasuku Nakajima: “Self-Growing Hydrogels Inspired by Biological Metabolism,” 2020 Gordon Research Conference on Multifunctional Materials and Structures, Ventura Beach Marriott, Ventura, CA, USA, 2020.1.20[International conference]
28. Tomoyasu Aizawa: “Development and Application of Novel Overexpression Systems for NMR Analysis of Antimicrobial Peptides,” 2nd India-Japan Workshop on Magnetic Resonance, Tata Institute of Fundamental Research (TIFR), Hyderabad, India, 2019.12.10[International conference]
29. Mitomo Hideyuki: “Active Gap Control of Gold Nanodots using Gels in Nanoscale,” The 3rd International Symposium for Advanced Gel Materials & Soft Matters (ISAGMSM), Shaanxi University of Science and Technology (SUST), Xi’an, China, 2019.6.16[International conference]
30. Ijiro Kuniharu: “Stimuli-Responsive Gold Nanoparticle Assembly and Those Applications,” 10th International Conference on Materials for Advanced Technologies (ICMAT 2019), Marina Bay Sands, Singapore, 2019.6.24[International conference]
31. Ijiro Kuniharu: “DNA Brush-Directed Aligning Self-Assembly of Gold Nanorods as Photonic Nanomaterials,” 16th European Conference on Organized Films (ECOF16), Université Paris Descartes, Centre Universitaire des Saints-Pères, Paris, 2019.7.10[International Conference]
32. Toshiyuki Nakagaki: “Adaptive Motion in Protozoan Ciliate,” ICMMA 2019 Int. Conf. on Spatio-Temporal Patterns on Various Levels of Hierarchy of Life, Meiji University, Tokyo, Japan, 2019.12.9[International conference]

33. Toshiyuki Nakagaki: “Nature-Inspired Design of Transport Network ～How the Natural System Works Properly~,” The 2nd General Assembly Meeting of The Association of Institutions of Higher Education of The Russian Federation and Japan. The 2nd Russia-Japan Student Forum, Moscow State University, Moscow, Russia, 2019.9.24[International conference]
34. Toshiyuki Nakagaki: “Transport Network in Living Systems Designed by Current-Reinforcement Rule,” The 13th Annual qBio Conference, San Francisco State University, San Francisco, California, USA, 2019.8.3[International Conference]
35. Katsuhiko Sato: “Direction-Dependent Contraction Forces on Cell Boundaries Induce Collective Migration of Epithelial Cells within their Sheet,” GSS International Mini-Symposium “Soft Matter Deformation and Function,” Hokkaido University, Sapporo, 2019.7.17[International Conference]
36. Toshiyuki Nakagaki: “Adaptive Development of Biological Network Based on Use-and-Growth Rule,” Exploratory Workshop on Geometry of Complex Web 2020, Hotel Eurotel Victoria, Les Diablerets, Swiss, 2020.2.3[International Conference]
37. Katsuhiko Sato: “Left-Right Asymmetric Aggregation in Chlamydomonas”, 2019 RIMS Workshop "Mathematical Methods in Biofluid Mechanics,” The Westin Hotel Awaji Island Resort & Conference Center, Awaji, Japan, 2019.10.30[International Conference]
38. Eiji Kondo: “Inverted V-shaped High Tibial Osteotomy for Medial Osteoarthritis of the Knee with Severe Varus Deformity,” Grand Hilton, Seoul, Korea, 2019.10.17[International Conference]
39. Tomohiro Onodera: “The Effect of the First Metatarsal Shortening in the Modified Lapidus procedure,” Grand Hilton Seoul, Seoul, Korea, 2019.10.18[International Conference]
40. Sinya Tanaka: “Engineered Hydrogels for Rapid Induction of Cancer Stem Cells,” The38th Sapporo International Cancer Symposium, Royton Sapporo, 2019.7.12[International Conference]
41. Sinya Tanaka: “Engineered Hydrogels for Rapid Induction of Cancer Stem Cells,” 2nd Joint Symposium China Medical University and Hokkaido University, Faculty of Medicine., China Medical University, Taichung, Taiwan, 2019.9.3[International Conference]
42. Sinya Tanaka: “Morphology and Genetic Features of Meningioma,” The Asian Society of Neuro-Oncology (ASNO)2019, HNBK International Convention Center, Taipei, Taiwan, 2019.9.26[International Conference]
43. Masumi Tsuda: “Rapid Induction of Cancer Stem Cells on Double-Network Hydrogels and Therapeutic Application,” The 10th Meeting of Asian Cellular Therapy Organization（JSBT-ACTO Joint Symposium） Sapporo Education & Culture Hall, Sapporo, 2019.11.7[International Conference]
44. Eiji Kondo: “Biological and Biomechanical Effects of Remnant-Preserving ACLR,” The 12th biennial Congress of International Society of Arhroscopy, Knee Surgery and Orthopaedic Sports Medicine, Cancun International Convention Center, Cancun, Mexico, 2019.5.13[International Conference]
45. Daniel R. King: “Applying the Double Network Concept on the Macroscale,” Special Seminar at North Carolina State University, North Carolina State University, Raleigh, NC, USA, 2018.6.7 [International conference]
46. Jian Ping Gong: “Tough Physical Double Network Hydrogels Based on Tri-Block Copolymers,” The 13th International Symposium on Polymer Physics (PP’2018), Xi’an International Conference Center, Xi’an City, Shaanxi Province, China, 2018.6.14[International Conference]
47. Jian Ping Gong: “In Vivo Robust Bonding of Double Network Hydrogels to Bones,” MACRO2018, The Cairns Conference Centre, Cairns, Australia, 2018.7.2[International Conference]
48. Hisashi Haga: “Collective Movement and 3D Morphogenesis of Epithelial Cells Responding to Viscoelastic Substrates,” Japan-Toronto Morphogenesis Symposium, The Peter Gilgan Centre for Research and Learning, Toronto, Canada, 2018.7.17[International Conference]

49. Takashi Tsukamoto: “Photochemical Properties of Microbial Rhodopsin Pumps and Channels,” Asia Pasific Society for Biology and Medical Sciences (APSBMS) 2018 Annual Meeting, Sapporo Convension Center, Sapporo, 2018.7.21[International Conference]
50. Takayuki Nonoyama: “Spontaneous Osteogenesis Penetration into Soft Material: A Simple & Natural Approach to Fix Materials in Body,” APSBMS 2018 Annual Meeting, Sapporo Convention Center, Sapporo, 2018. 7.23[International conference]
51. Daniel R. King: “Applying the Double Network Principle on the Macroscale,” International Symposium on Soft Matter: Interface and Active Materials, Beijing University of Chemical Technology (BUCT), Beijing, China, 2018.7.24[International conference]
52. Jian Ping Gong: “Novel Hydrogels with Reversible Sacrificial Bonds- From Toughness to Wet Adhesion to Composites -,” Japan-Korea Joint Symposium on Polymer Science 2018 (JKJS2018), Hokkaido University, Sapporo, 2018.7.24[International conference]
53. Hideyuki Mitomo: “Alignment Change of AuNRs on the DNA Brush Substrates by the Applied Electric Field towards Active Plasmonic Control,” SPIE optics + Photonics, San Diego Convention Center, San Diego, California, USA, 2018.8.19[International conference]
54. Takayuki Kurokaw: “Effect of Anisotropic compliance on Adhesion in Water,” First International Conference on 4D Materials and Systems (M01 Gel Symposium 2018), Yamagata University, Yonezawa, Yamagata, 2018.8.26-30[International Conference]
55. Daniel R. King, Tsuyoshi Okumura, Riku Takahashi, Jian Ping Gong: “Creating ‘Double network’ Composites via Macroscale Reinforcement,” First International Conference on 4D Materials and Systems (M01 Gel Symposium 2018), Yamagata University, Yonezawa, Yamagata, 2018.8.27[International Conference]
56. Shinya Tanaka: “Novel Analysis of Meningioma Stem Cells by Hydrogel Engineering,” The 19th International Congress of Neuropathology (ICN2018) Symposium, Keio Plaza Hotel Tokyo, 2018.9.25 [International Conference]
57. Takayuki Nonoyama: “Thermoresponsive Hydrogel Possessing Reversible Super Modulus Jumping,” Bangladesh Chemical Congress 2018, Dhaka University, Dhaka, Bangladesh, 2018.10.17-19 [International Conference]
58. Shinya Tanaka: “Frontier in Brain Tumor Pathology: Morphology and Genetic Features of Meningioma,” Pre-Congress Meeting for ASNO2018. Joint Session between C-SNO and JSBTP, Crowne Plaza Beijing Lido, Beijin, China, 2018.10.26[International Conference]
59. Shinya Tanaka: “Morphology and Genetic Features of Meningioma,” The 15th Meeting of Asian Society of Neuro-Oncology (ASNO2018), Crowne Plaza Beijing Lido, Beijin, China, 2018.10.27-28 [International Conference]
60. Jian Ping Gong: “Hydrogels with Dynamic Sacrificial Bonds-From Toughness to Adhesion to Composites –,” The 9th International Conference on Multiscale Materials Modeling (MMM2018), Osaka, 2018.10.28[International Conference]
61. Takayuki Kurokawa: “Effect of Inhomogeneous Compliance Induced by Fiber Orientation in Polyampholyte Hydrogel on Adhesion in Water,” International Congress on Pure & Applied Chemistry (ICPAC) 2018, Bayview Hotel Langkawi, Langkawi, Malaysia, 2018.10.30-11.2[International Conference]
62. Toshiyuki Nakagaki: “Adaptive Transport Network in a Living System Designed by Current-Reinforcement-Rule,” South Lake Workshop in Bioinformatics and System Biology, Wuhan University of Science and Technology, Wuhan, China, 2018.11.18[International Conference]
63. Daniel R. King: “Embracing Internationality: Becoming a Faculty Member Abroad,” MRS Fall 2018 Meeting: The Future of Materials Science Academia–Preparing for a career in Higher Education, Hynes Convention Center and Adjacent Sheraton Boston Hotel, Boston, MA, USA, 2018.11.26 [International Conference]

64. Jian Ping Gong: “Multi-scale Design of Hydrogels with Reversible Sacrificial Bonds -From Toughness to Adhesion to Composites –,” Soft Matter Physics: from the perspective of the essential heterogeneity, Kyushu University Nishijin Plaza, Fukuoka, 2018.12.10-12[International Conference]
65. Jian Ping Gong: “Toughening Soft Materials with Sacrificial Bonds,” 50th Anniversary of Macromolecules Sympo at the 253rd ACS National Meeting, Moscone Center, San Francisco, USA, 2017.4.3[International Conference]
66. Hideyuki Mitomo: “Polymer-Supported Self-assembly of Gold Nanoparticles,” IC ME&D 2017, Sogang University, Seoul, Korea, 2017.5.18[International Conference]
67. Daniel R. King: “Taking Inspirations from Nature to Design Functional Composite Materials,” Seminar at Beijing University of Chemical Technology, Beijing University of Chemical Technology, Beijing, China, 2017.5.23[International Conference]
68. Jian Ping Gong: “Could We Observe the Single Chain Behavior at Ultimate Extension via Double Network Gel?” 2017 Telluride Science Research Conference (TSRC) on Polymer Physics, Telluride, Colorado, USA, 2017.6.29[International Conference]
69. Kuniharu Ijiro: “Self-Assembly of Nanoparticles in Solution and at Surface,” International Workshop on Active Soft Matter and Ethology Hokkaido University, Sapporo, Hokkaido, 2017.8.4[International Conference]
70. Hideyuki Mitomo: “DNA Brush-Assisted Vertical Alignment of Gold Nanorods and those Chiral Plasmonics,” SPIE Optics + Photonics, San Diego Convention Center, San Diego, California, USA, 2017.8.10[International Conference]
71. Jian Ping Gong: “Hydrogels with Reversible Sacrificial Bonds: Tough, Self-healing, Adhesion,” International Symposium on Advanced Polymeric Materials 2017 (ISAPM 2017), Changchun University of Science and Technology, Changchun, China, 2017.8.28[International Conference]
72. Jian Ping Gong: “Hydrogels with Reversible Sacrificial Bonds: Tough, Self-healing, Adhesion,” Seminar at Changchun Applied Chemistry Institute, Changchun Applied Chemistry Institute, Changchun, China, 2017.8.30[International Conference]
73. Jian Ping Gong: “Hydrogels Based on Polymer Association: Toughness, Self-Healing, and Adhesion,” SUPOLEN, Aledemar Knossos Royal Hotel, Crete, Greece, 2017.9.20[International Conference]
74. Takayuki Nonoyama: “Soft Ceramics -Double Network Tough Hydrogels Meet Bioceramics,” ASAM-6, Hoa Binh Hotel, Hanoi, Vietnam, 2017.9.28[International Conference]
75. Norimasa Iwasaki: “Elbow Disorders in Athletes: Capitellar OCD in Young Throwers: How do We Manage it?” The 1st Asia-pacific Shoulder & Elbow Symposium, Prince Hotel, Tokyo, Japan, 2017.10.7 [International Conference]
76. Kuniharu Ijiro: “DNA-Directed Aligning Self-Assembly of Gold Nanorods as Plasmonic Nanomaterials,” 13th IUPAC International Conference on Novel Materials and their Synthesis (NMS-XIII), Nanjing Tech University, Nanjing, China, 2017.10.18[International Conference]
77. Toshiyuki Nakagaki: “Introduction to Recent Advances in RIES; Transport Network in Living Systems Designed by Current-Reinforcement Rule,” 2017 RIES-CIS Symposium, National Chiao Tung University, Taiwan, Chinese Taipei, 2017.10.27[International Conference]
78. Hideyuki Mitomo: “Structure Control of Self-Assembled Gold Nanoparticle Arrays,” 2017 RIES-CIS Symposium, National Chiao Tung University, Taiwan, Chinese Taipei, 2017.10.27[International Conference]
79. Kuniharu Ijiro: “Reversible pH or Temperature Stimulus-Response Self-Assembly of Nanoparticles,” 2017 RIES-CIS Symposium, National Chiao Tung University, Taiwan, Chinese Taipei, 2017.10.28[International Conference]

80. Shinya Tanaka: “Morphological and Genetic Features of Meningioma,” the 14th Meeting of the Asian Society for Neuro-Oncology (ASNO), Congress Convention Center, Osaka, Japan, 2017.10.30[International Conference]
81. Takashi Kikukawa: “Cyanobacterial Rhodopsin having TSD Motif,” 8th Asia and Oceania Conference on Photobiology, Imperial Palace Seoul Hotel, Seoul, Korea, 2017.11.15[International Conference]
82. Kuniharu Ijiro: “Active Gap SERS with Plasmonic Nanostructures on Hydrogels for the Sensitive Detection of Biomacromolecules,” 8th International Conference and Exhibition on Lasers, Optics & Photonics, Hilton Las Vegas, Las Vegas, USA, 2017.11.16[International Conference]
83. Jian Ping Gong: “Hydrogels with Sacrificial Bonds: Tough, Self-Healing, and Self-Adjustable Adhesion,” French National Conference on Polymers, Ecole Nationale Supérieure d’Architecture de Montpellier (ENSAM), Paris, France, 2017.11.24[International Conference]
84. Hisashi Haga: “Epithelial Cell Polarity Essential for Collective Migration and 3D Morphogenesis of Cell Sheets,” The 18th RIES-HOKUDAI International Symposium, Châteraisé Gateaux Kingdom Sapporo, Sapporo, Hokkaido, Japan, 2017.11.30[International Conference]
85. Takayuki Nonoyama: “Soft Ceramics: Fusion of Tough gel and Bioceramics,” The 18th RIES-HOKUDAI International Symposium, Châteraisé Gateaux Kingdom Sapporo, Sapporo, Hokkaido, Japan, 2017.12.1[International Conference]
86. Tomohiro Onodera: “An Acellular Single-Step Technique for Cartilage Injury of the Knee,” 2nd Indo-Japanese Knee Course, Novotel, Bengaluru, India, 2017.12.10[International Conference]
87. Kuniharu Ijiro: “DNA Brush-Directed Alignment of Extensive Gold Nanorod Arrays as Plasmonic Nanomaterials,” The 15th Pacific Polymer Conference (PPC-15), Xiamen International Conference & Exhibition Center, Xiamen, China, 2017.12.12[International Conference]
88. Takayuki Nonoyama: “Fusion of Double Network Tough Hydrogel and Bioceramics,” Pure and Applied Chemistry International Conference 2018 (PACCON2018), The 60th anniversary of His Majesty the King’s Accession to the Throne International Convention Center, Hat Yai, Thailand, 2018.2.7-9[International Conference]
89. Jian Ping Gong: “Repeatable under Water Adhesion of Hydrogels,” 17th International Conference on Deformation, Yield and Fracture of Polymers, Rolduc Abbey, Kerkrade, The Nethrlands, 2018.3.26[International Conference]
90. Jian Ping Gong: “Build Tough Hydrogels with Sacrificial Bonds,” Seminar at Okinawa Institute of Science and Technology, Okinawa Institute of Science and Technology, Okinawa, Japan, 2016.4.15[International Conference]
91. Jian Ping Gong: “Polyampholyte Hydrogels: Tough, Self-healing, and Self-adjustable Adhesion,” 11th International Symposium “Polyelectrolytes 2016,” Lomonosov Moscow State University, Moscow, Russia, 2016.6.28[International Conference]
92. Kuniharu Ijiro: “Self-assembled 2D Monolayers and 3D Vesicle of Au Nanoparticles for Photonic and Biomedical Applications,” KJF-ICOMEP 2016, ACROS Fukuoka, Fukuoka, Japan, 2016.9.4[International Conference]
93. Kenichi Niikura: “Surface Engineering of Gold Nanoparticles for Functional Self-Assembly,” RIKEN CEMS Topical Meeting “Nanoparticles / Nanotubes / Nanosheets,” RIKEN, Saitama, Japan, 2016.9.7[International Conference]
94. Takashi Kikukawa, Naoki Kamo, Makoto Demura: “Light-Induced Conformational Change of Inward Cl- Pump Halorhodopsin,” 13th International Conference on Flow Dynamics, Sendai International Center, Miyagi, Japan, 2016.10.11[International Conference]
95. Takayuki Kurokawa, Gentaro Shinohara, Kumar Roy, Daniel R. King, Tao Lin Sun, Jian Ping Gong: “Effect of Fibrous Skeleton at Clingfish Suction Pad,” 5th Nagoya Biomimetics International Symposium (NaBIS), Nagoya Institute of Technology (NITech), Aichi, Japan,

2016.10.21[International conference]

96. Jian Ping Gong: “Toughening of Soft Materials with Sacrificial Bonds,” The International Rubber Conference (IRC) “Gels and Related Soft Materials” Session, Kitakyushu International Conference Center, Fukuoka, Japan, 2016.10.26[International Conference]
97. Kuniharu Ijiro: “Salmon DNA-based Preparation of Nanomaterials,” The 17th Chitose International Forum on Photonics Science & Technology (CIF17), Chitose Institute of Science and Technology, Hokkaido, Japan, 2016.11.14[International Conference]
98. Hisashi Haga: “3D Morphogensis of Epithelial Cells Responding to Viscoelasticity of the Extracellular Matrix,” Japan-Austria Joint Meeting “Understanding the Logic Behind Developmental Dynamics,” Institute of Science and Technology Austria, Klosterneuburg, Austria, 2016.11.28[International Conference]
99. Kuniharu Ijiro, Satoshi Nakamura, Hideyuki Mitomo, Yasutaka Matsuo, Kenichi Niikura: “DNA Brush-Directed Self-Assembly of Gold Nanorods into Vertically Aligned Arrays,” The 11th SPSJ International Polymer Conference (IPC 2016), Fukuoka International Congress Center, Fukuoka, Japan, 2016.12.13[International Conference]

6) Patent Applications

1. Application Number: EP19306702.2, “Microfluidic or Millifluidic Chip Comprising a Pressure Sensing Unit Using Colour-Switching Hydrogels, ” Application filed: 2019.12.19, Applicant: PSL Research University Paris, The French National Centre for Scientific Research, ESPCI-The City of Paris Industrial Physics and Chemistry Higher Educational Institution, Inventor: Anke Lindner, Lucie Ducloué, Md Anamul Haque, Jian Ping Gong
2. Application Number: Japanese Patent Application 2019-200219, “Antibodies for Detecting Mycoplasma Pneumoniae in Specimens, and Methods, Reagents, and Kits for Detecting Mycoplasma Pneumoniae Using Such Antibodies,” Application filed: 2019.11.1, Applicant: Asahi Kasei Corporation, Hokkaido University, Inventor: Tomoyasu Aizawa, Hiroyuki Kumeta, Yoshihiro Harada, Ko Inou, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana
3. Application Number: Japanese Patent Application 2019-200248, “Antibodies for Detecting Streptococcus Pneumoniae in Specimens, and Methods, Reagents, and Kits for Detecting Streptococcus Pneumoniae Using Such Antibodies,” Application filed: 2019.11.1, Applicant: Hokkaido University, Inventor: Tomoyasu Aizawa, Kumeta Hiroyuki, Yoshihiro Harada, Ko Inou, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana
4. Application Number: Japanese Patent Application 2019-200263, “Antibodies for Detecting Pseudomonas Aeruginosa in a Sample, and Methods, Reagents, and Kits for Detecting Pseudomonas Aeruginosa Using Such Antibodies,” Application filed: November 1, 2019, Applicant: Asahi Kasei Corporation, Hokkaido University, Inventor: Tomoyasu Aizawa, Kumeta Hiroyuki, Yoshihiro Harada, Ko Inou, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana
5. Application Number: Japanese Patent Application 2019-200264, “Antibodies for Detecting Staphylococcus Aureus in Specimens, and Methods, Reagents, and Kits for Detecting Staphylococcus Aureus Using Such Antibodies”, Application filed: 2019.11.1, Applicant: Asahi Kasei Corporation, Hokkaido University, Inventor: Tomoyasu Aizawa, Kumeta Hiroyuki, Yoshihiro Harada, Ko Inou, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana
6. Application Number: Japanese Patent Application 2019-200192, “Antibodies for Detecting Haemophilus Influenzae in Specimens, and Methods, Reagents, and Kits for Detecting Haemophilus Influenzae Using Such Antibodies,” Application filed: 2019.11.1, Applicant: Hokkaido University, Inventor: Tomoyasu Aizawa, Kumeta Hiroyuki, Yoshihiro Harada, Ko Inou, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana

7. Application Number: Japanese Patent Application 2019-200280, “Antibodies for Detecting Salmonella in Specimens, and Methods, Reagents, and Kits for Detecting Salmonella Using Such Antibodies,” Application filed: 2019.11.1, Applicant: Asahi Kasei Corporation, Hokkaido University, Inventor: Tomoyasu Aizawa, Hiroyuki Kumeta, Yoshihiro Harada, Yuichiro Takahashi, Yasuhiro Hashimoto, Kenji Matsuyama, Koji Maehana
8. Application Number: Japanese Patent Application 2019-503117, “Composition for Treating Fibrocartilage Tissue Damage,” Application filed: 2018.3.1, Applicant: Mochida Pharmaceutical Co. Ltd., Hokkaido University, Inventor: Eiji Kondo, Norimasa Iwasaki, Tomohiro Onodera, Wooyoung Kim, Yasuyuki
9. Application Number: Japanese Patent Application 2017-503742, “Method for Detecting Active Low Molecular Weight GTP-Binding Protein in Fixed Living Tissue,” Application filed: 2015.3.4, Applicant: Hokkaido University, Inventor: Shinya Tanaka, Tsuda Masumi, Michie Tanino
10. Application Number: Japanese Patent Application 2019-221049, “Elastomer Composite with Elastomer and Fiber Structure,” Application filed: 2019.12.6, Applicant: Hokkaido University, LG Japan Lab, Inventor: Shinnosuke Koji, Takayuki Kurokawa, Jian Ping Gong
11. Application Number: Taiwan 108138425, “Method for Producing Artificial Skin,” Application filed: 2019.10.24, Applicant: Hokkaido University and Shiseido Co. Ltd., Inventor: Kenji Noda, Akio Nasu, Takayuki Kurokawa, Jian Ping Gong
12. Application Number: Japanese Patent Application 2019-548757, “Gel Material,” Application filed: 2019.8.27, Applicant: Hokkaido University, Toray Co. Ltd., Inventor: Jian Ping Gong, Takayuki Kurokawa, Guo Hui, Takahiro Matsuda, Yu Chengtao
13. Application Number: Japanese Patent Application 2019-545066, “High Toughness Fiber Composite Elastomer,” Application filed: 2018.9.21, Applicant: Hokkaido University, Osaka Organic Chemical Industry Co. Ltd., Inventor: Jian Ping Gong, Takayuki Kurokawa, Tao Lin Sun, Lian Chen, Wei Cui, Yoshiyuki Saruwatari
14. Application Number: Taiwan 107133464, “High Toughness Fiber Composite Elastomer,” Application filed: 2018.9.21, Applicant: Hokkaido University and Osaka Organic Chemical Industries Co. Ltd., Inventor: Jian Ping Gong, Takayuki Kurokawa, Tao Lin Sun, Chen L, Cui W, Yoshiyuki Saruwatari
15. Application Number: Japanese Patent Application 2018-082339, “Hydrogel and method for producing hydrogel,” Application filed: 2018.4.23, Applicant: Hokkaido University, NGK Spark Plug Co., Ltd., Inventor: Masaya Iwata, Shinjiro Kasahara, Jian Ping Gong, Takayuki Kurokawa, Takayuki Nonoyama (PCT/JP2019/017264)
16. Application Number: Japanese Patent Application 2018-568662, “Method for Producing Cancer Stem Cells,” Application filed: 2018.2.20, Applicant: Hokkaido University, Inventor: Shinya Tanaka, Kazuhiko Yasuda, Jian Ping Gong, Masumi Tsuda, Takayuki Kurokawa.
17. Application Number: Japanese Patent Application 2017-028833, “Method for manufacturing cancer stem cells,” Application filed: 2017.2.20, Applicant: Hokkaido University, Inventor: Shinya Tanaka, Kazuhiko Yasuda, Jian Ping Gong, Masumi Tsuda, Takayuki Kurokawa
18. Application Number: US16/487247, “Method for Manufacturing Cancer Stem Cells,” Application filed: 2018.2.20, Applicant: Hokkaido University, Inventor: Shinya Tanaka, Kazuhiko Yasuda, Jian Ping Gong, Masumi Tsuda, Takayuki Kurokawa
19. Application Number: Japanese Patent Application 2018-558040, “Temperature-Responsive Gel Having LCST With No Volume Phase Transition, and Production Method Therefo,” Application filed: 2017.12.20, Applicants: Hokkaido University, Inventor: Takayuki Nonoyama. Jian Ping Gong, Yong Wang Lee, Kumi Ota
20. Application Number: US 16/471224, “Temperature-Responsive Gel Having LCST With No Volume Phase Transition, And Production Method Therefor,” Application filed: 2017. 12.20,

Applicant: Hokkaido University, Inventor: Takayuki Nonoyama, Jian Ping Gong, Yong Wang Lee, Kumi Ota

21. Application Number: EP 17884942.8, “Temperature-Responsive Gel Having LCST With No Volume Phase Transition, And Production Method Therefor,” Application filed: 2017.12.20, Applicant: Hokkaido University, Inventor: Takayuki Nonoyama, Jian Ping Gong, Yong Wang Lee, Kumi Ota
22. Application Number: Japanese Patent Application 2019-523252, “Self-Healing Material,” Application filed: 2017.6.6, Applicant: Hokkaido University, Osaka Organic Chemical Industry Co., Ltd., Inventor: Jian Ping Gong, Takayuki Kurokawa, Tao Lin Sun, Liang Chen, Wei Cui, Yoshiyuki Saruwatari
23. Application Number: Japanese Patent Application 2016-118546, “Aqueous Gel,” Application filed: 2016.6.15, Applicant: Hokkaido University, Osaka Organic Chemical Industry Co., Ltd., Inventor: Jian Ping Gong, Takayuki Kurokawa, Haiyan Yin, Yoshiyuki Saruwatari

Appendix D Selected List of Awards

1. Takayuki Nonoyama: “Specific Session: Young Excellent Presentation Award,” The Ceramic Society of Japan the 33rd Fall Meeting, 2020.9.4
2. Tasuku Nakajima: “2019 Hokkaido University Commendation for Excellent Teaching,” 2020.9.25
3. Tasuku Nakajima: “Hokkaido University: President’s Award for Excellence in Research and Teaching for AY2020,” 2021.2.19
4. Daniel R. King: “Award for Encouragement of Research in Polymer Science,” Creation and Application of Soft / Hard Composite Materials: The Society of Polymer Science, Japan, 2021.3.15
5. Jian Ping Gong: “The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology：Prizes for Science and Technology, Research Category (2019),” 2019.4.9
6. Takayuki Nonoyama: “2018 Polymer Research Encouragement Award,” Polymer Society of Japan, 2019.5.30
7. Seiichiro Ishihara: “Best Talk Award,” Advanced Model Animal Support Platform, Young Support Technology Workshop for the 1st Year of Reiwa, 2019.7.9
8. Seiichiro Ishihara: “Oral Presentation Award First Place,” 5th Hokkaido University Interdisciplinary Symposium, 2019.7.11
9. Tomohiro Onodera: “JSSF Japan-Korea Travelling Fellowship,” Japanese Society for Surgery of the Foot, 2019.8.14
10. Takeru Tsujimoto, Hideki Sudo, Masahiro Todoh M, Katsuhisa Yamada, Koji Iwasaki, Takashi Ohnishi, Naoki Hirohama, Takayuki Nonoyama, Daisuke Ukeba, Katsuro Ura, Yoichi M. Ito, Norimasa Iwasaki: “The 25th Japan Cartilage Metabolism Society Award,” A Preclinical Proof-of-concept Study: An Acellular Bioresorbable Ultra-Purified Alginate Gel Promotes Intervertebral Disc Repair, 2019.11.23
11. Norimasa Iwasaki: “Excellent Research Award,” 2018 Hokkaido University Graduate School of Medicine, 2019.1.22
12. Ryo Fujita, Masahiko Takahata, Masahiro Ota, Tomohiro Shimizu, Dai Sato, Hideyuki Kobayashi, Norimasa Iwasaki, Daigo Nakazawa, Kimura-Hiromi Suda, Ikuya Nakamura: “Young Researcher Award,” Bisphosphonates in Advanced Chronic Kidney Disease Efficacy and Safety of Low-Dose High-Frequency Formulation and High-Dose Low-Frequency Formulation: The 39th Japan Bone Morphometric Society, 2019.5.11
13. Ken Endo, Ken Kakuya, Tomoaki Suzuki, Yuki Matsui, Yusuke Yuka, Yusuke Nagano, Taisuke Kawamura, Norimasa Iwasaki: “Best Paper Award,” Study on the Optimal Degree of Schwann Cell Differentiation for Axon Regeneration: No. 62 The Japan Society for Hand Surgery Annual Meeting, 2019.4.18
14. Katsuhisa Yamada, Hideki Sudo, Norimasa Iwasaki, Akihiko Chiba: “Best Presentation Award (Basic),” Cobalt-Chrome Notch-Free Preventive Rod Is Useful for Spinal Deformity Correction-Mechanical Properties of Bending Method and Metal Materials -: 137th Hokkaido Orthopaedics and Traumatology Society, 2019.6.23
15. Mohamad Alaa Terkawi: “Society Award,” Transcriptional Profile of Human Macrophages Stimulated by Ultra-High Molecular Weight Polyethylene Particulate Debris of Orthopedic Implants Uncovers a Common Gene Expression Signature of Rheumatoid Arthritis: Hokkaido Orthopaedics and Traumatology Society, 2019.1
16. Takayuki Nonoyama: “Publicity Award,” Temperature-Responsive Active Soft Material That Instantly Becomes 1000 Times Harder at High Temperatures, Public Relations Committee: Society of Polymer Science, 2018.8.29
17. Hideyuki Mitomo, Satoru Hamajima, Yasutaka Matsuo, Kenichi Niikura, Kuniharu Ijiro: “Best Presentation Award,” Asian Conference on Nanoscience and Nanotechnology (AsiaNANO 2018),

Active Gap Control of Gold Nanodots on the Gel Surface, 2018.10.21

18. Kuniharu Ijiro: “Distinguished Award 2018 for Novel Materials and Their Synthesis,” Development of Stimuli-Responsive Gold Nanostructure Assembly and Those Applications, 14th IUPAC International Conference on Novel Materials and their Synthesis (NMS-XIV), 2018.10.23
19. Kazuya Furusawa: “Award for Encouragement of Research,” IUMRS-ICAM 2017, The 15th International Conference on Advanced Materials, Phase Behaviors of Collagen Solution,” 2017.9.1
20. Tomohiro Onodera: “Japan Medical Association Encouragement Award for Medical Research,” Identification of a New Molecular Target for Ganglioside-Targeted Articular Cartilage Damage, 2017.11.1
21. Kuniharu Ijiro: “35th Scientific Award of the Chemical Society of Japan,” Creation and Application of Stimuli-Responsive Gold Nanostructured Aggregates, 2018.3.21
22. Tasuku Nakajima: “Award for Encouragement of Research in Polymer Science from the Society of Polymer Science,” 2016.5.26

Appendix E List of External Grants

Grants from Japan Society for the Promotion of Science (JSPS)

1. Grant-in-Aid for Scientific Research (B), "Elucidation of Epithelial Keratinization / Non-Keratinization Patterns Using Differences in Scaffolding Material Hardness and Application to Cultured Oral Mucosa Preparation Methods," 2020-2022, 17,680,000JPY, Co-Investigator: Hisashi Haga, Seiichiro Ishihara
2. Grant-in-Aid for Scientific Research (B), "Nanoscale Photothermometry for Thermal Analysis," 2020-2022, 17,940,000JPY, Co-Investigator: Hideyuki Mitomo
3. Grant-in-Aid for Scientific Research (C), "A Novel Mechanism of Collective Migration of Cohesive Cells Embedded in 3D Space," 2020-2022, 4,290,000JPY, Principal Investigator: Katsuhiko Sato
4. Grant-in-Aid for Young Scientists, "Fiber Reinforced Soft Composites with Tunable Extensibility, Stiffness, and Strength for Synthetic Bio-tissue Applications," 2020-2022, 3,770,000 JPY, Principal Investigator: Daniel R. King
5. Grant-in-Aid for Scientific Research (B), "Involvement of 12α-hydroxylated Bile Acids in the Onset and Deterioration of Fatty Liver," 2019-2021, 17,680,000JPY, Co-Investigator: Tomoyasu Aizawa
6. Grant-in-Aid for Scientific Research (S), "Super-Resolution Live-Cell Imaging of Cell-Attached Nanointerface using LSPR Sheets," 2019-2023, 193,830,000 JPY, Co-Investigator: Kuniharu Ijiro
7. Grant-in-Aid for Scientific Research (A), "Induction of Concerting Function Based on Anisotropic Shape Dynamic Change of Nanoparticle Core Hybrid Dendrimer," 2019-2022, 45,110,000 JPY, Co-Investigator: Hideyuki Mitomo
8. Fund for the Promotion of Joint International Research (Fostering Joint International Research (B)), "Membrane Cleavage Mechanism of Dynamin Elucidated by Reconstitution Approach and Disease Onset Mechanism Caused by its Failure," 2019-2022, 18,330,000 JPY, Co-Investigator: Yukinori Nishigami
9. Grant-in-Aid for Scientific Research (C), "Adaptive Control for in Vivo Reconstruction of Uniaxially Oriented, High-toughness Synthetic Collagen Gel Fiber Bundle," 2019-2021, 4,290,000 JPY, Principal Investigator: Eiji Kondo, Co-Investigator: Kazunori Yasuda, Lei Wang
10. Grant-in-Aid for Challenging Research (Exploratory), "Elucidation of Sugar Chain Antigen Change on Cultured Cells and Immune Response Generation Mechanism in Autologous Cell Transplantation," 2019-2020, 6,500,000JPY, Principal Investigator: Norimasa Iwasaki
11. Grant-in-Aid for Scientific Research (A), "Reprogramming of cancer stem cells by high-performance gel and creation of therapeutic drug development platform," 2019-2023, 45,110,000 JPY, Principal Investigator: Shinya Tanaka, Co-investigator: Masumi Tsuda, Takayuki Kurokawa
12. Grant-in-Aid for Early-Career Scientists, "Analysis of Epigenetic in Hydrogel-induced Cancer Stem," 2019-2020, 4,160,000 JPY, Principal Investigator: Jun Suzuka
13. Grant-in-Aid for Scientific Research (C), "Analysis of Cypress-Derived Pollen-Food Allergy Syndrome-Causing Antigenic Peptide BP14," 2018-2020, 4,420,000JPY, Principal Investigator: Tomoyasu Aizawa
14. Grant-in-Aid for Scientific Research (C), "Elucidation of Molecular Mechanism by Which a Transporter with a Potential to Transport a Variety of Substrates Is Regulated," 2018-2020, 4,420,000JPY, Co-Investigator: Minoru Kikukawa
15. Grant-in-Aid for Early-Career Scientists, "Mutual Conversion of Ion-Pump and Ion-Channel Rhodopsins by Amino Acid Replacement," 2018-2019, 4,290,000JPY, Principal investigator: Takashi Tsukamoto
16. Grant-in-Aid for Strengthening International Joint Research (B), "Elucidating the Characteristics of Nitrogen in Biomolecules by Neutron Diffraction and Computational Chemistry," 2019-2021,

17,680,000 JPY, Co-Investigator: Takashi Tsukamoto

17. Grant-in-Aid for Early-Career Scientists, “Cancer Metastasis Regulated by Tissue Stiffness,” where cancer is likely to metastasize,” 2018-2019, 4,160,000JPY, Principal Investigator: Seiichiro Ishihara
18. Fund for the Promotion of Joint International Research (Fostering Joint International Research (B)), “Structural Analysis of Tumor Hotspots, an Epithelial Tissue-Intrinsic Novel Oncogenic Niche,” 2018-2021, 17,940,000 JPY, Co-Investigator: Seiichiro Ishihara
19. Grant-in-Aid for Scientific Research(B), “Creation of Ultra-Sensitive Biosensor Using Triangular Nanoplate and Lipid Membrane-Guided System,” 2018-2020, 17,810,000JPY, Principal Investigator: Hideyuki Mitomo
20. Grant-in-Aid for Scientific Research(C), “Development of Functionally Enhanced Protein by Synthetic Polymer Assist,” 2018-2020, 4,420,000JPY, Principal Investigator: Yusuke Yonamine
21. Grant-in-Aid for Scientific Research(B), “Mathematical Analysis of Vortex Peculiar to Viscoelastic Fluid,” 2018-2021, 16,900,000JPY, Co-Investigator: Katsuhiko Sato
22. Grant-in-Aid for Scientific Research(C), “Functional analysis of Crk and Exosome in organ metastasis determination and arousal of cancer,” 2018-2020, 4,420,000JPY, Principal Investigator: Masumi Tsuda Co-Investigator: Shinya Tanaka, Lei Wang
23. Grant-in-Aid for Scientific Research on Innovative Areas (Research in a proposed research area), “Soft Crystals: Science and Photofunctions of Easy-Responsive Systems with Felxibility and Higher-Ordering: Fabrication of Soft Photonic Crystals for Novel Functions,” 2017-2021, 49,660,000JPY, Principal Investigator: Jian Ping Gong Co-Investigator: Takayuki Kurokawa, Takayuki Nonoyama
24. Grant-in-Aid for Scientific Research(S), “Utilizing the Sacrificial Bonding Principle to Create Soft-Hard Composites with Toughness That Surpasses Metals and Novel Functions,” 2017-2021, 204,100,000JPY, Principal Investigator: Jian Ping Gong
25. Grant-in-Aid for Young Scientists(A), “Experimental Investigation of Single Polymer Chain Mechanics via Analysis of Mechanical Analysis of Gels,” 2017-2020, 19,370,000JPY, Principal Investigator: Tasuku Nakajima
26. Grant-in-Aid for Challenging Exploratory Research, “ls Possessing Thermal Hardening and Toughening,” 2017-2019, 6,240,000JPY, Principal Investigator: Takayuki Nonoyama
27. Grant-in-Aid for Scientific Research(C), “The Mechanism of Contact Following Inducing Cancer Collective Invasion and the Verification of Universality,” 2017-2019, 4,940,000 JPY, Principal Investigator: Hisashi Haga
28. Grant-in-Aid for Scientific Research(B), “Collective Migration of Epithelial Cells: A Fundamental Mechanics of Morphogenesis,” 2017-2019, 19,630,000JPY, Principal Investigator: Katsuhiko Sato
29. Grant-in-Aid for Challenging Exploratory Research, “Development of Therapeutic Drug Using a Novel Immune Network Analysis Method for Controlling Osteoarthritis,” 2017-2019, 6,240,000JPY, Principal Investigator: Tomohiro Onodera, Co-Investigator: Terkawi Alaa

Major Grants from Other Sources

30. 2020 Science and Technology Agency (JST) PRESTO Research Area, “Establishment of Principals for Novel Polymeric Material ‘Extremely Prestretched Network’,” 2020-2023, Principal Investigator: Tasuku Nakajima
31. Collaborative Research, Cancer Research Institute of Kanazawa University, “Cancer Metastasis Mechanism Approaching from Mechanobiology,” 2020-2022, Principal Investigator: Seiichiro Ishihara
32. Industry-Academia Collaborative Research, “Optimization of Solid Fat Network Evaluation Conditions for Fat Products Using an Atomic Force Microscope,” 2020-2021, Principal Investigator: Hisashi Haga, Co- Investigator: Seiichiro Ishihara

33. Hokkaido University FY2020 Support System for the Collaborative Research of Next-Generation Researchers, “Comprehensive Analysis of Gene Expression Fluctuation Patterns in Pancreatic Cancer Cells in Response to Mechanical Stimuli,” Principal Investigator: Seiichiro Ishihara
34. NYAS/AMED Interstellar Initiative, “Targeted Nanotherapy for Rescuing Endothelial Dysfunction under Biomimetic Conditions of Atherosclerosis,” 2020-2021, Principal Investigator: Seiichiro Ishihara
35. The Yasuda Medical Foundation 2020 Young Cancer Research Grant, “Cancer Metastasis Mechanism Approached from the Hardness of Organs,” 2020-2022, Investigator: Seiichiro Ishihara
36. Creative Research Institution Project, “Creation of Ultra- ‘Synthetic Method-Creation of Highly Functional Materials by High-Efficiency Preparation Method’,” 2020-2023, Co- Investigator: Hideyuki Mitomo
37. FY2020 Kurita Water and Environment Funding, “Study of Ciliate Run-Through Mechanism,” 2020-2021, Principal Investigator: Yukinori Nishigami
38. Terumo Life Science Foundation Specific R & D grant, “Development of LIVING Multifunctional Cell Gel and Application to Cartilage Regenerative Medicine,” 2021-2023, Principal Investigator: Norimasa Iwasaki, Co-Investigator: Tomohiro Onodera
39. AMED Research on Development of New Medical Devices, “Custom-made Surgical Guide for Intra-Articular Malunion Healing Fracture Surgery Doctor-led Clinical Trial for Practical Use,” 2020-2023, Principal Investigator: Norimasa Iwasaki
40. Hokkaido University Hospital Startup Support Program, “Development of Auxiliary Diagnostic System Using New Gait Analysis Method,” 2020-2021, Principal Investigator: Norimasa Iwasaki
41. Hirose Foundation, “Osteomacs (Bone Macrophages) That Can Be Applied as a New Therapeutic Agent for Osteoporosis,” 2021-2022, Principal Investigator: Alaa Terkawi
42. JA Kyosai Research Institute Traffic Accident Research, 2020-2022, “New Qualitative with O-17 Labeled Water for Traumatic Knee Cartilage Injury,” Principal Investigator: Tomohiro Onodera
43. AMED Project for Cancer Research and Therapeutic Evolution (P-CREATE), “Research and Development of Cancer Heterogeneity Control Using Biomaterials,” 2020-2021, Principal Investigator: Shinya Tanaka
44. Outsourced Business, “Development of Functional Food Material Applying Fruit Body (Tentative Name: Ryukyu Summer Grass) with Okinawan Eri Silkworm Pupae as Host,” 2019-2020, Co-Investigator: Tomoyasu Aizawa
45. Contract business, “Metabolomic Analysis of Shimagwa Leaves and Fruits,” 2019-2020, Tomoyasu Aizawa
46. Industry-academia Collaborative Research, “Tissue Regeneration Using Three-Dimensional Fiber Structure,” 2020-2021, Principal Investigator: Seiichiro Ishihara
47. Northtech Foundation Sapporo Talent Subsidy, “MMP-Dependent Infiltration Mechanism of Cancer Cells Caused by Compressive Stress,” 2019-2020, Principal Investigator: Seiichiro Ishihara
48. Astellas Metabolism Study Group: Research Grant, “Compressive Stress-Induced Acquisition of Invasion Ability of Cancer Cells,” 2019-2020, Principal Investigator: Seiichiro Ishihara
49. Uehara Memorial Foundation for Life Sciences, “Research Grant, Acquiring Invasion of Cancer Cells Caused by Compressive Stress,” 2020-2021, Principal Investigator: Seiichiro Ishihara
50. Collaborative Research: Cancer Research Institute of Kanazawa University “Mechanism of Cancer Metastasis Approaching Mechanobiology,” 2020-2021, Principal Investigator: Seiichiro Ishihara
51. Public Interest Incorporated Foundation Iketani Science and Technology Foundation 2019 Research Grant, “Development of Strict Control System for Aggregation Temperature of Temperature Responsive Gold Nanoparticles,” 2019-2020, Principal Investigator: Hideyuki Mitomo
52. Public Interest Incorporated Foundation Izumi Science and Technology Foundation Research Grant, “Creation of Gold Nanoparticle Regular Polyhedron Capsule Aiming at Development into Drug Delivery System,” 2019-2021, Principal Investigator: Hideyuki Mitomo

53. Joint research with GC Planning Inc., “Research on Collective Intelligence and its Application to Social Dynamics and Economic Phenomena,” 2019-2021, Principal Investigator: Toshiyuki Nakagaki
54. Joint Research Fund, “Evaluation of Motor Organ Regeneration Therapy by Autologous Cartilage Transplantation Using Collagen Membrane,” 2019-2020, Principal Investigator: Eiji Kondo
55. Innovative Medical Technology Creation Center Project Bridge Research Seeds A, “Establishment of a New Qualitative Evaluation Method for Articular Cartilage by MRI Using O-17 Labeled Water as a Water Tracer,” 2019-2020, Principal Investigator: Tomohiro Onodera
56. 2019 Mitsubishi Foundation grant, “Identification of Sugar Chain Antigen Change Accompanying Cell Culture and Elucidation of Immune Response Generation Mechanism in Autologous Cell Transplantation,” 6,000,000 JPY, Principal Investigator: Norimasa Iwasaki
57. FY2019 Hokkaido University Hospital Startup Support Program, “Development of a Novel Cartilage Regeneration Treatment Method by Combined Use of Bone Marrow Aspiration Concentrated Stem Cells and High-Purity Alginate Gel,” 2,400,000 JPY, Principal Investigator: Norimasa Iwasaki
58. The Cabinet of Japan, ImPACT Ito Kohzo Program, “Realization of Ultra-thin and Tough Polymer,” 2016-2018, 120,000,000JPY (Total Period 2014-2018, 200,000,000), Principal Investigator: Jian Ping Gong

Grants from Industry

122,384,808 JPY in total from 12 companies in Japan during FY 2016-2020.

Appendix F List of GSS Seminars

No.	Name of Lecturer	Date	Seminar Title
1	**Costantino Creton** Professor, ESPCI Paris, PSL Research University, and CNRS, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2020.2.12	Quantitative Bond Scission in Fracture of Soft Materials
2	**Tetsuharu Narita** Research Associate, ESPCI Paris, PSL Research University, and CNRS, France Associate Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2020.1.21	Recent Advancements in Diffusing-Wave Spectroscopy for Polymer Dynamics: High Frequency Microrheology and Dynamic Mapping
3	**Chung-Yuen Hui** Professor, Department of Mechanical and Aerospace Engineering, Cornell University, USA Global Station for Soft Matter, GI-CoRE, Hokkaido University	2020.1.14	The Single Filament Fragmentation Test
4	**Wei Hong** Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, China Department of Aerospace Engineering, Iowa State, USA University Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2020.1.14	Fracture of Viscoelastic Solids
5	**Yong Wang** Professor, Pennsylvania State University, USA	2019.11.18	Biomimetic Materials for Protein and Cell Delivery
6	**Angela Pitenis** Assistant Professor, University of California, Santa Barbara, USA	2019.9.19	Water Content and Lubricity of Aqueous Gels
7	**Bryan Coughlin** The University of Massachusetts Amherst, USA	2019.6.17	Polymer Membranes: Designing Next Generation Separators and Transport Mediators for Energy Generating Devices
8	**Alba Marcellan** ESPCI Paris/Sorbonne University, France Associate Professor, Global Station for Soft Matter, Hokkaido University	2019.5.16	Mechanical Properties of Tissue-Like Gels Produced by Injection of Spray-Dried
9	**Mokarram Hossain** Senior Lecturer College of Engineering Swansea University, Wales, UK	2019.5.10	Polymers Under Multiple Loadings: From Material Characterizations to Computational Modelling

10	**Tetsuharu Narita** Research Associate, ESPCI Paris, PSL Research University, and CNRS, France Associate Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2019.3.11	Mechanical Properties of Tough Hydrogels Having Permanent and Tunable Transient Crosslinks
11	**Jun Yamamoto** Soft Matter Physics Group, Kyoto University	2019.3.11	Slippery Interfaces on the Thin Polymer Alignment Layers
12	**Costantino Creton** ESPCI Paris, PSL Research University, and CNRS, France Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2019.1.9	Mechanophores to Reveal Molecular Scission on DN Elastomers, Adhesion Under Water: From Molecular Interactions to Macroscopic Adhesion
13	**Chung-Yuen Hui** Professor, Department of Mechanical and Aerospace Engineering, Cornell University, USA	2019.1.9	Mechanics of an Adhesive Tape in a Zero-Degree Peel Test: Effect of Large Deformation and Material Nonlinearity
14	**Hanqing Jiang** Professor, School for Engineering of Matter, Transport and Energy, Arizona State University, USA	2018.12.17	Multiphysics Modeling and Experiments of Functional Materials: Hydrogels, Batteries, and Origamis
15	**Qiang Fu** Professor, College of Polymer Science and Engineering, Sichuan University, China	2018.8.2	Low-Temperature Sintering of Stereocomplex-Type Polylactide Nascent Powder: From Compression Molding to Injection Molding
16	**Mingbo Yang** Professor, College of Polymer Science and Engineering, Sichuan University, China	2018.8.2	Core-Shell Structure and the Toughness of PA6/MEPDM/HDPE Ternary Blends
17	**Wei Hong** Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, China Department of Aerospace Engineering, Iowa State University, USA Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2018.7.17	Polymerized Ionic Liquids and Ionic Semiconductors
18	**Weiyi Lu** Assistant Professor, Department of Civil and Environmental Engineering, Michigan State University, USA	2018.7.9	Liquid Nanofoam-Functionalized Hydrogel with Enhanced Strength and Deformability
19	**Alba Marcellan** Pierre and Marie Curie University, France Associate Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2018.5.14	Mechanical Behavior at Single Fiber Scale
20	**Xiaoyu Li, Longhai Guo** College of Material Science and Engineering, Beijing University of Chemical Technology, China	2018.4.26	Synthesis of Core/Shell Latex Particles and Their Application

21	**Dominique Hourdet** CNRS, ESPCI Paris, PSL Research University, Pierre and Marie Curie University, Sorbonne University, France Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2018.4.10	Responsive Gelation in Aqueous Media
22	**Thomas Salez** CNRS, University of Bordeaux, France Assistant Professor, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2018.4.10	Soft and Wet is Different
23	**Costantino Creton** Professor, ESPCI Paris, PSL Research University, and CNRS, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2018.1.12	Mechanochemistry to Detect Stresses
24	**Tetsuharu Narita** Associate Professor, ESPCI Paris, PSL Research University, and CNRS, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.11.13	Rheological Properties of Physical and Chemical Gel of a Giant Polysaccaride 'sacran'- Effect of Chain Rigidity
25	**Takeshi Ueki** Senior Researcher, Mechanobiology Group, International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS)	2017.11.8	A Platform for Soft Materials Science: Self-assembly, Dissipative Structure, and Self-organization of Block Copolymers
26	**Takashi Nakanishi** Group Leader, Frontier Molecules Group, International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS)	2017.11.8	Functional Molecular Liquids: Alkylated-π Molecular Design, Liquid Physical and Optoelectronic Properties
27	**Anke Lindner** Professor, ESPCI Paris, PSL Research University, and University Paris Diderot, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.10.26	E-coli Suspensions, a Model Active Fluid
28	**Tsutomu Indei** Postdoctoral Researcher, Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.10.20	Rheological Studies of Associating Polymer Gels
29	**Wei Hong** Associate Professor, Iowa State University, USA Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.7.14	Mechanics of a Magneto Self-Healing Soft Composite
30	**Cécile Monteux** Associate Professor, ESPCI Paris, PSL Research University, and CNRS, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.7.10	Generation and Stability of Foams Made from Physical Gels

31	**Costantino Creton** Professor, ESPCI Paris, PSL Research University, and CNRS, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.4.14	An Experimental Investigation of Fracture in Filled Natural Rubber
32	**Chun-Jen Huang** Professor, National Central University, Taiwan	2017.4.11	Functional Electrolyte Materials in Biomedical Applications
33	**Alba Marcellan** Associate Professor, ESPCI Paris, PSL Research University, and Pierre and Marie Curie University, France Global Station for Soft Matter, GI-CoRE, Hokkaido University	2017.3.3	Some Strategies for Gel Toughening: from Polymer Adsorption onto Solid Nanoparticles to Polymer Coil-to-globule Transition Acting as Reinforcing Filler
34	**Hugh R. Brown** Professor Emeritus, University of Wollongong, Australia	2016.11.15	Modelling the Failure of Multiple Network Gels and Elastomers at the Chain Level
35	**Hiroshi Jinnai** Institute of Multidisciplinary Research for Advanced Materials, Tohoku University	2016.9.30	Challenges for Nano-scale Imaging of Polymeric Nanostructures by Electron Microscopy
36	**Jonathan T. Pham** Max Planck Institute for Polymer Research, Germany	2016.9.28	Elastocapillary Deformations: Preparing Nanoparticle Helices and Understanding Soft Materials Contact
37	**Kazue Kurihara** Professor, Institute of Multidisciplinary Research for Advanced Materials, Tohoku University	2016.8.31	Study on Friction Materials Using Surface Force Measurement

Appendix G List of Science Outreach

Press Release

1. Gong group: “Developed Polymer Gel that Instantly Becomes 2,000 Times Harder at High temperature,” Hokkaido University, 2019.11.19
2. Gong group: “Developed Adhesive that Can be Used Repeatedly in Seawater,” Hokkaido University, 2019.11.12
3. Gong group: “Developing a Gel that Strengthens with Training! ~Polymer Material that Takes in “Nutrient” from the Outside and Grows Strongly and Strongly Under Mechanical Load~,” Hokkaido University, 2019.2.1
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Global Institution for Collaborative Research and Education (GI-CoRE)
Final Evaluation for the Global Station for Soft Matter projects

1. Aims

The Global Institution for Collaborative Research and Education (GI-CoRE) shall implement an external evaluation of the research, education and organizational framework of the Global Station for Soft Matter projects which started on April 1, 2016. As the projects have welcomed the final (fifth) year of the implementation period upon the Fiscal Year 2020, the feedback of this evaluation shall be used to improve the future project.

2. Evaluation Structure

A "Hokkaido University Global Institution for Collaborative Research and Education External Evaluation Committee" shall be established in Soft Matter Global Station in accordance with the External Evaluation Implementation Guidelines for the Hokkaido University Global Institution for Collaborative Research and Education Global Station (Document 2). All evaluations and reports shall be undertaken in English.

☐ Global Station for Soft Matter External Evaluation Committee

Candidates from Soft Matter GS: 2 foreign members, 1 Japanese member

*When the evaluation is completed, the GI-CoRE Steering Committee shall receive a report from the Committee chair.

3. Evaluation Method

☐The External Evaluation Committee shall check the contents of the Research Progress Report (Document 3) sent in advance from HU before implementing the investigation, and shall evaluate the evaluation items prescribed in Document 4.

☐A 5-level evaluation ratings (S to D) and comments shall be obtained for each "Evaluation Item".

Evaluation Ratings	Evaluation Explanation
S	Achieved outcomes surpassed the original plan (Outstanding)
A	Good progress has been maintained and expected outcomes have been achieved (Excellent)
B	Most expected outcomes have been achieved with some slight delays (Good)
C	Although certain outcomes were achieved, overall results were insufficient (Satisfactory)
D	No expected outcomes were achieved (Unsatisfactory)

4. Required Expenses

Travel expenses (only when applicable) and honoraria shall be provided to the Committee Members in accordance with HU regulations. It will be arranged and covered by Global Station for Soft Matter, Hokkaido University depending on the situation of COVID-19.

5. Publishing of Evaluation Results

Evaluation of this project shall be broadly announced, with the results both published on the relevant HU websites and published as booklets which are sent to external organizations such as the Japanese Ministry of Education, Culture, Sports, Science and Technology.

GI-CoRE Global Station External Evaluation Schedule

Year and Month	Agenda
Fiscal Year 2019 (2019-2020)	
November	**Selection/Arrangement of the Evaluation Committee Members** *Criteria: 2 foreign and 1 Japanese members (candidates who can conduct evaluation in English) *Confirmation of affiliation, main achievements, contact details, etc.
December	**GI-CoRE Steering Committee #23** *Fixing overviews of evaluation items, evaluation structure, schedule, etc. *Fixing the Evaluation Committee Members
January to March	*Starting to create the 2020 Research Progress Report (in English) *Official appointment request (letters from the GI-CoRE Director) *Fixing evaluation forms
Fiscal Year 2020 (2020-2021)	
April	**Commission of Evaluation Committee Members**
May	**Completion of the Research Progress Report** *Forwarding the report to the Evaluation Committee Members for their document screening
June to July	**Preparation of On-site Investigation**
End of August to Early September	**Online Investigation August 31st to September 1st** Online investigation based on the document screening
End of September	**Submission of Summary Report and Results of the Evaluation Committee** Each Committee Member shall forward their evaluation results, based on the document screening and on-line meeting. The Chair shall summarize the Evaluation from each Committee and make a report.
December	**GI-CoRE Steering Committee #27** *Report of the results of the Evaluation from the External Evaluation Committee Members
March	**Expiration of the GSS project under the GI-CoRE System**
Fiscal Year 2021 (2021-2022)	
April	**Internalization of the GSS project into the affiliated faculty**
July	**Publication of the Final Evaluation Report**

Hokkaido University
Global Institution for Collaborative Research and Education (GI-CoRE)
External Evaluation Implementation Guidelines for the Global Stations

December 15, 2015

Establishment of the Global Institution for Collaborative Research and Education Steering Committee

1. Purpose

These implementation guidelines shall provide the necessary matters for the implementation of evaluation of the Global Station by non-University affiliated persons (hereinafter the “GS External Evaluation”) of the Hokkaido University Global Institution for Collaborative Research and Education (GI-CoRE).

2. Committee

(1) The "Hokkaido University Global Institution for Collaborative Research and Education External Evaluation Committee (hereinafter the "Committee")" shall be established by GI-CoRE in order to perform the matters prescribed in each of the following items.

(i) Implementation of GS External Evaluation

(ii) Matters related to the creation and publishing of the report pertaining to the GS External Evaluation

(2) A Committee shall be established for each Global Station that is target for external evaluation.

3. Composition

(1) The Committee shall be composed of third parties other than constituent members of Hokkaido University, and designated by the Director of GI-CoRE from persons prescribed in each of the following items.

(i) Person designated by the Director of GI-CoRE who is an expert both within and outside Japan in the research field of the Global Station to be externally evaluated

(ii) Persons whom the Director of GI-CoRE deems necessary

(2) The Committee members prescribed in the preceding paragraph shall be commissioned by the Director of GI-CoRE after approval by the GI-CoRE Steering Committee.

4. Term of Office

(1) The term of office for Committee Members shall be 1 year. However, if a Committee Member vacancy occurs, the term of office of the successor shall be the remaining term of the predecessor.

(2) Committee Members may be reappointed.

5. Committee Chair

(1) A Committee Chair shall be appointed and selected through mutual election by the Committee members.

(2) The Committee Chair shall call a Committee meeting as required, and shall chair the said meeting.

6. Proceedings

(1) A Committee meeting may not be held unless a majority of the members are present.

(2) Committee meeting proceedings shall be decided by a majority of the attending members. In case of a tie, the Committee Chair shall decide the issue.

7. Implementation of GS External Evaluation

(1) The Committee shall implement the GS External Evaluation as prescribed in the following Article.

(2) The Committee may hear the opinions of persons concerned and implement firsthand investigations related to the implementation of the GS External Evaluation.

8. Evaluation Items

The Committee shall evaluate the items prescribed by GI-CoRE in each of the following items.

(1) Items related to research

(2) Items related to education

(3) Items related to the structure of the research and education center

(4) Other items deemed necessary by the Committee

9. Creation and Publishing of the Report

The Committee shall collate the evaluation results prescribed in the preceding paragraph and publish the results in a report.

10. Response to Evaluation Results

The Director of GI-CoRE shall promptly work to implement improvements in view of the report prescribed in the previous paragraph for items in which improvements are deemed necessary.

11. General Affairs

General affairs for the Committee shall be processed by the Division of International Planning, International Affairs Department.

12. Miscellaneous Provisions

Necessary matters concerning GS External Evaluation other than those prescribed within these implementation guidelines shall be prescribed separately by the GI-CoRE Steering Committee.

Supplementary Provisions

These guidelines shall come in force on 12 December 2017.

Supplementary Provisions

These guidelines shall come into force on March 7, 2019 and shall be applied from July 1, 2018.

REGULATIONS FOR THE HOKKAIDO UNIVERSITY GLOBAL INSTITUTION FOR COLLABORATIVE RESEARCH AND EDUCATION

HU Doc. No.151
April 1, 2014

(Purpose)

Article 1 These *Regulations* shall prescribe the organization and administration of the Hokkaido University Global Institution for Collaborative Research and Education (hereinafter referred to as "the Institution for Research and Education"), based upon the *Rules Concerning the Organization of Hokkaido University* (HU Doc. No. 31 of 2004), Article 37(4).

(Objectives)

Article 2 The objectives of the Institution for Research and Education shall be to invite teaching staff from Japan and overseas with world-class education and research results, to promote international collaborative research and international collaborative education (hereinafter referred to as "international collaborative research and education") that capitalizes upon the distinctive characteristics of Hokkaido University (hereinafter referred to as the "University"), and to provide support for international collaborative research being furthered independently by faculties or schools.

(Employees)

Article 3 A Director and other necessary teaching staff shall be placed in the Institution for Research and Education.

(The Director)

Article 4 The President shall be appointed as the Director of the Institution for Research and Education.

2. The Director shall supervise the work of the Institution for Research and Education.

(The assistant director)

Article 5 An assistant director shall be placed in the Institution for Research and Education.

2. A vice president designated by the President shall be appointed as the assistant director.
3. The assistant director shall assist the Director in his or her duties and shall take over those duties in the event of the latter being incapacitated.

(Global stations)

Article 6 The following global stations shall be placed in the Institution for Research and Education to promote international collaborative research and education that capitalizes upon the distinctive characteristics of the University.

(1) The Global Station for Soft Matter
(2) The Global Station for Big Data and Cybersecurity
(3) The Global Station for Arctic Research
(4) The Global Station for Biosurfaces and Drug Discovery

2. Full-time teaching staff from the University (including specially appointed academic staff who come under each item of Article 3 of the *Hokkaido University Specially Appointed Academic Staff Regulations* (HU Doc. No. 35 of 2006). The same applies to Article 7(2) below.) and teaching staff invited from Japan and overseas shall be placed in the Institution

for Research and Education.

3. The period for which a global station is established shall be five years. However, this period can be extended within five years if the steering committee provided for in Article 8 deems it necessary.

(Global station leaders)

Article 7 A global station leader shall be placed in each of the global stations referred to in the items of Article 6(1).

2. The global station leader shall be one of the teaching staff of the said global station who has been designated by the Director.

3. The global station leader shall supervise the work of the said global station under the orders of the Director.

4. The term of office of the global station leaders shall be three years or less, and they can be reappointed.

(Steering Committee)

Article 8 A steering committee shall be placed in the Institution for Research and Education to deliberate important matters concerning the said institution.

2. The organization and administration of the steering committee shall be prescribed separately.

(Administration)

Article 9 The administrative work of the Institution for Research and Education shall be processed in the Division of International Planning, the International Affairs Department.

(Miscellaneous provisions)

Article 10 In addition to what is prescribed in these *Regulations*, necessary matters regarding the operation of the Institution for Research and Education shall be prescribed separately by the President after approval by the steering committee.

Supplementary Provisions

These *Regulations* come into force on April 1, 2014.

Supplementary Provisions

These *Regulations* come into force on April 1, 2015.

Supplementary Provisions

These *Regulations* come into force on April 1, 2016.

Supplementary Provisions

These *Regulations* come into force on July 1, 2018.

Supplementary Provisions

These *Regulations* come into force on March 1, 2020.

Supplementary Provisions

These *Regulations* come into force on April 1, 2020.

REGULATIONS FOR THE GLOBAL INSTITUTION FOR COLLABORATIVE RESEARCH AND EDUCATION STEERING COMMITTEE

HU Doc. No. 152
April 1, 2014

(Purpose)

Article 1 These *regulations* shall provide for the necessary matters concerning the organization and administration of the Global Institution for Collaborative Research and Education Steering Committee (hereinafter referred to as "the committee"), based upon Article 8(2) of the *Regulations for the Global Institution for Collaborative Research and Education* (HU Doc. No. 151 of 2014, "*Regulations for the Institution for Education and Research*" in Article 3).

(Topics for Deliberation)

Article 2 The committee shall deliberate on the issues set forth in item (6) through item (10) of Article 2 of the *National University Corporation Hokkaido University Agenda for Hearing with Faculty Council Rules* (HU Doc. No. 42 of 2015, referred to as "*Hearing Rules*" in the following paragraph) and deliver opinions to the President.

2. In addition to the matters specified in the preceding paragraph, the committee shall deliberate the following matters pertaining to the Hokkaido University Global Institution for Collaborative Research and Education (hereinafter referred to as "the Institution for Research and Education" in (5) below).

(1) Matters regarding personnel affairs of the faculty (excluding matters set forth in item (6) through item (10) of Article 2 of the *Hearing Rules*).

(2) Matters regarding the establishment, reform or termination of global stations.

(3) Matters regarding the evaluation of the educational and research activities of global stations.

(4) Matters regarding budgets.

(5) Other important matters pertaining to the administration of the Institution for Research and Education.

(Structure)

Article 3 The committee shall consist of the following members:

(1) The director of the Global Institution for Collaborative Research and Education (referred to as "the director" in Article 5)

(2) The assistant director of the Global Institution for Collaborative Research and Education (referred to as "the assistant director" in Article 5)

(3) One vice president designated by the President (excluding the person mentioned in the previous item)

(4) One dean or director from each of the following categories (a-d), each of whom shall be designated by the President

a) The Graduate School of Law, the Faculty of Education, the Research Faculty of Media and Communication, the Faculty of Economics and Business, the Faculty of Humanities and Human Sciences, the Faculty of Public Policy

b) The Faculty of Fisheries Sciences, the Faculty of Environmental Earth Science, the Faculty of Science, the Research Faculty of Agriculture, the Faculty of Advanced Life Science, the Faculty of Engineering, the Faculty of Veterinary Medicine, the Faculty of Information Science and Technology

c) The Faculty of Pharmaceutical Sciences, the Faculty of Health Sciences, the Faculty of Medicine, the Faculty of Dental Medicine, Hokkaido University Hospital

d) Each affiliated research institute, each research center, the Field Science Center for Northern Biosphere

(5) Each global station leader as prescribed in Article 7 of the *Regulations* for the Institution for Education and Research

(6) Other persons whom the President deems appropriate

2. The President shall appoint the committee members mentioned in the preceding item (6)

(Term of Office)

Article 4 The terms of office of the committee members indicated in paragraph 1(4) and paragraph 1(6) of the previous article shall be two years. However, the term of office of substitute committee members shall be the remaining term of office of the previous committee member.

2. The committee members indicated in the preceding paragraph may be reappointed.

(Committee Chair)

Article 5 The director shall be appointed as the committee chair.

2. The committee chair shall call committee meetings and preside over the said meetings.

3. The assistant director shall take over the director's duties in the event of the latter being incapacitated.

(Proceedings)

Article 6 The committee cannot validly convene unless at least two-thirds of the committee members are present.

2 Committee proceedings, other than those prescribed separately, shall be decided by the majority vote of the attending committee members.

(Attendance of Persons Other Than Committee Members)

Article 7 In cases deemed necessary by the committee, persons other than committee members may be permitted to attend committee meetings, and explanations or opinions of the said persons may be heard.

(Committees on Special Issues)

Article 8 Committees on special issues may be established within the committee when necessary in order to deliberate specialized matters.

(General Affairs)

Article 9 The administrative affairs of the committee shall be processed in the Division of International Planning, the International Affairs Department.

(Miscellaneous Provisions)

Article 10 In addition to what is prescribed in these *regulations*, necessary matters regarding the operation of the committee shall be prescribed by the said committee.

Supplementary Provisions
These *regulations* come into force on April 1, 2014.

Supplementary Provisions (HU Doc. No. 196 of April 1, 2015)
These *regulations* come into force on April 1, 2015.

Supplementary Provisions (HU Doc. No. 191 of October 1, 2016)
These *regulations* come into force on October 1, 2016.

Supplementary Provisions (HU Doc. No. 163 of April 1, 2017)
1. These *regulations* come into force on April 1, 2017.
2. The dean of the Graduate School of Dental Medicine who was specified as a committee member in c) of paragraph 1(4) of Article 3 prior to the revision (hereinafter referred to as "the former committee member" in this paragraph) shall be deemed to have been appointed as a committee member under the revised *regulations* in c) of paragraph 1(4) of Article 3 on the enforcement date of these regulations. The term of office of the said member shall be the remaining term of office of the former committee member on the enforcement date, notwithstanding the revised provisions of Article 4(1).

Supplementary Provisions (HU Doc. No. 182 of June 20, 2017)
These *regulations* come into force on June 20, 2017 and apply retroactively from April 1, 2017.

Supplementary Provisions (HU Doc. No. 98 of July 1, 2018)
These *regulations* come into force on July 1, 2018.

Supplementary Provisions (HU Doc. No. 134 of April 1, 2019)
1. These *regulations* come into force on April 1, 2019.
2. The dean of the Graduate School of Letters who was specified as a committee member in c) of paragraph 1(4) of Article 3 prior to the revision (hereinafter referred to as "the former committee member" in this paragraph) shall be deemed to have been appointed as a committee member under the revised *regulations* in c) of paragraph 1(4) of Article 3 on the enforcement date of these regulations. The term of office of the said member shall be the remaining term of office of the former committee member on the enforcement date, notwithstanding the revised provisions of Article 4(1).

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