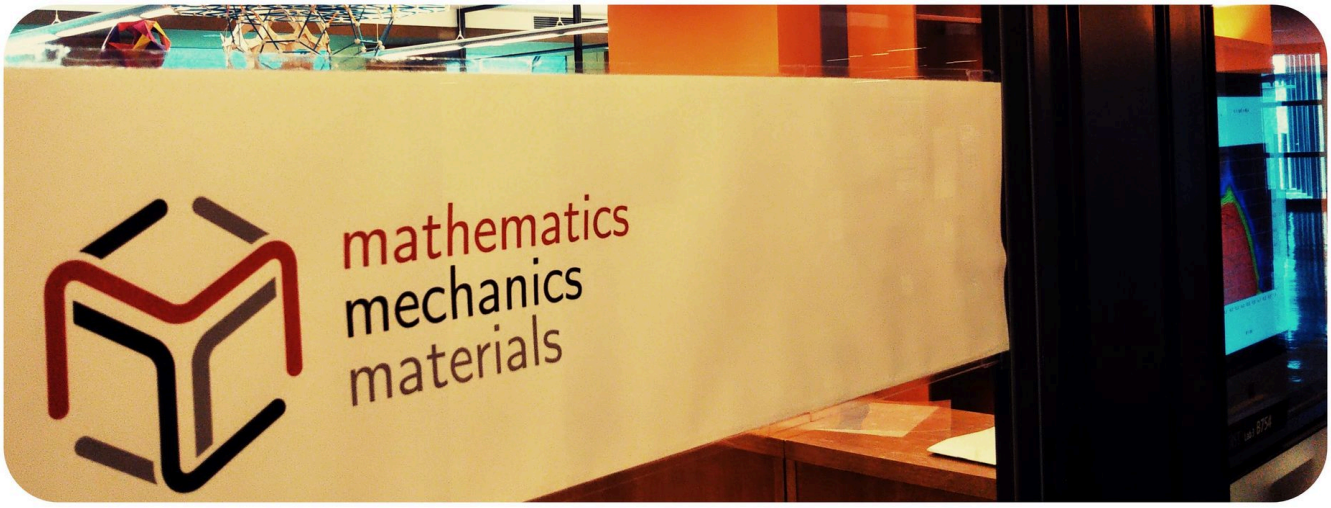
OIST OKINAWA INSTITUTE OF SCIENCE AND TECHNOLOGY GRADUATE UNIVERSITY

Mechanics and Materials Unit (Eliot Fried)

FY2019 Annual Report

Mathematics, Mechanics, and Materials Unit
Professor Eliot Fried



Abstract

FY2019 was a productive year for the Mathematics, Mechanics, and Materials Unit. During this period, unit members published 6 peer-reviewed journal articles, 2 peer-reviewed conference papers, gave 22 oral or poster presentations, and applied for 1 patent. They also kept busy with an unprecedented number of diverse outreach activities in Okinawa and mainland Japan. The unit also organized an OIST-funded worksop on Origami and Deployable Mechanisms and — in collaboration with the National Institute of Technology, Okinawa College — an external meeting of the Okinawa Future Semiconductor Technical Committee that was sponsored by Prefectural Government of Okinawa under the H30 Innovation Building Project.

1. Staff

As of March 31, 2020

- Dr. Eliot Fried, Professor
- Dr. Johannes Schönke, Staff Scientist
- Dr. Vikash Chaurasia, Postdoctoral Scholar
- Dr. Alessandro Giussani, Postdoctoral Scholar
- Dr. Stoffel Janssens, Postdoctoral Scholar
- Dr. Adel Fernando Sarmiento Rodriguez, Postdoctoral Scholar
- Dr. Burhannudin Sutisna, Postdoctoral Scholar
- Dr. James Kwiecinski, JSPS Postdoctoral Fellow
- Dr. David Vazquez Cortes, Research Unit Technician
- Mr. Michael Grunwald, Research Unit Technician
- Mr. Dmitrii Koldaev, Graduate Student
- Mr. Alexandru Mihai, Graduate Student
- Mr. Ali Rahmani, Graduate Student

- Mr. Martín Forsberg Conde, Visiting Research Student
- Ms. Naoko Tokumoto, Research Unit Administrator

Alumni

- Dr. Nicolas Moreno Chaparro, Postdoctoral Scholar
- Dr. Alice Clair Taylor, Postdoctoral Scholar
- Ms. Yi-shan Cheng, Research Intern
- Mr. Sutashu Tomonaga, Research Intern
- Mr. Trinh Truong Duc, Visiting Research Student

2. Collaborations

2.1 Unstretchable two-dimensional materials

- Type of collaboration: Joint research
- Researchers:
  - Professor Yi-Chao Chen, University of Houston, Houston, TX, USA
  - Professor Roger Fosdick, University of Minnesota, Minneapolis, MN, USA
  - Professor Brian Seguin, Loyola University Chicago, IL, USA

2.2 Fabrication of diamond-based surface-acoustic-wave devices

- Type of collaboration: Joint research
- Researchers:
  - Professor Satoshi Fujii, Okinawa National College of Technology, Naha, Okinawa, JAPAN

2.3 Modeling of size-dependent crystal plasticty in TRIP steel

- Type of collaboration: Joint research
- Researchers:
  - Professor Takeshi Iwamoto, Academy of Science and Technology, Hiroshima University, JAPAN

3. Activities and Findings

3.1 Hierarchically Ordered Nanocomposites based on Block Copolymers and Nanodiamonds

The use of nanodiamonds (NDs) as reinforcing fillers in polymer nanocomposites has been limited by challenges related to creating uniform dispersions. In this work, we address this issue by exploiting enthalpic and entropic factors of co-assembly between block copolymers (BCPs) and NDs. The BCP self-assembly and their selective interaction with NDs is utilized to obtain hierarchically ordered nanocomposites (Fig. 3.1a), analogous to those found in the abalone nacre or bone. In addition, the well-ordered spatial distribution of NDs in the nanocomposites may enhance their ability as reinforcing fillers, applicable for energy storage, biotech, coating, and tribology. This work involves ND surface functionalization to promote selective interaction with one of the BCP blocks and employ BCPs with various configurations to obtain well-ordered micellar nanocomposites (Fig. 3.1b) prepared via solvent-based techniques. In general, our study has demonstrated a successful strategy to avoid the inadvertent agglomerations of NDs, and the fabricated hybrid nanostructures can also be used as building blocks for hierarchically ordered nanocomposites.

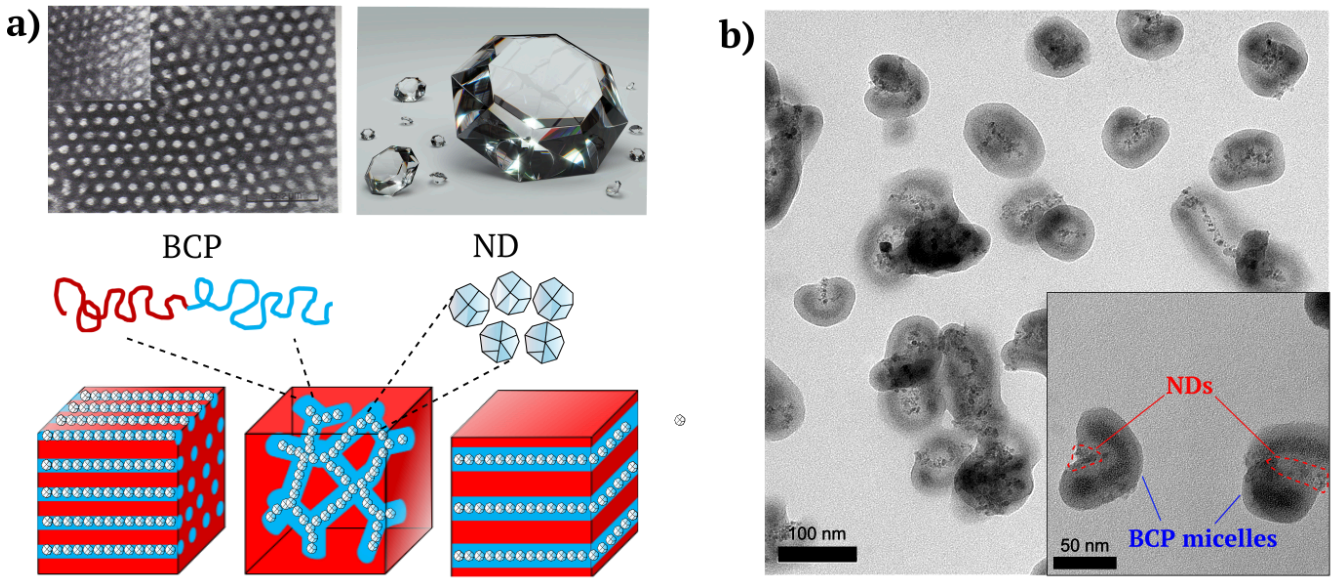


Fig. 3.1 a) Schematics of block copolymer (BCP) and nanodiamond (ND) forming hierarchically ordered nanocomposites, and b) TEM image of BCP-ND nanocomposites from a dispersion in acetone/isopropanol mixture.

3.2 Fabrication of a nanocrystalline diamond-glass platform for the development of micro- and nanodevices

Low-cost and robust platforms are important for the development of next-generation micro- and nanodevices. To build such platforms, nanocrystalline diamond (NCD) is a highly suitable material due to its excellent properties, such as biocompatibility and optical transparency, while glass substrates with through vias are ideal interposers for 3D integration. However, developing devices that are composed of NCD films and through glass vias (TGVs) has rarely been attempted due to challenges with processing these robust materials.

We developed a low-cost process, free of photolithography and transfer-printing, for fabricating arrays of TGVs that on one side are sealed with suspended portions of a thin NCD film. These robust structures are highly transparent and are intended to serve as a platform for the development of a variety of devices, such as microwells for single-cell analysis. The process is demonstrated by fabricating TGVs that are sealed with an NCD film of thickness 175 nm and of diameter 60 μm. A dark-field optical micrograph of these TGVs is depicted in Fig. 3.2(a) and a scanning electron microscope image of one TGV is depicted in Fig. 3.2(b).

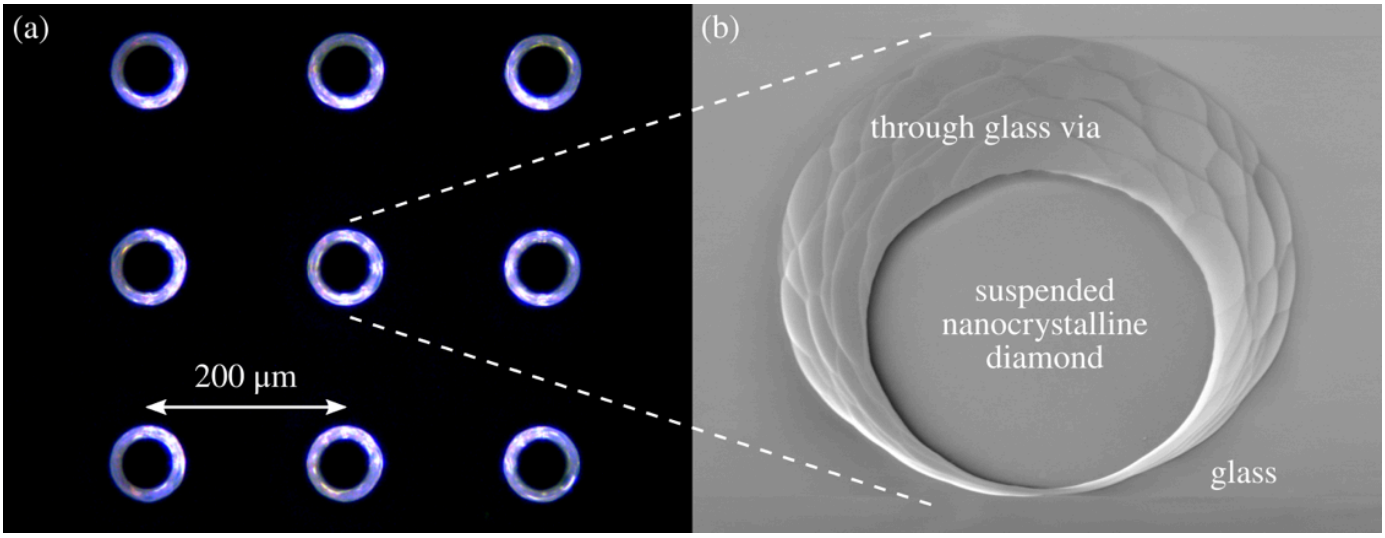


Fig. 3.2 (a) Dark-field optical micrograph of a glass substrate with nanocrystalline diamond sealed through glass vias (TGVs). (b) Scanning electron microscope image of the centre TGV.

3.3 The initial stages of microwave plasma chemical vapor deposition of nanocrystalline diamond films in the presence of an oxygen admixture

Nanocrystalline diamond (NCD) films formed by microwave plasma enhanced chemical vapor deposition (MWCVD) possess outstanding properties, which make them desirable for a variety of applications, including optical and tribological coatings, micro- and nano-electro-mechanical systems and biosensors.

NCD films by MWCVD are typically grown from a hydrocarbon and hydrogen gas mixture. Adding a small amount of oxygen to the reactant gases is known to hinder the formation of non-diamond carbon, and to reduce the incorporation of impurities like hydrogen, boron, and silicon, which may affect the mechanical, electrical, and optical characteristics of the NCD layers. The impact of oxygen on the overall film properties has been widely investigated in the literature. However, the initial stages of growth in the presence of an oxygen admixture have barely been explored.

We seeded silicon substrates with detonated nano-diamonds and loaded them into our MWCVD reactor, aiming at depositing NCD thin films from a methane, hydrogen and oxygen gas mixture. We thoroughly investigated the interaction between the nanometric diamond seeds and the oxygen-enriched plasma. We found that, for a given seeds' density and set of gas flows and plasma power, an upper reactor pressure exists above which no diamond film growth occurs, irrespective of the substrate temperature. At lower reactor pressures, compact NCD layers form and both the induction time to coalescence and the deposition rate are inversely proportional to the substrate temperature. If the concentration of the oxygen admixture is raised, the seeds are washed out and no diamond film deposition takes place even for reactor pressures below the pressure threshold.

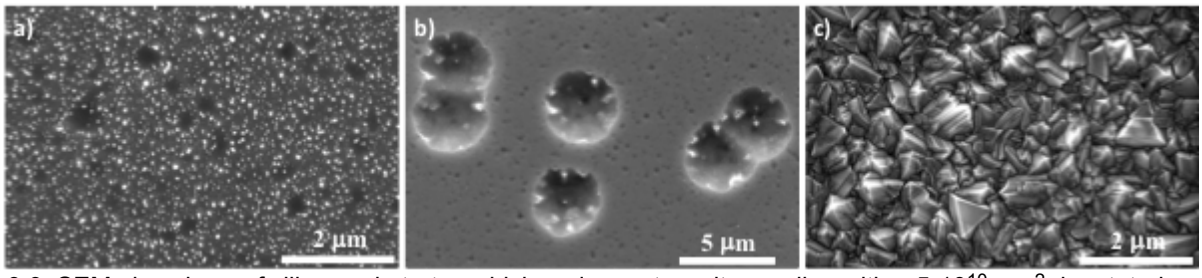
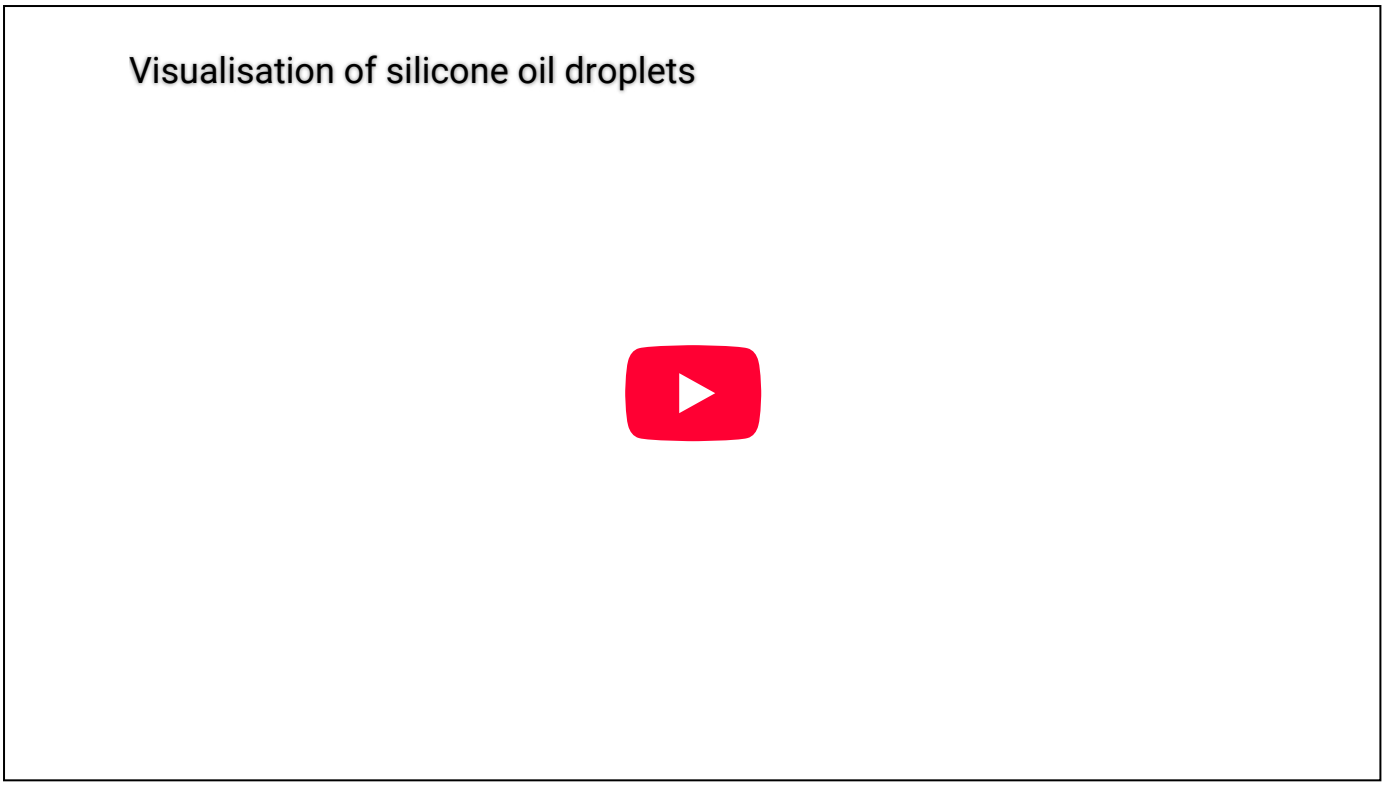


Fig. 3.3 SEM plan views of silicon substrates which underwent ex situ seeding with ~ $5 \cdot 10^{10}$ cm^{-2} denotated nano-diamonds and 6 hour deposition in our MWCVD reactor employing 1% [CH_4] and 0.5% [O_2] in H_2, 500 sccm total flow, 4000 W plasma input power. a) At a reactor pressure of 40 Torr (pressure threshold), the seeds did not coalesce into a closed film. b) At 40 Torr reactor pressure, undesired overshoot of the oxygen flow in the first second from opening the oxygen mass flow controller resulted in complete dissolution of the seeds and formation of micrometric craters. This shows how critical the stability of the seeds in the initial stages of deposition is in the presence of an oxygen admixture. c) Decreasing the reactor pressure to 30 Torr (below pressure threshold) yielded a closed and faceted NCD film.

3.4 Visualisation of fingering instabilities in spreading silicone oil droplets

Experiments in which small amounts of high viscosity (5CST) silicone oils were added to low viscosity silicone oil (0.65cst) were performed. During the spreading of the droplets, fingering instabilities with morphology sensitive to the amount of the high viscosity oil added were observed. Shadowgraphy was used to visualize full droplets spreading at the milimeter scale and laser interference is used to visualize the spreading of the droplets at the micrometer scale.



4. Publications

4.1 Journals

1. A. Rahmani, M. Tamtaji, A.M. Dehkordi. Numerical simulation of a cubic spout-fluid bed: Influences of inlet gas temperature and jet to bed cross-section ratio, *International Journal of Chemical Reactor Engineering* **18** (2020), 20190144-1–15. (doi:10.1515/ijcre-2019-0144)
2. V. Chaurasia, Y.-C. Chen, E. Fried. Interacting charged elastic loops on a sphere, *Journal of the Mechanics and Physics of Solids* **134** (2020), 103771-1–32. (doi:10.1016/j.jmps.2019.103771)
3. S.D. Janssens, D. Vásquez-Cortés, A. Giussani, J.A. Kwiecinski, E. Fried. Nanocrystalline diamond-glass platform for the development of three-dimensional micro- and nanodevices, *Diamond & Related Materials* **98** (2019), 107511-1–8. (doi:10.1016/j.diamond.2019.107511)
4. B. Sutisna, V. Musteata, B. Pulido, T. Puspasari, D-M. Smilgies, N. Hadjichristidis, S. P. Nunes. High flux membranes, based on self-assembled and H-bond linked triblock copolymer nanospheres, *Journal of Membrane Science* **585** (2019), 10–18. (doi: 10.1016/j.memsci.2019.04.045)
5. E. Fried, L. Lussardi. Monotonicity formulae for smooth extremizers of integral functionals, *Rendiconti Lincei – Matematica e Applicazioni* **30** (2019), 365–377. (doi:10.4171/RLM/851)
6. S.P. Clavijo, A.F. Sarmiento, L.F.R. Espath, L. Dalcin, A.M.A. Cortes, V.M. Calo. Reactive *n*-species Cahn–Hilliard system: A thermodynamically-consistent model for reversible chemical reactions, *Journal of Computational and Applied Mathematics* **350** (2019), 143–154. (doi: 10.1016/j.cam.2018.10.007)
7. R.A. Van Gorder, A.L. Krause, J.A. Kwiecinski. Amplitude death criteria for coupled complex Ginzburg–Landau systems, *Nonlinear Dynamics* **97** (2019), 151–159. (doi: 10.1007/s11071-019-04961-3)
8. J.A. Kwiecinski, S.W. Biber, R.A. Van Gorder. Chaotic Rotations of a Rigid Ellipsoidal Body Exhibiting Spin-Orbit Misalignment in a Periodic Orbit, *International Journal of Bifurcation and Chaos* **Vol. 29, No. 07** (2019), 1930018. (doi: 10.1142/S0218127419300180)

4.2 Books and other one-time publications

Nothing to report

4.3 Presentations

4.3.1 Oral Presentations

1. E. Fried, *Single degree-of-freedom everting linkages with nonorientable topology,* Seminar, The University of British Columbia, Vancouver, Canada, April 2 (2019).
2. S. Janssens, D. Vázquez-Cortés, A. Giussani, J.A. Kwiecinski, and E. Fried, *Fabrication of a nanocrystalline diamond-glass platform for the development of micro- and nanodevices*, Laboratoire des Sciences des Procédés et des Matériaux, CNRS, Université Paris 13, Sorbonne Paris Cité, Villetaneuse, France, April 5 (2019).
3. J. Schönke, *Möbius Kaleidocycles*, Nakano campus, Meiji University, Tokyo, Japan, April 25 (2019).
4. J. Schönke, *Möbius Kaleidocycles—Folding Linkages with a Single Degree of Freedom from Paper,* Event: MIMS現象数理学拠点共同研究集会「折紙を基盤とする数理と折紙工学への応用発展」, Center for Mathematical Modeling and Applications, Meiji University, Tokyo, Japan, April 26-27 (2019).
5. J. Schönke, G. Royer-Carfagni, *Matrix Analysis of Möbius Kaleidocycles,* Event: Origami and Deployable Mechanisms OIST Workshop 2019, Okinawa, Japan, May 28-31 (2019).
6. S. Janssens, *Diamond−glass platform for the fabrication of 3D micro- and nanodevices*, Japan Science and Technology Agency (JST) Technology Showcase, Tokyo, Japan, June 11 (2019).
7. E. Fried, *The Shape, Energy and Stability of Graphene Möbius Bands,* Event: AMSE 2019 (International Congress on Advanced Materials Sciences and Engineering, Osaka, Japan, July 22-24 (2019).
8. J. Schönke, *Möbius Kaleidocycles and Closed Curves of Minimal Constant Torsion,* Seminar, Technical University Vienna, Austria, July 25 (2019)
9. E. Fried, *Phase fields, constraints, and the Cahn – Hilliard equation,* Seminar, Mechanical Science and Engineering, University of Illinois Urbana-Champaign, Illinois, USA, September 11 (2019).
10. E. Fried, *Möbius kaleidocycles*, Event: 55th Meeging of the Society for Natural Philosophy (SNP): Microstructure, defects, and growth in mechanics, Loyola University Chicago, Chicago USA, September 13-15 (2019).
11. V. Chaurasia, *Interacting charged elastic loops on a sphere*, Event: 55th Meeging of the Society for Natural Philosophy (SNP): Microstructure, defects, and growth in mechanics, Loyola University Chicago, Chicago, USA, September 13-15 (2019).
12. J. Schönke, *Möbius Kaleidocycles and Closed Curves of Minimal constant Torsion,* Event: Quasiperiodic tiling and related topics, RIMS, Kyoto University, Kyoto, Japan, October 7-9 (2019).
13. S. Janssens, D. Vázquez-Cortés, A. Giussani, J.A. Kwiecinski, and E. Fried, *Fabrication of a nanocrystalline diamond-glass platform for the development of micro- and nanodevices*, Event: JSPS-CNRS diamond detector workshop, Yuzawa-city, Akita, Japan, October 29- November 1 (2019).
14. E. Fried, *Closed Nonorientable Ribbons from Unstretchable Helicoidal Material Surfaces,* Seminar, Aerospace and Mechanical Engineering, University of Southern California, Los Angeles, USA, November 20 (2019).
15. E. Fried, *Möbius kaleidocycles,* Seminar, Department of Mechanical Engineering, Stanford University, USA, November 22 (2019).
16. J. Schönke, *Origami Möbius Kaleidocycles,* Event: Academic Festival, University of Meiji, Tokyo, Japan, November 23 (2019).
17. S. Janssens, M. Abdelgawad, E. Fried, *Aqueous droplets in a Leidenfrost state on near room temperature sulphuric acid*, Event: 72th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Washington, USA, November 23-26 (2019).
18. S. Janssens, D. Vázquez-Cortés, A. Giussani, J.A. Kwiecinski, and E. Fried, *Fabrication of a nanocrystalline diamond-glass platform for the development of micro- and nanodevices*, Event: Hasselt Diamond Workshop 2020 SBDD XXV, Hasselt, Belgium, March 11-13 (2019).
19. E. Fried, *Suspended nanocrystalline diamond films for microtechnologies and for exploring how curvature effects wrinkling,* Seminar at Colege of Engineering, University of Hawai'i Manoa, Hawai'i, USA, March 25 (2019).

4.3.2 Other Presentations

1. J. Schönke, M. Grunwald, E. Fried, *Nine-Hinged Möbius Kaleidocycles,* Art Exhibition, Event: Bridges 2019, Linz, Austria, July 16-20 (2019).
2. S. Janssens, D. Vázquez-Cortés, A. Giussani, J.A. Kwiecinski, and E. Fried, *Fabrication of a nanocrystalline diamond-glass platform for the development of micro- and nanodevices*, Poster Presentation, Event: 30th International Conference on Diamond and Carbon Materials, Seville, Spain, September 8-12 (2019)
3. D. Vázquez-Cortés, E. Fried, *Visualisation of silicone oil droplets,* Video Presentation, Event: 72th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Washington, USA, November 23-26 (2019).

5. Intellectual Property Rights and Other Specific Achievements

5.1 Visiting Professor at Universit□e Paris Nord: Dr. Stoffel Janssens

Dr. Stoffel Janssens was invited to work in a laboratory of Prof. Jocelyn Achard as a Visiting Professor.

Universit□e Paris Nord - LSMP - CNRS - Villetaneuse, France
Period: From March 18 to April 5, 2019

5.2 JSPS Postdoctoral Fellowship for Research

Postdoctoral Fellow: Dr. James Kwiecinski
Period: From September 2019 to August 2021

5.3 Patent Application: Dr. Stoffle Janssens

Title: Fabrication of a through glass via that is sealed with a suspended film.

6. Meetings and Events

6.1 Meetings

6.1.1 Seminars

Mr. Rafael Ferrin (Iwate University, Japan)

- Date: June 21, 2019
- Venue: D015, Lab 1 , OIST Campus
- Seminar: Design proposals for hyper-redundant robotic arms and human-friendly robotic articulations

Professor Fernando P. Duda (Federal University of Rio de Janeiro, Brasil)

- Date: July 10, 2019
- Venue: C016, Lab 1 , OIST Campus
- Seminar: Modeling of surface reactions mediated by bulk diffusion

Professor Huajian Gao (School of Mechanical and Aerospace Engineering, College of Engineering, Nanyang Technological University, Singapore)

- Date: December 17, 2019
- Venue: D015, Lab 1 , OIST Campus
- Seminar: Mechanics of cell-nanomaterial interactions and some applications in nanomedicine and nanotoxicity

6.1.2 Long Term Visiting Researcher

- Professor Yi-chao Chen, University of Houston
- Professor Fernando P. Duda, Federal University of Rio de Janeiro
- Professor Brian Seguin, Loyola University Chicago
- Dr. James Kwiecinski (was a visiting researcher until the end of August 2019. And, he joined as a JSPS Postdoctoral Research Fellow at MMMU.)

6.2 Events

6.2.1 Origami and Deployable Mechanisms: ODM2019

- Date: May 28-31, 2019
- Venue: OIST Conference Center
- Co-organizers: Professor Gianni Royer-Carfagni, University of Parma

6.2.1 Okinawa Future Semiconductor Technical Committee

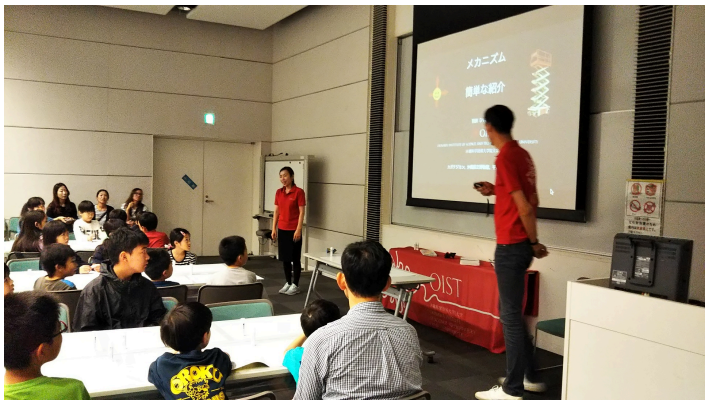
- Date: September 26, 2019
- Venue: OIST Seminar room C210, Center building
- Committee Chair: Prof. Fujii, N.I.T., Okinawa College
- Sponsor: H30 Innovation Building Project in Okinawa Prefecture, and H30 KOSEN
  Okinawa General Bureau, Cabinet Office, Prof. Fried OIST

7. Other

7.1 KAGAKUJIKAN 2019

This was one of the science event for Japan Science Week.

- Hands on session: Let's make Möbius Kaleidocycles
- Date: April 20, 2019
- Venue: Okinawa Prefectural Museum and Art Museum



7.2 Okinawa Science Mentoring Program 2019

Dr. Burhannudin Sutisna mentored an Okinawan high school student to conduct a research on block copolymer self-assembly and polymer chemistry during Okinawa Science Mentoring Program (OSMP) 2019.

7.3 Okinawa-city Science Festa 2019

- Hands on session: Let's make Möbius Kaleidocycles
- Date: September 8, 2019
- Venue: Okinawa-city Gymnasium

7.4 OIST Science Festival 2019

- Hands on session: Let's make Möbius Kaleidocycles
- Date: November 16, 2019
- Venue: OIST Main Campus

7.5 Mechanism workshops in Miyako island: Dr. Johannes Schönke

Miyako High School

- Date: January 31, 2020
- Venue: Miyako High School, Miyakojima-city, Okinawa

Miyako Schience Festa (Miyako Island KAGAKU-ASOBI Festa)

- Date: February 2, 2020
- Venue: JTA Dome, Miyakojima-city, Okinawa

7.6 Talk at Kyuyo high school: Dr. James Kwiecinski

- Date: February 19, 2020
- Venue: Kyuyo High School, Okinawa-city

7.7 The flow behavior of simple and Möbius ring-like objects: Dr. Nicolas Moreno Chaparro

- See more: https://vimeo.com/307164022

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