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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			J. Ardie Dillen
					19b. TELEPHONE NUMBER 724-779-2711

RPPR Final Report

as of 03-Mar-2023

Agency Code: 21XD

Proposal Number: 80235EMCF

Agreement Number: W911NF-22-1-0049

INVESTIGATOR(S):

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Report Date: 31-Dec-2022

Date Received: 01-Mar-2023

Final Report for Period Beginning 01-May-2022 and Ending 31-Dec-2022

Title: 2022 MRS Spring Meeting

Begin Performance Period: 01-May-2022

End Performance Period: 31-Dec-2022

Report Term: 0-Other

Submitted By: Sandra Forrest

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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0

STEM Participants:

Major Goals: Funding was requested from the Army Research Office to allow symposium organizers to cover registration fees and provide partial travel reimbursement for invited speakers, early-career researchers and student based on merit and need.

Multidisciplinary research is touted as essential to innovation. That is why, from May 8-13, 2022, researchers working in seemingly unrelated fields will gathered in Honolulu to promote, share and discuss issues and developments across disciplines. The virtual portion of the 2022 MRS Spring Meeting was held from May 23-25, 2022, to promote issues and developments across disciplines.

The 2022 MRS Spring Meeting & Exhibit was the key forum to present research to an interdisciplinary and international audience. It provides a window on the future of materials science, and offers an opportunity for researchers—from students and postdoctoral fellows, to Nobel and Kavli Prize Laureates—to exchange technical information and network with colleagues.

Accomplishments: Symposium EQ05 The symposia was dedicated to bringing together researchers across the globe from a wide range of disciplines including material science, chemistry, condensed matter physics, surface science, device engineering and reliability physics, light matter interactions and photonics to communicate important recent developments, which address key questions pertaining to the fundamental structure-property relationships and applications using novel experimental and theoretical approaches with special focus on: 1. Understanding and tailoring materials chemistry to obtain high purity thin-films 2. Design principles for the selection of spacer cations $\pm$ charge, shape, size and heteroatom 3. Advanced structural, and imaging of perovskites 4. Excitonics and photo-phononics 5. Spintronics and spin-orbitronics 6. Electron transport and device physics 7. Device engineering, interfaces, reliability science. Symposium EQ09 The topic of our symposium is oriented to fundamental knowledge and understanding in chemistry, physics, engineering, and materials for photonics, electronics, and quantum sciences. Discussions in the proposed symposium covered the synthesis, characterization, physics, and device engineering comprising emerging light-emitting materials.

Our symposium was conducted in connection with the ARO program, oriented to fundamental knowledge and the understanding of the chemistry, physics, engineering, and materials for photonics, electronics, and quantum sciences. In order to effectively conduct related discussions, our symposium consisted of 13 sub-sessions.

Symposium NM05 This symposium provided a forum for the presentation of recent advances of nanodiamonds in quantum sensing, diagnostic and biomedical applications as well as addressing fabrication and characterisation advances needed for the new applications. The fast developing quantum sensing and communication, as well as

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developing nanodiamonds as new diagnostic and therapeutic materials, gather leading scientists, industry, young researchers and students from the USA and across the world to this symposium. Continuing the tradition of the nanodiamond symposium since it was first established in 2012, the symposium in 2022 again successfully bridges the scientists in industry and academia across all aspect of nanodiamond together, creating new collaborations that are critically needed to further developing fluorescent nanodiamond for the increasingly important sensing applications.

Symposium QT09 The symposium addressed the reinvigorated topic of strong coupling between light and matter in the infrared and THz spectral ranges (frequency range 1-300 THz), including the emergence of novel quantum interactions. In the strong coupling regime, two or more modes coherently interact and exchange energy at a rate much faster than the energy decay in either material. Under these conditions, the modes take on a hybrid character with properties and information shared between the constituent components. Thus, strong coupling can enable one system to adopt the beneficial properties of another. As such, strong coupling promises advances in quantum optics, control of chemical and biological reaction pathways, and, tailoring of emission properties of infrared emitters.

Strong coupling has been demonstrated in a wide range of materials (including two-dimensional materials, metamaterials, and biological and molecular systems). At its heart, strong coupling relies heavily upon the material properties that can couple to light, and thus investigations of strong coupling require the development of a concerted materials-centric understanding of light-matter interactions. Currently, however, strong coupling phenomena are viewed as interesting phenomenon observed within a variety of research fields, limiting cross-pollination of ideas and concepts between different research communities. It is the intent of this symposium to bring together leaders in strong coupling research across research disciplines. We hope a unified approach will allow us to advance our fundamental understanding of the transition from weak to ultra-strong coupling and from classical to quantum behavior, among other topics.

Symposium SB03 The symposium attracted an international and interdisciplinary audience to discuss latest research activities in soft robotics, bioinspired robotics, soft multifunctional materials, and robotic matter. The in-person sessions took place from Wednesday, May 11, to Friday, May 14, 2022, and the virtual session was held on Wednesday, May 25, 2022. The 3-day in-person sessions featured 10 invited speakers, 18 oral presentations, and 9 poster presentations. The invited speakers (2 women, 8 men) were from Germany, Switzerland, the United States, and the United Kingdom. Several invited speakers were not able to attend due to COVID-related circumstances. The virtual session had one invited speaker and 9 oral presentations. Altogether, symposium contributors represented North America, Europe, and Asia. The symposium was organized by four experts (2 women and 2 men representing North America, Europe, and Asia) in the topic areas, with three organizers at the early-career stage.

Symposium SB4 The goal of this symposium was to bring together researchers with common interests in bioelectronic interfaces, which facilitate the transduction of biological signals and the stimulation of biological organs/tissues, open new opportunities for various applications such as healthcare, robotics, sports, and e-games. These devices often require the conformal attachment of devices on the curvilinear human skin or organ surface and the long-term operational reliability even under severe mechanical deformation. For these purposes, many researchers have been searching for specialized constituent materials, particularly, targeting stretchable/flexible/soft conductors, semiconductors, and dielectrics, in conjunction with processing/integration methods toward robust high-performance devices. This symposium covered the recent progress in advanced soft materials, processing, and device architectures for bio-electronic interfaces in the fields of healthcare, robotics, sports, and Internet of Things (IoT), etc.

Symposium SF05 The goal of Autonomous Materials is to create a new vision for material composites. These composite materials will encompass effort from the "Smart Materials" and "Smart Systems" community (PZTs, for example), as well as new work in soft structural sensing (e.g., stretchable photonic networks), structural energy, dynamic mechanical energy (electrohydraulic energy storage), material computation (e.g., BZ reactions), self-healing, ionotronics, stretchable electronics, etc. One specific difference in our goals from prior topics, such as Smart Materials, is that we will prioritize research at scales and properties that allow for processing as materials (e.g., injection molding, 3D printing, layup, etc).

Symposium SF09 ARO funds were used to encourage the best oral and poster presenter in the symposium. We hope to continue the international networking and active collaborative research based on this support even after the 2022 MRS spring meeting. In addition, since the HEM symposium is also scheduled to be held at the 2023 MRS spring meeting, we will continue to update the latest research and contribute to the active growth of the HEM field.

Symposium SF13 This multi-disciplinary symposium aimed to cover a variety of advances in the design and fabrication of living machines as a new generation of robots, and in increasing the efficiency, autonomy, and lifespan of these systems. It also aimed to bring together speakers and audiences from materials science, chemistry, biology, robotics, and computation (among others) to share their perspectives and ideas for future

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challenges of this exciting field.

Training Opportunities: Nothing to Report

Results Dissemination: the program for the MRS 2022 meeting is posted on our website: www.mrs.org

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

ARTICLES:

Publication Type: Journal Article

Peer Reviewed: Y

Publication Status: 1-Published

Journal: MRS Advances

Publication Identifier Type: DOI

Publication Identifier: 10.1557/s43580-022-00322-2

Volume: 7

Issue: 30

First Page #: 766

Date Submitted: 3/1/23 12:00AM

Date Published: 8/1/22 12:00PM

Publication Location: Warrendale PA

Article Title: Fluorescence modulation of nanodiamond NV⁻ centers for neurochemical detection

Authors: Mai S. Rashwan, Zeinab M. Anwar, Harihara Baskaran, Heidi B. Martin

Keywords: Fluorescence isotherms nanodiamond neurochemical

Abstract: Nanodiamond (ND) with nitrogen vacancy (NV⁻) color centers has emerged as an important material for quantum sensing and imaging. Fluorescent, carboxylated ND (140 nm) is investigated for the detection of dopamine (DA), caffeine (CA), and ascorbic acid (AA). Over a 200 nM range, DA and CA quenched the ND fluorescence by 7.1 and 9.8%, respectively. For AA, fluorescence was quenched (2.9%) at nM concentrations and enhanced at μ M concentrations. The quenching fit well to Langmuir adsorption isotherms. For DA-CA mixtures, the CA at nM concentrations did not affect DA quenching but interfered when at μ M concentrations. The DA at nM or μ M concentrations lessened CA quenching. For DA-AA mixtures with DA at mM concentrations, AA quenched fluorescence throughout the nM and μ M range, with increased quenching in the nM range. These studies support ND fluorescence modulation as a possible sensor modality for bioanalyte detection.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

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Journal: MRS Advances

Publication Identifier Type: DOI

Publication Identifier: 10.1557/s43580-022-00331-1

Volume: 7

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First Page #: 663

Date Submitted: 3/1/23 12:00AM

Date Published: 8/1/22 4:00AM

Publication Location: WARRENDALE PA

Article Title: Integrated hydrogel sensor-actuator for glucose sensitivity and drug elution

Authors: Ashwin Velraj, Jeffrey Bates

Keywords: NANODIAMOND HYDROGEL DRUG SENSOR-ACTUATOR

Abstract: Nanodiamond (ND) with nitrogen vacancy (NV?) color centers has emerged as an important material for quantum sensing and imaging. Fluorescent, carboxylated ND (140 nm) is investigated for the detection of dopamine (DA), caffeine (CA), and ascorbic acid (AA). Over a 200 nM range, DA and CA quenched the ND fluorescence by 7.1 and 9.8%, respectively. For AA, fluorescence was quenched (2.9%) at nM concentrations and enhanced at ?M concentrations. The quenching fit well to Langmuir adsorption isotherms. For DA-CA mixtures, the CA at nM concentrations did not affect DA quenching but interfered when at ?M concentrations. The DA at nM or ?M concentrations lessened CA quenching. For DA-AA mixtures with DA at mM concentrations, AA quenched fluorescence throughout the nM and ?M range, with increased quenching in the nM range. These studies support ND fluorescence modulation as a possible sensor modality for bioanalyte detection.

Distribution Statement: 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: MRS Advances

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Publication Identifier: 10.1557/s43580-022-00336-w

Volume: 7

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Date Submitted: 3/1/23 12:00AM

Date Published: 9/1/22 4:00AM

Publication Location: WARRENDALE PA

Article Title: Clarification of phase stability and oxidation mechanism for TiZrHfTaX (X=?Ta, Cr) using thermodynamic calculation

Authors: Yuki Komiya, Daiki Haginiwa, Yasuo Kogo, Yutaro Arai

Keywords: OXIDATION NANODIAMOND NITROGEN QUANTUM THERMODYNAMIC

Abstract: Nanodiamond (ND) with nitrogen vacancy (NV?) color centers has emerged as an important material for quantum sensing and imaging. Fluorescent, carboxylated ND (140 nm) is investigated for the detection of dopamine (DA), caffeine (CA), and ascorbic acid (AA). Over a 200 nM range, DA and CA quenched the ND fluorescence by 7.1 and 9.8%, respectively. For AA, fluorescence was quenched (2.9%) at nM concentrations and enhanced at ?M concentrations. The quenching fit well to Langmuir adsorption isotherms. For DA-CA mixtures, the CA at nM concentrations did not affect DA quenching but interfered when at ?M concentrations. The DA at nM or ?M concentrations lessened CA quenching. For DA-AA mixtures with DA at mM concentrations, AA quenched fluorescence throughout the nM and ?M range, with increased quenching in the nM range. These studies support ND fluorescence modulation as a possible sensor modality for bioanalyte detection.

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Acknowledged Federal Support: Y

RPPR Final Report

as of 03-Mar-2023

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Volume: 7

Issue: 31

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Date Submitted: 3/1/23 12:00AM

Date Published: 8/1/22 8:00AM

Publication Location: WARRENDALE PA

Article Title: Material design for TiZrHfNbTaBx: A boundary material of refractory high-entropy alloys and ceramics

Authors: Yutaro Arai, Manami Saito, Yasuo Kogo

Keywords: HIGH-ENTROPY CERMAMICS, tIzRhFnBtAbX

Abstract: Nanodiamond (ND) with nitrogen vacancy (NV?) color centers has emerged as an important material for quantum sensing and imaging. Fluorescent, carboxylated ND (140 nm) is investigated for the detection of dopamine (DA), caffeine (CA), and ascorbic acid (AA). Over a 200 nM range, DA and CA quenched the ND fluorescence by 7.1 and 9.8%, respectively. For AA, fluorescence was quenched (2.9%) at nM concentrations and enhanced at ?M concentrations. The quenching fit well to Langmuir adsorption isotherms. For DA-CA mixtures, the CA at nM concentrations did not affect DA quenching but interfered when at ?M concentrations. The DA at nM or ?M concentrations lessened CA quenching. For DA-AA mixtures with DA at mM concentrations, AA quenched fluorescence throughout the nM and ?M range, with increased quenching in the nM range. These studies support ND fluorescence modulation as a possible sensor modality for bioanalyte detection.

Distribution Statement: 2-Distribution Limited to U.S. Government agencies only; report contains proprietary info
Acknowledged Federal Support: Y

Partners

I certify that the information in the report is complete and accurate:

Signature: Sandra Forrest

Signature Date: 3/1/23 3:41PM

2022 MRS Spring Meeting

EQ05: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices

Symposium Organizers

Aditya Mohite

Rice University
Chemical and Biomolecular Engineering
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Organic-inorganic halide perovskites (3D, 2D and 0D) have emerged as a novel semiconductor platform for understanding and discovering the rich structure and property relationship arising from the interaction of organic-inorganic interfaces and assemblies. They are formed with organic and inorganic two-dimensional layers, which self-assemble in solution to form highly ordered periodic stacks. Their properties appear to imbibe the best attributes from classical semiconductors, multi quantum wells (MQWs), 2D materials beyond graphene such as transition metal dichalcogenides and organic semiconductors, which has enabled a large compositional and structural phase space and resulted in the discovery of novel and emergent physical properties. In addition to applications for fabricating efficient and stable solar cells and light emitting diodes, and detectors, new properties and behaviors such as water-stability, light-induced structural dynamics, ferroelectricity, Rashba effect, polarized emission from chiral 2DPKs, single photon emitters, and optical modulators. However, despite these advances, there are serious scientific and engineering challenges, which if resolved may pave the path for optoelectronic and energy conversion technologies with state-of-the-art performance and technologically relevant durability.

Objectives

This symposium is dedicated to bringing together researchers across the globe from a wide range of disciplines including material science, chemistry, condensed matter physics, surface science, device engineering and reliability physics, light matter interactions and photonics to communicate important recent developments, which address key questions pertaining to the fundamental structure-property relationships and applications using novel experimental and theoretical approaches with special focus on: 1. Understanding and tailoring materials chemistry to obtain high purity thin-films 2. Design principles for the selection of spacer cations $\pm$ charge, shape, size and heteroatom 3. Advanced structural, and imaging of perovskites 4. Excitonics and photo-phononics 5. Spintronics and spin-orbitronics 6. Electron transport and device physics 7. Device engineering, interfaces, reliability science.

Topics will include:

- Controlled synthesis of halide perovskite from single crystals to thin-films
- Advanced chemical engineering of halide perovskites with tailored physical properties
- Photo-phononics and its correlation with structure and chemistry
- Exciton generation, recombination and transport
- Many-body effects, biexcitons, hot carriers, electron-phonon coupling, exciton-polaritons
- Tailoring defects, dopants, film morphology for efficient light emission
- Proximity induced interactions in halide perovskites and their heterostructures
- Halide perovskite based photonics, optics and lasers
- Spintronics and spin-orbitronics
- Device physics and electron transport
- Scalability, sustainability and reliability science of perovskite based devices and technologies

Invited Speakers:

- **Harry Atwater** (California Institute of Technology, USA)
- **Osman Bakr** (King Abdullah University of Science and Technology, Saudi Arabia)
- **Jean Christophe Blancon** (Rice University, USA)
- **Filippo De Angelis** (University of Perugia, Italy)
- **Letian Dou** (Purdue University, USA)
- **Jacky Even** (University of Rennes, France)
- **Guilia Grancini** (University of Pavia, Italy)
- **Laura Herz** (University of Oxford, United Kingdom)
- **Jinsong Huang** (University of North Carolina at Chapel Hill, USA)
- **Deep Jariwala** (University of Pennsylvania, USA)
- **Antoine Kahn** (Princeton University, USA)
- **Mercouri Kanatzidis** (Northwestern University, USA)
- **Hemamala Karunadasa** (Stanford University, USA)
- **Claudine Katan** (Université de Rennes 1, France)
- **Jong Hyun Kim** (Ajou University, Republic of Korea)
- **Bo Ram Lee** (Pukyong National University, Republic of Korea)
- **Tae-Woo Lee** (Seoul National University, Republic of Korea)

- **Kiang Ping Loh** (National University of Singapore, Singapore)
- **Maria Antonietta Loi** (University of Groningen, Netherlands)
- **Lynn Loo** (Princeton University, USA)
- **Biwu Ma** (Florida State University, USA)
- **Barry Rand** (Princeton University, USA)
- **Bayrammurad Saparov** (University of Oklahoma, USA)
- **Ted Sargent** (University of Toronto, Canada)
- **Ruth Shinar** (Iowa State University, USA)
- **Franky So** (North Carolina State University, USA)
- **Yana Vaynzof** (Technische Universität Dresden, Germany)
- **Michael Wong** (Rice University, USA)
- **Omer Yaffe** (Weizmann Institute of Science, Israel)
- **William W. Yu** (Louisiana State University, USA)
- **Ni Zhao** (The Chinese University of Hong Kong, Hong Kong)
- **Kai Zhu** (National Renewable Energy Laboratory, USA)

total abstract submissions: 236

Presented Abstracts - 124 (103 onsite/21 virtual)

Onsite attendance - average 33/peak 84 (versus 28/54 overall)

Virtual Attendance - 21 (versus overall average 14)

ARO Funds Spent: \$0

SYMPOSIUM EQ05

Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices

May 9 - May 25, 2022

Symposium Organizers

Do Young Kim, Oklahoma State University
Jovana Milic, University of Fribourg
Aditya Mohite, Rice University
Stephen Sai-Wing Tsang,

* Invited Paper

SESSION EQ05.01: Thin-Film Processing, Characterization, Properties I

Session Chairs: Do Young Kim and Barry Rand

Monday Morning, May 9, 2022

Hawai'i Convention Center, Level 3, 316A

10:30 AM EQ05.01.02

Monitoring the Transition from Molecular Surface Passivation to 2D Layer Formation on 3D Perovskite Films Tim Kodalle¹, Raphael Moral², Lucas Scalon², Rodrigo Szostak², Maged Abdelsamie³, Ana Nogueira² and Carolin M. Sutter-Fella¹; ¹Lawrence Berkeley National Laboratory (LBNL, LBL), United States; ²University of Campinas, Brazil; ³Lawrence Berkeley National Laboratory, United States

10:45 AM EQ05.01.03

Increasing the Reverse Bias Breakdown Potential of Perovskite Solar Cells with a Conformal SnOx Barrier Layer Isaac Gould^{1,2}, Samuel Johnson^{1,2}, Jay Patel^{1,2}, Axel Palmstrom² and Michael McGehee^{1,2}; ¹CU Boulder, United States; ²National Renewable Energy Laboratory, United States

11:00 AM EQ05.01.04

Relationship Between Annealing Temperature and the Presence of PbI₂ Platelets at the Surfaces of Triple-Halide Perovskite Films Dan R. Wargulski, Ke Xu, Hannes Hempel, Marion Flatken, Steve Albrecht and Daniel Abou-Ras; Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

11:15 AM *EQ05.01.05

Two-Dimensional Organic-Perovskite Hybrid Materials and Heterostructures Letian Dou; Purdue University, United States

SESSION EQ05.02: Thin-Film Processing, Characterization, Properties II

Session Chairs: Biwu Ma and Aditya Mohite

Monday Afternoon, May 9, 2022

Hawai'i Convention Center, Level 3, 316A

1:30 PM EQ05.02.01

Enhanced Visible Light Absorption in Layered Cs₃Bi₂Br₉ Through Mixed-Valence Sn(II) / Sn(IV) Doping Seán R. Kavanagh^{1,2,3}, Chantalle Krajewska⁴, Lina Zhang¹, Dominik Kubicki⁵, Krishanu Dey⁵, Krzysztof Galkowski⁵, Clare P. Grey⁵, Samuel D. Stranks⁵, Robert Palgrave¹, Aron Walsh² and David O. Scanlon¹; ¹University College London, United Kingdom; ²Imperial College London, United Kingdom; ³CDT-ACM, United Kingdom; ⁴Massachusetts Institute of Technology, United States; ⁵University of Cambridge, United Kingdom

1:45 PM EQ05.02.03

Fully Roll-to-Roll Fabricated Perovskite PV Modules with Printed Carbon Electrodes Doojin Vak and Luke Sutherland; CSIRO Manufacturing, Australia

2:00 PM *EQ05.02.04

Metal Halide Perovskite Interfaces—Role in Doping and Degradation Barry P. Rand; Princeton University, United States

2:30 PM BREAK

3:00 PM EQ05.02.05

Universal Current Losses in Perovskite Solar Cells Due to Mobile Ions Jarla Thiesbrummel¹, Vincent Le Corre¹, Francisco Peña-Camargo¹, Lorena Perdigón-Toro¹, Felix Lang¹, Fengjiu Yang², Max Grischek^{2,1}, Emilio Gutierrez-Partida¹, Jonathan Warby¹, Steve Albrecht², Dieter Neher¹ and Martin Stollerfoht¹; ¹University of Potsdam, Germany; ²Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

3:15 PM EQ05.02.06

Light-Activated Interlayer Contraction in 2D Perovskites for High-Efficiency Solar Cells Wenbin Li^{1,1}, Siraj Sidhik¹, Boubacar Traore², Reza Asadpour³, Jin Hou¹, Hao Zhang¹, Austin Fehr¹, Joseph Essman¹, Yafei Wang¹, Justin Hoffman⁴, Ioannis Spanopoulos⁴, Jared Crochet⁵, Esther Tsai⁶, Joseph Strzalka⁷, Claudine Katan², Muhammad Alam³, Mercouri Kanatzidis⁴, Jacky Even², Jean-Christophe Blancon¹ and Aditya D. Mohite^{1,1}; ¹Rice University, United States; ²Univ Rennes, INSA Rennes, France; ³Purdue University, United States; ⁴Northwestern University, United States; ⁵Los Alamos National Laboratory, United States; ⁶Brookhaven National Laboratory, United States; ⁷Argonne National Laboratory, United States

3:30 PM EQ05.02.07

Toward Scalable Fabrication of High-Quality Metal Halide Perovskite Films Through Confined-Volume Printing Adam Printz, Matthew Dailey, Yanan Li and Patrick Lohr; The University of Arizona, United States

3:45 PM EQ05.02.08

Post 10-Month MISSE 13 Space Flight Testing of Encapsulated MAPI Thin Film William G. Delmas¹, Samuel Erickson¹, Calista Lum¹, Jorge Arteaga¹, Kyle Crowley², Jennifer Williams³, Lyndsey McMillon-Brown², Timothy Peshek² and Sayantani Ghosh¹; ¹University of California, Merced, United States; ²John H. Glenn Research Center, The National Aeronautics and Space Administration, United States; ³Wilberforce University, United States

4:00 PM EQ05.02.09

Doping Organic Interlayers in Perovskite Solar Cells with Carbon Dioxide Jason A. Röhr, Jaemin Kong, Hang Wang, Juan Meng and André D. Taylor; New York University, United States

SESSION EQ05.03: Poster Session I: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices I

Session Chairs: Do Young Kim and Aditya Mohite

Monday Afternoon, May 9, 2022

5:00 PM - 7:00 PM

Hawai'i Convention Center, Level 1, Kamehameha Exhibit Hall 2 & 3

EQ05.03.01

Gas Sensing Properties at Room Temperature of Halide Perovskite Cs₂SnI₆ Thin Film Grown by Chemical Vapor Deposition Method Phung D. Hoat, Hyojun Lim, Sunwoo Jin, Sunghoon Bae, Vo V. Khoe, Intaek Lee, Joohan Kim, Joon-Hyung Lee, Sangwook Lee, Roy B. Chung, Ji Hoon Lee, Tae Hoon Lee and Young-woo Heo; School of Materials Science and Engineering, Kyungpook National University, Korea (the Republic of)

EQ05.03.02

Strategy for Highly Efficient Perovskite Solar Cell —The Ratio of Precursor with GBL:DMF:DMSO Mixing Solution Changmin Lee, Sye Hamad Ullah Shah, Dong Hyun Kim, Geonwoo Jeong, Dong Hyun Choi, Tae Wook Kim, Hyung Ju Chae, Hyun Woo Jo, Min Jae Park, Amjad Islam and Seung Yoon Ryu; Korea University, Korea (the Republic of)

EQ05.03.03

Compositional Engineering Triple-Cation Tin-Lead Iodides for Narrow-Band-Gap Perovskite Solar Cells Sung Woong Yang¹, Yeonghun Yun¹, Devthade Vidyasagar¹, Rajendra Kumar Gunasekaran¹, Jina Jung¹, Won Chang Choi¹, Ji Hoon Lee¹, Chang-Lyoul Lee² and Sangwook Lee¹; ¹Kyungpook National University, Korea (the Republic of); ²Gwangju Institute of Science and Technology, Korea (the Republic of)

EQ05.03.06

Visualizing Current Flow In Solar Cell Electrodes Greyson Christoforo and Henry Snaith; University of Oxford, United Kingdom

EQ05.03.07

Direct Observation of Photoinduced, Non-Equilibrium Phase Transition in CH₃NH₃PbI₃ via Time-Resolved X-Ray Diffraction Shobhana Panuganti, Mercouri Kanatzidis and Richard Schaller; Northwestern University, United States

EQ05.03.08

Energetics of π – Conjugated Surface Ligands on Metal Halide Perovskites and Their Influence on Interfacial Charge Transfer and Photovoltaic Performance Harindi R. Atapattu¹, Ke Ma², Sailajah Gukathasan¹, Samuel Awuah¹, Letian Dou² and Kenneth R. Graham¹; ¹University of Kentucky, United States; ²Perdue University, United States

EQ05.03.09

Ultra-Stable and Robust Response to X-Rays in 2D Layered Perovskite Micro-Crystalline Films Directly Deposited on Flexible Substrate Matteo Verdi^{1,2}, Ferdinand Lédée¹, Andrea Ciavatti^{1,2}, Laura Basiricò^{1,2} and Beatrice Fraboni^{1,2}; ¹University of Bologna, Italy; ²National Institute for Nuclear Physics-INFN, Italy

EQ05.03.11

Photoinduced Changes in Crystallinity in Two-Dimensional Layered Perovskites Shelby Cuthriell, Mercouri Kanatzidis and Richard Schaller; Northwestern University, United States

EQ05.03.12

Optimizing Substrate Chemistry and Perovskite Composition for Reproducible Manufacturing of Efficient and Stable Perovskite Solar Cells Annikki L. Santala, Rohit Prasanna, Max Hoerantner and Hyunjong Lee; Swift Solar Inc., United States

EQ05.03.13

Interfacial Strategies for Efficient and Stable Spray-Coated Perovskite Solar Cells in Open Air Mathilde Fievez, Austin Flick, Nicholas Rolston and Reinhold H. Dauskardt; Stanford University, United States

EQ05.03.14

Machine Learning for Automatic, Accelerated Semiconductor Characterization from Time-Resolved Photoluminescence (TPRL) via Iterated Bayesian Inference—Case of CH₃NH₃PbI₃→Clx Calvin Fai, Anthony Ladd and Charles J. Hages; University of Florida, United States

Final Program July 2022

SESSION EQ05.04: Thin-Film Processing, Characterization, Properties III

Session Chairs: Kenneth Graham and Adam Printz

Tuesday Morning, May 10, 2022

Hawai'i Convention Center, Level 3, 316A

8:30 AM EQ05.04.01

Ultra-Thin Transition Metal Dichalcogenide Photovoltaics for Space Applications [Peter Bermel](#); Purdue University, United States

8:45 AM EQ05.04.02

Pressure-Dependent Structural and Optical Properties of Dion-Jacobson and Ruddlesden-Popper Layered Hybrid Perovskites Loreta A. Muscarella¹, [Algirdas Duciukas](#)^{2,3}, Mathias Dankl², Michal Andrzejewski⁴, Nicola P. Casati⁴, Ursula Roethlisberger², Joachim Maier³, Michael Grätzel², Bruno Ehrler¹ and Jovana V. Milic^{5,2}; ¹AMOLF, Netherlands; ²École Polytechnique Fédérale de Lausanne, Switzerland; ³Max Planck Institute for Solid State Research, Switzerland; ⁴Paul Scherrer Institute, Switzerland; ⁵Adolph Merkle Institute, Switzerland

9:00 AM EQ05.04.03

Diverging Expressions of Anharmonicity in Halide Perovskites Adi Cohen¹, Thomas Brenner¹, Johan Klarbring², Rituraj Sharma¹, Douglas Fabini³, Roman Korobko¹, Pabitra K. Nayak⁴, Olle Hellman² and Omer Yaffe¹; ¹Weizmann Institute of Science, Israel; ²Linköping University, Sweden; ³Max Planck Institute for Solid State Research, Germany; ⁴Tata Institute of Fundamental Research, India

9:15 AM EQ05.04.04

From 2D to 3D—A Green Solvent System for Templated Sequential Deposition of Efficient and Stable Perovskite Solar Cells [Benjamin Gallant](#), Philippe Holzhey, Karim Elmostekawy, Laura Herz and Henry Snaith; University of Oxford, United Kingdom

9:30 AM BREAK

10:00 AM EQ05.04.05

2D Surface Engineering for Efficient and Stable Perovskite Solar Cells [Kai Zhu](#); National Renewable Energy Laboratory, United States

10:15 AM EQ05.04.06

Is Synthesis Complexity Responsible for Defect Formation in Wide Bandgap Halide Perovskites? Tianyi Huang¹, Shaun Tan¹, Finn Babbe² and [Carolyn M. Sutter-Fella](#)²; ¹University of California, Los Angeles, United States; ²Lawrence Berkeley National Laboratory, United States

10:30 AM *EQ05.04.07

Integrated Halide Perovskite Photoelectrodes for High-Efficiency and Durable Solar Water-Splitting Michael Wong and [Aditya D. Mohite](#); Rice University, United States

SESSION EQ05.05: Synthesis and Structural Characterization

Session Chairs: Aditya Mohite and Bayram Saparov

Tuesday Afternoon, May 10, 2022

Hawai'i Convention Center, Level 3, 316A

1:30 PM EQ05.05.01

Vertically Aligned Two-Dimensional Halide Perovskite as Artificial Synapses Toward Neuromorphic Computing [Seung Ju Kim](#) and Ho Won Jang; Seoul National University, Korea (the Republic of)

1:45 PM EQ05.05.02

A Selenophene-Containing Conjugated Organic Ligand for Two-Dimensional Halide Perovskite [Zitang Wei](#), Kang Wang and Letian Dou; Purdue University, United States

2:00 PM EQ05.05.03

Induced Chirality in Halide Perovskite Clusters Through Surface Chemistry [Aaron Forde](#)^{1,1}, Dibyajyoti Ghosh², Dmitri Kilin³, Amanda Evans¹, Sergei Tretyak¹ and Amanda Neukirch¹; ¹Los Alamos National Laboratory, United States; ²Indian Institute of Technology Delhi, India; ³North Dakota State University, United States

2:15 PM EQ05.05.04

Intermediate-Phase Engineering via Dimethylammonium as Excess Cation for Stable Perovskite Solar Cells [Philippe J. Holzhey](#)^{1,2}; ¹University of Oxford, United Kingdom; ²Adolphe-Merkel Institute, Switzerland

2:30 PM *EQ05.05.05

Molecular Dopants—Tools to Control the Electronic Structure of Metal Halide Perovskite Interfaces Fengyu Zhang, Hannah L. Smith and [Antoine Kahn](#); Princeton University, United States

3:00 PM BREAK

3:30 PM *EQ05.05.07

Alloying Metals in Halide Perovskites Kurt Lindquist¹, Michael Boles¹, Bridget Connor¹, Stephanie Mack^{2,3}, Jeffrey B. Neaton^{2,3} and [Hemamala Karunadasa](#)^{1,4}; ¹Stanford University, United States; ²Lawrence Berkeley National Laboratory, United States; ³University of California, Berkeley, United States; ⁴SLAC National Accelerator Laboratory, United States

4:00 PM EQ05.05.09

Defects Activity in Wide Bandgap Metal Halide Perovskite Semiconductors [Annamaria Petrozza](#); Istituto Italiano di Tecnologia, Italy

SESSION EQ05.06: Poster Session II: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices II

Session Chairs: Do Young Kim and Aditya Mohite

Tuesday Afternoon, May 10, 2022

5:00 PM - 7:00 PM

Hawai'i Convention Center, Level 1, Kamehameha Exhibit Hall 2 & 3

EQ05.06.01

Intact 2D/3D Halide Junction Perovskite Solar Cells via Solid-Phase In-Plane Growth (SIG) Yeoun-Woo Jang^{1,1}, Seungmin Lee², Jun Hong Noh^{2,2} and Mansoo Choi^{1,1}; ¹Seoul National University, Korea (the Republic of); ²Korea University, Korea (the Republic of)

EQ05.06.02

Probing the Stability and Degradation of 2D Perovskites Using *In Situ* Infrared Spectroscopy Robert Balow, Blake S. Simpkins and Daniel Ratchford; U.S. Naval Research Laboratory, United States

EQ05.06.03

Preparation of (CH₃NH₃)₃BiI₂ Thick Film via Mist Deposition Method for X-Ray Detection Mioko Kawakami, Yuki Haruta, Shinji Wada, Takumi Ikenoue, Masao Miyake and Tetsuji Hirato; Kyoto University, Japan

EQ05.06.04

Halide Segregation in Ruddlesden-Popper Perovskites Alessandro Caiazzo, Kunal Datta, Zehua Chen, Junyu Li, Geert Brocks, Shuxia Tao, Peter Bobbert, Martijn M. Wienk and René A. Janssen; TU Eindhoven, Netherlands

EQ05.06.05

Demonstrating Metal Halide Perovskite Reversible Glass Transition via *In Situ* X-Ray Scattering Damara G. Dayton¹, Julian Mars¹, Michael Toney¹, Akash Singh² and David B. Mitzi²; ¹University of Colorado Boulder, United States; ²Duke University, United States

EQ05.06.06

Universal Charge Transfer p-Doping Approach for Developing Intrinsic Properties of Perovskite Films Youjin Reo, Huihui Zhu, Ao Liu and Yong-Young Noh; Pohang University of Science and Technology, Korea (the Republic of)

EQ05.06.07

Illuminating Structure-Property Relationships of Methylammonium-Free Lead Halide Perovskites Through Advanced Characterization Studies of Halide- and Phase- Segregation Diana K. LaFollette¹, An Yu^{2,1} and Juan Pablo Correa Baena¹; ¹Georgia Institute of Technology, United States; ²Tianjin University, China

EQ05.06.08

Doped Lead Halide Perovskites for Ionizing Radiation Detection Ashley Conley, Katelyn Dagnall, Ephraïem Sarabamoun, Lucy U. Yoon, Matthew Alpert, Eric Holmgren, Seung-Hun Lee and Joshua J. Choi; University of Virginia, United States

EQ05.06.11

A Facile Surface Passivation for Thermally Stable Planar Perovskite Solar Cells by Using a Novel IDTT-Based Small Molecule Additive Hyuntae Choi and Taiho Park; Pohang University of Science and Technology, Korea (the Republic of)

EQ05.06.13

Highly Efficient Solar Cells Using Monodisperse Perovskite Quantum Dots Seyoung Lim and Taiho Park; Pohang University of Science and Technology, Korea (the Republic of)

EQ05.06.15

Strongly Anharmonic Octahedral Tilting in 2D Hybrid Halide Perovskites Matan Menahem¹, Zhenbang Dai², Sigalit Aharon¹, Rituraj Sharma¹, Maor Asher¹, Yael Diskin-Posner¹, Roman Korobko¹, Andrew M. Rappe² and Omer Yaffe¹; ¹Weizmann Institute of Science, Israel; ²University of Pennsylvania, United States

EQ05.06.17

CsPbBr₃ Thin Film Grown by Dual-Source Evaporation for PeLED Sung hoon Bae, Sunwoo Jin, Vo V. Khoe, Intaek Lee, Hyojun Lim, Joohan Kim, Sangwook Lee, Joon-Hyung Lee, Roy B. Chung, Tae Hoon Lee and Young-woo Heo; Kyungpook National University, Korea (the Republic of)

SESSION EQ05.07: Photo-Physics, Spin, Photonics I

Session Chairs: Deep Jariwala and Kai Zhu

Wednesday Morning, May 11, 2022

Hawai'i Convention Center, Level 3, 316A

8:30 AM EQ05.07.01

Study of Synthesis Parameters on the Formation and Physical Properties of 2D/3D Hybrid Halide Perovskite Heterostructures for Solar Cells Thomas Campos^{1,2}, Pia Dally^{2,3}, Muriel Bouttemy³, Gaelle Trippe-Allard¹, Aurelien Duchatelet^{4,2}, Jean Rousset^{4,2}, Damien Garrot^{5,1} and Emmanuelle Deleporte¹; ¹Light, Material and Interfaces Laboratory (LuMin), France; ²Institut Photovoltaïque d'Ile-de-France (IPVF), France; ³Institut Lavoisier de Versailles (ILV), France; ⁴EDF R&D, France; ⁵Groupe d'Etudes de la Matière Condensée (GEMaC), France

8:45 AM EQ05.07.02

Phase Segregation in Mixed-Halide Perovskites Impacts Charge-Carrier Dynamics While Preserving Mobility Silvia G. Motti, Jay Patel, Robert Oliver, Henry Snaith, Michael Johnston and Laura Herz; University of Oxford, United Kingdom

9:00 AM EQ05.07.04

Understanding and Suppressing Non-Radiative Losses in Methylammonium-Free Wide Bandgap Perovskite Solar Cells [Robert Oliver](#) and Henry Snaith; University of Oxford, United Kingdom

9:15 AM *EQ05.07.05

Intrinsic Nanostructure and Halide Segregation in Metal Halide Perovskites [Laura Herz](#); University of Oxford, United Kingdom

10:15 AM EQ05.07.06

Understanding the Photophysics of Layered Lead Halide Perovskites [Eelco K. Tekelenburg](#)¹, Simon Kahmann^{1,2}, Herman Duim¹, Machteld Kamminga^{1,3}, Graeme Blake¹ and Maria Antonietta Loi¹; ¹University of Groningen, Netherlands; ²University of Cambridge, United Kingdom; ³University of Copenhagen, Denmark

10:15 AM BREAK

10:30 AM EQ05.07.07

Strain Modified Carrier Dynamics in 2D Perovskites [Daniel Ratchford](#)¹, Vanessa M. Breslin¹, Tara J. Michael², Junghoon Yeom¹, Robert Balow¹, Blake S. Simpkins¹, Jeff Owrutsky¹ and Adam Dunkelberger¹; ¹Naval Research Laboratory, United States; ²NRC Postdoc Fellow, United States

10:45 AM *EQ05.07.08

Scalable, Template Driven Formation of Highly Crystalline Lead-Tin Halide Perovskite Films [Maria Antonietta Loi](#); University of Groningen, Netherlands

SESSION EQ05.08: Photo-Physics, Spin, Photonics II

Session Chairs: Letian Dou and Laura Herz

Wednesday Afternoon, May 11, 2022

Hawai'i Convention Center, Level 3, 316A

1:30 PM EQ05.08.01

Effect of Sub-Bandgap States in 2D Halide Perovskite Photodetector [Eunyoung Choi](#)¹, Yurou Zhang², Arman M. Soufiani¹, Richard F. Webster¹, Peter J. Reece¹, Jan Seidel¹, Jung-Ho Yun² and Jae Sung Yun^{1,3}; ¹University of New South Wales, Australia; ²University of Queensland, Australia; ³University of Surrey, United Kingdom

1:45 PM EQ05.08.02

Energy Cascade in Ruddlesden-Popper Lead Halide Perovskites—Exciton Delocalization and the Role of Organic Spacer [Sankaran Ramesh](#)^{1,2}, David Giovanni¹, Marcello Righetto¹, Jia Wei Melvin Lim^{1,2}, Qiannan Zhang¹, Yue Wang¹, Senyun Ye¹, Qiang Xu¹, Jian Qing^{3,4}, Xiao-Ke Liu⁴, Heyong Wang⁴, Zhongcheng Yuan⁴, Zhan Chen^{4,3}, Lintao Hou³, Feng Gao⁴, Nripan Mathews^{2,1} and Tze Chien Sum¹; ¹Nanyang Technological University, Singapore; ²Energy Research Institute@NTU, Singapore; ³Jinan University, China; ⁴Linköping University, Sweden

2:00 PM *EQ05.08.03

Atomic Imaging of Octahedral Tilting in Two-dimensional Ruddlesden-Popper Perovskites [Kian Ping Loh](#); National University of Singapore, Singapore

2:30 PM BREAK

3:00 PM EQ05.08.04

Perovskite Solar Cells with Enhanced Mechanical Reliability [Min Chen](#)^{1,2}, Nitin Padture² and Joseph Luther¹; ¹National Renewable Energy Laboratory, United States; ²Brown University, United States

3:15 PM EQ05.08.05

First-Principles Characterization of Surface Phonons of Halide Perovskite CsPbI₃ and Their Role in Stabilization [Ruoxi Yang](#) and Liang Z. Tan; Lawrence Berkeley National Laboratory, United States

3:30 PM EQ05.08.06

Investigating Excited State Coherence and Coupling in Engineered Spin-Cast Superlattices of 2D Halide Perovskites [Bogdan Dryzhakov](#) and Bin Hu; University of Tennessee Knoxville, United States

3:45 PM EQ05.08.07

Energy Transfer in Stability-Optimized Perovskite Nanocrystals [Andreas Singldinger](#), Michèle Greiner, Moritz Gramlich, Carola Lampe, Nina A. Henke and Alexander S. Urban; Ludwig-Maximilians-Universität München, Germany

4:00 PM EQ05.08.08

Chiral Induced Spin Selectivity in Halide Perovskites Enables Room Temperature Spin Light-Emitting Diodes [Young-Hoon Kim](#)^{1,2}; ¹Hanyang University, Korea (the Republic of); ²National Renewable Energy Laboratory, United States

4:15 PM EQ05.08.09

In Operando, Photovoltaic, Microscopic Evaluation of Recombination Centers in Halide Perovskite-Based Solar Cells [Arava Zohar](#)^{1,2}, Michael Kulbak², Silver Hamill Turren-Cruz³, Pabitra K. Nayak⁴, Adi Kama⁵, Anders Hagfeldt⁶, Henry Snaith⁷, Gary Hodes² and David Cahen²; ¹University of California, Santa Barbara, United States; ²Weizmann Inst, Israel; ³Jaume I University, Spain; ⁴Tata Institute of Fundamental Research, India; ⁵Bar-Ilan University, Israel; ⁶Ecole Polytechnique Fédérale de Lausanne, Switzerland; ⁷University of Oxford, United Kingdom

SESSION EQ05.09: Poster Session III: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices III

Session Chairs: Do Young Kim and Aditya Mohite

Wednesday Afternoon, May 11, 2022

5:00 PM - 7:00 PM

Hawai'i Convention Center, Level 1, Kamehameha Exhibit Hall 2 & 3

EQ05.09.01

Enhancing Moisture Stability of Alumina Passivated Inverted (p-i-n) Structure Perovskite Solar Cells Using SiO₂ Encapsulation Tamanna Mariam, Ramez H. Ahangharnejhad, Zhaoning Song, Prabodika N. Kaluarachchi, Manoj K. Jamarkattel, Shannon Costello, Manoj Rajakaruna, Suman Rijal, Zahrah Almutawah, Abdul Quader, Adam Phillips, Yanfa Yan, Randy Ellingson and Michael J. Heben; University of Toledo, United States

EQ05.09.02

Ultralow Dark Current in Near-Infrared Perovskite Photodiodes by Reducing Charge Injection and Interfacial Charge Generation Riccardo Ollearo¹, Junke Wang¹, Matthew J. Dyson¹, Christ H. Weijtens¹, Marco Fattori¹, Bas T. van Gorkom¹, Albert van Breemen¹, Stefan C. Meskers¹, Gerwin Gelinck^{2,1} and René A. Janssen^{1,3}; ¹Eindhoven University of Technology, Netherlands; ²TNO at Holst Centre, Netherlands; ³Dutch Institute for Fundamental Energy Research, Netherlands

EQ05.09.03

The A-Site Cation Effect on the Structural Dynamics of Lead-Bromide Perovskites Guy Reuveni, Yael Diskin-Posner and Omer Yaffe; Weizmann Institute of Science, Israel

EQ05.09.04

Molecular Engineering of Interfacial Materials to Afford Perovskite Solar Cells and Modules with Improved Efficiency and Stability Kasparas Rakstys; Kaunas University of Technology, Lithuania

EQ05.09.05

Time to Go Bifacial—A Commercialization Pathway for Perovskite Photovoltaics Zhaoning Song and Yanfa Yan; University of Toledo, United States

EQ05.09.06

Large-Scale Room Temperature One-Pot Synthesis of Perovskite Nanoplatelets for Blue Light-Emitting Diodes Ju-Hyun Yoo¹, Tae-Woo Lee² and Jin-Woo Park¹; ¹Yonsei University, Korea (the Republic of); ²Seoul National University, Korea (the Republic of)

EQ05.09.07

Room Temperature Superfluorescence Melike Biliroglu¹, Gamze Findik¹, Juliana Mendes¹, Dovletgeldi Seyitliyev¹, Lei Lei¹, Qi Dong¹, Yash Mehta¹, Vasily Temnov², Franky So¹ and Kenan Gundogdu¹; ¹North Carolina State University, United States; ²French National Centre for Scientific Research and Ecole Polytechnique, France

EQ05.09.09

Solution-Processed Li Doped NiO_x as a Hole Transport Layer for Pb-Sn Mixed Low Bandgap Perovskite Solar Cells You Jin Ahn¹, So Jeong Park¹, Sun Kyung Hwang¹, Ik Jae Park² and Jin Young Kim¹; ¹Seoul National University, Korea (the Republic of); ²Sookmyung Women's University, Korea (the Republic of)

EQ05.09.12

Space-Charge-Limited Electron and Hole Transport in Methyl Ammonium Lead Iodide Perovskites Mohammad Sajedi Alvar, Paul W. Blom and Gert-Jan Wetzel; Max Planck Institute for Polymer Research, Germany

EQ05.09.15

Investigation of the Interactions Between Photo-Generated Charge Carriers and Defects in Perovskite Solar Cells by Photoluminescence Spectroscopy Zhihua Xu; University of Minnesota-Duluth, United States

EQ05.09.16

Room-Temperature NO₂ Gas Sensor Based on Cs₂TeI₆ Thin Film Under Blue-Light Illumination Phung D. Hoat, Hyojun Lim, Sunwoo Jin, Sunghoon Bae, Vo V. Khoe, Intaek Lee, Joohan Kim, Joon-Hyung Lee, Sangwook Lee, Roy B. Chung, Ji Hoon Lee, Tae Hoon Lee and Young-woo Heo; School of Materials Science and Engineering, Kyungpook National University, Korea (the Republic of)

SESSION EQ05.10: Photo-Physics, Spin, Photonics III

Session Chairs: Gerd Bacher and Maria Antonietta Loi

Thursday Morning, May 12, 2022

Hawai'i Convention Center, Level 3, 316A

8:00 AM *EQ05.10.01

Room Temperature Macroscopic Quantum Phenomena in Hybrid Perovskites Kenan Gundogdu and Franky So; North Carolina State University, United States

8:30 AM EQ05.10.02

X-Ray Induced Modification of the Photophysical Properties of MAPbBr₃ Single Crystals Giovanni Armaroli¹, Laura Ferlauto^{1,2}, Ferdinand Lédée^{1,2}, Matilde Lini¹, Andrea Ciavatti¹, Alessandro Kovtun³, Francesco Borgatti⁴, Gabriele Calabrese⁵, Silvia Milita³, Beatrice Fraboni¹ and Daniela Cavalcoli¹; ¹Department of Physics and Astronomy, University of Bologna, Italy; ²Interdepartmental Center for Industrial Research of the University of Bologna, Italy; ³Institute of Organic Synthesis and Photoreactivity - (CNR-ISOF), Italy; ⁴Institute for Nanostructured Material Study (CNR – ISMN), Italy; ⁵Institute for Microelectronics and Microsystems (CNR – IMM), Italy

8:45 AM EQ05.10.03

Quantification of Efficiency Losses Due to Mobile Ions in Perovskite Solar Cells via Fast-Hysteresis Measurements Martin Stollerfoht, Vincent Le Corre, Jarla Thiesbrummel and Dieter Neher; University of Potsdam, Germany

9:00 AM EQ05.10.04

Optoelectronic Properties of Tin-Based Narrow-Bandgap Halide Perovskites Isabella Poli¹, Francesco Ambrosio^{1,2}, Antonella Treglia^{1,3}, Samuele Martani^{1,3}, Giulia Folpini¹, Filippo De Angelis^{2,4} and Annamaria Petrozza¹; ¹Istituto Italiano di Tecnologia, Italy; ²CNR di Scienze e Tecnologie Chimiche “Giulio Natta” (CNR- SCITEC), Italy; ³Politecnico di Milano, Italy; ⁴University of Perugia, Italy

9:15 AM *EQ05.10.05

Preparation of High-Efficiency Light Emitters Based on Copper and Silver Halides Bayram Saparov¹, Tielyr Creason¹ and Mao-Hua Du²; ¹University of Oklahoma, United States; ²Oak Ridge National Laboratory, United States

9:45 AM BREAK

10:15 AM EQ05.10.06

The Halogen Exchange Equilibrium in Halide Perovskites—Halide Diffusion, Spontaneous Electronic Doping, and Implications Towards Stability Julian A. Vigil, Nathan Wolf, Adam Slavney, Abraham Saldivar Valdes and Hemamala Karunadasa; Stanford University, United States

10:30 AM EQ05.10.07

Lattice Configuration and Crystal Orientation of Single CsPbBr₃ Nanoplatelets Probed by Optical Spectroscopy Gerd Bacher¹, Alexander Schmitz¹, L. Leander Schaberg¹, Frederico Montanerella² and Maksym Kovalenko²; ¹Univ Duisburg-Essen, Germany; ²ETH Zürich, Switzerland

SESSION EQ05.11: Devices, Stability Sustainability I
Session Chairs: Peter Bermel and Franziska Muckel
Thursday Afternoon, May 12, 2022
Hawai'i Convention Center, Level 3, 316A

1:30 PM *EQ05.11.01

Strong Light-Matter Coupling in Two-Dimensional Halide Perovskites Deep Jariwala; University of Pennsylvania, United States

2:00 PM EQ05.11.03

2D Perovskites for Wavelength-Selective Photodetectors Tamara Czerny and Franziska E. Muckel; University Duisburg-Essen, Germany

2:15 PM *EQ05.11.04

Understanding the Influence of Defects, Light and Ion Conduction in Metal Halide Perovskites for Stability Jinsong Huang; University of North Carolina-Chapel Hill, United States

2:45 PM BREAK

3:15 PM EQ05.11.05

Open-Circuit and Short-Circuit Loss Management in Inverted Wide-Gap Perovskite *pin* Solar Cells Pietro Caprioglio, Joel Smith, Robert Oliver, Akash Dasgupta and Henry Snaith; University of Oxford, United Kingdom

3:30 PM EQ05.11.06

Thermoelectric Performance of Two-Dimensional Halide Perovskites Featuring Conjugated Ligands Sheng-Ning P. Hsu, Bryan W. Boudouris and Letian Dou; Purdue University, United States

3:45 PM EQ05.11.07

Dynamic Structural Fluctuations and Strongly Anharmonic Phonons in Inorganic Halide Perovskites Xing He¹, Tyson Lanigan-Atkins¹, Matthew Krogstad², Chengjie Mao¹, Mayanak Gupta^{1,3}, Daniel Pajerowski⁴, Guangyong Xu⁵, Tao Hong⁴, Feng Ye⁴, Duck Young Chung², Mercuri Kanatzidis^{6,2}, Jinsong Huang⁷, Stephan Rosenkranz², Raymond Osborn² and Olivier Delaire¹; ¹Duke University, United States; ²Argonne National Laboratory, United States; ³Bhabha Atomic Research Center, India; ⁴Oak Ridge National Laboratory, United States; ⁵National Institute of Standards and Technology, United States; ⁶Northwestern University, United States; ⁷University of North Carolina at Chapel Hill, United States

4:00 PM EQ05.11.08

Long-Range Carrier Transport and Recombination in All-Back-Contact Perovskite Solar Cells Kevin J. Prince^{1,2}, Darius Kuciauskas¹, Mirzo Mirzokarimov¹, Matthew Sibila³, Marco Nardone³, Colin A. Wolden^{2,1} and Lance M. Wheeler¹; ¹National Renewable Energy Laboratory, United States; ²Colorado School of Mines, United States; ³Bowling Green State University, United States

SESSION EQ05.12: Devices, Stability, Sustainability II
Session Chairs: Kenan Gundogdu and Jinsong Huang
Friday Morning, May 13, 2022
Hawai'i Convention Center, Level 3, 316A

8:30 AM EQ05.12.03

Understanding Charge Transport in Lead-Tin Perovskite Field Effect Transistors with Superior Performance Krishanu Dey and Samuel D. Stranks; University of Cambridge, United Kingdom

8:45 AM *EQ05.12.04

Towards Spectrally Stable Blue Perovskite Light Emitting Diodes Biwu Ma; Florida State University, United States

9:15 AM EQ05.12.05

Controlled Ion Transport in Metal Halide Perovskites for Field-Effect Transistors Working at Room-Temperature Beomjin Jeong; Pusan National University, Korea (the Republic of)

9:30 AM BREAK

10:00 AM EQ05.12.06

Exploiting Perovskites Multidimensionality for High Performance Photodiodes Alessandro Caiazza¹, Riccardo Ollearo¹, Junyu Li¹, Albert van Breemen², Martijn M. Wienk¹, Gerwin Gelinck^{1,2} and René A. Janssen¹; ¹TU Eindhoven, Netherlands; ²TNO Holst Centre, Netherlands

10:15 AM EQ05.12.08

3D/2D Hybrid Perovskite Heterostructures for Thin-Film Field-Effect Transistors Amita Ummadisingu and Henning Sirringhaus; University of Cambridge, United Kingdom

10:30 AM EQ05.12.09

Highly Efficient Perovskite-CIS Monolithic Tandem Solar Cells Marco A. Ruiz Preciado^{1,1}, Ihteaz M. Hossain^{1,1}, Thomas Feeney^{1,1}, Ahmed Farag^{1,1}, Hang Hu^{1,1}, Saba Gharibzadeh^{1,1}, Fabrizio Gota^{1,1}, Roja Singh^{1,1}, Marcel Simor², Pieter J. Bolt² and Ulrich W. Paetzold^{1,1}; ¹Karlsruhe Institute of Technology, Germany; ²TNO, Netherlands

SESSION EQ05.13: Devices, Stability, Sustainability III

Session Chairs: Charles Hages and In Soo Kim

Friday Afternoon, May 13, 2022

Hawai'i Convention Center, Level 3, 316A

1:30 PM *EQ05.13.01

Suppression of Defects and Ion-Migration for Efficient Perovskite Emitters and Light-Emitting Diodes Tae-Woo Lee; Seoul National University, Korea (the Republic of)

2:00 PM EQ05.13.02

Self-Healing Polymer-Based Encapsulation for Lead-Sealed, Submersible, Stretchable and Scalable Modular Perovskite-Based Optoelectronics Jinhyun Kim¹, Duhwan Seong², Donghee Son² and In Soo Kim¹; ¹Korea Institute of Science and Technology, Korea (the Republic of); ²Sungkyunkwan University, Korea (the Republic of)

2:15 PM EQ05.13.03

High Sensitivity Flexible X-Ray Detectors Based on Printed Perovskite Inks Andrea Ciavatti^{1,2}, Roberto Sorrentino³, Laura Basiricò^{1,2}, Bianca Passarella³, Mario Caironi³, Annamaria Petrozza³, Beatrice Fraboni^{1,2} and Matteo Verdi⁴; ¹DIFA - University of Bologna, Italy; ²National Institute for Nuclear Physics, Italy; ³Istituto Italiano di Tecnologia, Italy; ⁴University of Bologna, Italy

2:30 PM EQ05.13.04

The Influence of Intrinsic Semiconductor Properties and Device Architecture on the Temperature Coefficients of Single Junction and Multi-Junction Perovskite Photovoltaics Jay Patel^{1,2}, Daniel A. Morales², Samuel Johnson², Artiom Magomedov², Joseph Luther¹ and Michael McGehee^{2,1}; ¹National Renewable Energy Laboratory, United States; ²University of Colorado, United States

2:45 PM BREAK

3:15 PM EQ05.13.05

Mighty Morphin' Power of Perovskites Lance M. Wheeler¹, Bryan Rosales¹, Kevin J. Prince^{1,2}, Colin A. Wolden^{2,1}, Laura Mundt³ and Laura T. Schelhas¹; ¹National Renewable Energy Laboratory, United States; ²Colorado School of Mines, United States; ³SLAC National Accelerator Laboratory, United States

3:30 PM EQ05.13.07

Highly Transparent, Scalable and Stable Perovskite Photovoltaics without Compromising Aesthetics Tianran Liu, Xiaoming Zhao, Ping Wang, Quinn C. Burlingame, Minjie Chen and Lynn Loo; Princeton University, United States

3:45 PM EQ05.13.08

Rapid Spray Plasma Processing for High-Throughput, Multi-Modal Curing of Perovskite Solar Modules Austin Flick, Nicholas Rolston, Mathilde Fievez and Reinhold H. Dauskardt; Stanford University, United States

SESSION EQ05.14: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices I

Session Chair: Jovana Milic

Wednesday Morning, May 25, 2022

EQ05-Virtual

8:00 AM *EQ05.12.02

Strategies for Efficient Inverted Architecture Devices Yana Vaynzof; Technical University Dresden, Germany

8:30 AM EQ05.14.03

Are Space Charges at Interfaces Between Halide Perovskites and Charge Carrier Transporting Layers Ionically or Electronically Induced? Mina Jung, Gee Yeong Kim, Alessandro Senocrate, Davide Moia and Joachim Maier; Max Planck Institute for Solid State Research, Germany

8:45 AM EQ05.14.04

Photo De-Mixing in Two-Dimensional Dion-Jacobson Mixed Halide Perovskites Ya-Ru Wang¹, Alessandro Senocrate¹, Marko Mladenović², Algirdas Ducinkas³, Gee Yeong Kim¹, Ursula Roethlisberger², Jovana V. Milic³, Davide Moia¹, Michael Grätzel³ and Joachim Maier¹; ¹Max Planck Institute for

Solid State Research, Germany; ²Ecole Polytechnique Fédérale de Lausanne, Switzerland; ³Ecole polytechnique Fédérale de Lausanne, Switzerland

9:00 AM EQ05.14.05

A-Site Cation Influence on the Conduction Band of Lead Bromide Perovskites and Its Connection to Slow Hot Carrier Cooling Gabriel J. Man¹, Chinnathambi Kamal², Aleksandr Kalinko³, Dibya Phuyal⁴, Joydev Acharya⁵, Soham Mukherjee¹, Pabitra K. Nayak³, Håkan Rensmo¹, Michael Odelius² and Sergei M. Botorin¹; ¹Uppsala University, Sweden; ²Stockholm University, Sweden; ³Photon Science DESY, Germany; ⁴KTH Royal Institute of Technology, Sweden; ⁵Tata Institute of Fundamental Research, India

9:15 AM EQ05.14.06

Luminescence Imaging of Perovskite Solar Cells Akash Dasgupta¹, Suhas Mahesh² and Henry Snaith¹; ¹University of Oxford, United Kingdom; ²University of Toronto, Canada

9:30 AM EQ05.14.07

Quasi-2D Hybrid Organic-Inorganic Perovskites: DFT Modeling Approach Omar A. Allam^{1,1}, Yoonseo Nah², Ilgeum Lee², Dong Ha Kim² and Seung Soon Jang¹; ¹Georgia Institute of Technology, United States; ²Ewha Womans University, Korea (the Republic of)

9:35 AM EQ05.14.08

Accessing Radiation-Matter Interactions in Perovskite Photovoltaics for Space Applications—*Readying the Launch* Ahmad R. Kirmani¹, Bibhudutta Rout², Ian R. Sellers³ and Joseph Luther¹; ¹National Renewable Energy Laboratory, United States; ²University of North Texas System, United States; ³The University of Oklahoma, United States

SESSION EQ05.15: Semiconductor Physics of Halide Perovskites—From Fundamentals to Devices II

Session Chair: Jovana Milic

Wednesday Morning, May 25, 2022

EQ05-Virtual

10:30 AM EQ05.15.01

Enhanced Self-Assembled Monolayer Surface Coverage by ALD NiO in p-i-n Perovskite Solar Cells Nga Phung¹, Marcel Verheijen¹, Anna Todinova¹, Kunal Datta¹, Michael Verhage¹, Amran Al-Ashouri², Hans Köbler², Antonio Abate², Steve Albrecht² and Mariadriana Creatore¹; ¹TU Eindhoven, Netherlands; ²Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

10:45 AM EQ05.15.02

On the Equilibrium Electrostatic Potential and Light-Induced Charge Redistribution in Halide Perovskite Structures Davide Regalado^{1,2,3}, Aleksandra Bojar^{1,2,3}, Sean Dunfield^{4,5}, Pilar Lopez-Varo¹, Mathieu Frégnaux^{1,6}, Vincent Dufoulon^{1,7}, Shan-Ting Zhang¹, José Alvarez^{1,2,3}, Joseph J. Berry⁴, Jean-Baptiste Puel^{1,8}, Philip Schulz^{1,7} and Jean-Paul Kleider^{1,2,3}; ¹Institut Photovoltaïque d'Ile-de-France, France; ²Université Paris-Saclay, CentraleSupélec, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, France; ³Sorbonne Université, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, France; ⁴National Renewable Energy Laboratory, United States; ⁵University of Colorado Boulder, United States; ⁶Institut Lavoisier de Versailles, Université de Versailles Saint-Quentin-en-Yvelines, Université Paris-Saclay, CNRS, UMR 8180, France; ⁷CNRS, École Polytechnique, IPVF, UMR 9006, France; ⁸EDF R&D, France

11:00 AM EQ05.15.03

Tailoring Interfacial Energetics to Minimize Voltage Losses in FASnI₃ Vesta Zhelyaskova, Jay Patel, Michael McGehee and Sean E. Shaheen; University of Colorado Boulder, United States

11:05 AM EQ05.15.04

An Accurate Description of Excitonic Absorption in GaAs and Tri-Halide Perovskites (MAPbX₃) by Combining the Sommerfeld Enhancement Factor and Bands Fluctuations Kevin Lizarraga and Andres Guerra; Pontifica Universidad Catolica del Peru, Peru

11:10 AM EQ05.15.05

Anomalous Charge Transport in Lead Halide Perovskite Field-Effect Transistors Youcheng Zhang^{1,2}, Amita Ummadisingu¹ and Henning Sirringhaus¹; ¹Cavendish Laboratory, Department of Physics, University of Cambridge, United Kingdom; ²University of Cambridge, United Kingdom

11:25 AM EQ05.15.06

Monolithic All-Perovskite Tandem Solar Cells with Minimal Optical and Energetic Losses Junke Wang¹, Kunal Datta¹, Dong Zhang^{2,1}, Valerio Zardetto², Willemijn H. Remmerswaal¹, Christ H. Weijtens¹, Martijn M. Wienk¹ and René A. Janssen^{1,3}; ¹Eindhoven University of Technology, Netherlands; ²TNO, Netherlands; ³Dutch Institute for Fundamental Energy Research, Netherlands

11:40 AM EQ05.15.07

Study of Energetic Distribution of Traps in Perovskite Solar Cell With Iron Pyrite as a Hole Transport Layer Punit Sharma; Indian Institute of Technology Delhi, India

11:45 AM EQ05.15.08

Quantitatively Assessing Hybrid Perovskite Degradation Using Spectroscopic Ellipsometry Alvaro Tejada Esteves^{1,2}, Sven Peters³, Amran Al-Ashouri¹, Silver Hamill Turren-Cruz¹, Steve Albrecht¹, Florian Ruske¹, Bernd Rech¹, Andres Guerra² and Lars Korte¹; ¹Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany; ²Pontificia Universidad Católica del Perú, Peru; ³SENTECH Instruments GmbH, Germany

11:50 AM EQ05.14.02

Exploring Carrier-Driven Exciton Formation in Upconverting Perovskite/Rubrene Bilayers Using Drift-Diffusion Simulations Calvin Fai¹, Karunanantharajah Prashanthan², Frederik Eistrup², Klaus Lips², Thomas Unold², Charles J. Hages¹ and Rowan MacQueen²; ¹University of Florida, United States; ²Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

SESSION EQ05.16: Semiconductor Physics of Halide Perovskites—From Fundamentals to
Devices III Session Chair: Stephen Sai-Wing Tsang
Wednesday Afternoon, May 25,
2022 EQ05-Virtual

9:00 PM *EQ05.16.01

Strategic Approaches for Achieving High-Power Perovskite Solar Cells Under Indoor Light Conditions—Defect Control by Interface Engineering

Jong Hyun Kim; Ajou University, Korea (the Republic of)

9:30 PM *EQ05.16.02

Ligand-Engineered Bandgap Stability in Mixed-Halide Perovskite LEDs Bo Ram R. Lee¹, Yasser Hassan², Jong Hyun Park³, Michael Crawford⁴, Aditya Sadhanala², Jeongjae Lee⁵, James Sadighian⁴, Edoardo Mosconi⁶, Ravichandran Shivanna⁷, Eros Radicchi⁶, Mingyu Jeong³, Changduk Yang³, Hyosung Choi⁸, Sung Heum Park¹, Myoung Hoon Song³, Filippo Angelis⁹, Cathy Wong⁴, Richard Friend⁷ and Henry Snaith²; ¹Pukyong National University, Korea (the Republic of); ²University of Oxford, United Kingdom; ³Ulsan National Institute of Science and Technology, Korea (the Republic of); ⁴Oregon State University, United States; ⁵Seoul National University, Korea (the Republic of); ⁶Istituto CNR di Scienze e Tecnologie Chimiche ‘Giulio Natta’ (CNR-SCITEC), Italy; ⁷University of Cambridge, United Kingdom; ⁸Hanyang University, Korea (the Republic of); ⁹University of Perugia, Italy

10:00 PM EQ05.16.03

Hole Selective Monolayers Directing to the Efficiency More Than 23% in Tin-Lead Mixed Perovskite Solar Cells Gaurav Kapil^{1,2}, Takeru Bessho², Qing Shen¹, Hiroshi Segawa² and Shuzi Hayase¹; ¹The University of Electro-communications, Japan; ²The University of Tokyo, Japan

10:15 PM EQ05.16.04

High Efficiency Tin-Lead Mixed Halides Perovskite Solar Cells via Additive Engineering with Enhanced Electronic Properties and Stability Shahrir Razey Sahamir, Muhammad Akmal Kamarudin, Qing Shen and Shuzi Hayase; The University of Electro-Communications, Japan

10:30 PM EQ05.16.05

Visualizing Defects in Charge Transport Layers of Halide Perovskite-Based Solar Cells by Fluorescence Quenching Microscopy Hannah Kwon¹, Jinhyun Kim¹, Hyejun Kim¹, Hyun Chul Kim¹, Seok Joon Kwon² and In Soo Kim¹; ¹Korea Institute of Science and Technology (KIST), Korea (the Republic of); ²Sungkyunkwan University (SKKU), Korea (the Republic of)

Final Report for MRS Block Grant funded by ARO

2022 MRS Spring Meeting, Symposium EQ09:

“Emerging Light Emitters for Photonics and Optoelectronics-Hybrid Perovskites and Other Low-Dimensional Emitters”

Lead Organizer:

Prof. Tae-Woo Lee, Ph.D

Seoul National University

Department of Materials Science and Engineering

Republic of Korea

Tel 82-10-2257-3677, twlees@snu.ac.kr, taewleeoffice@gmail.com

Our symposium, *“Emerging Light Emitters for Photonics and Optoelectronics-Hybrid Perovskites and Other Low-Dimensional Emitters”*, was carried out from May 9th to May 13th with ARO funding. The topic of our symposium is oriented to fundamental knowledge and understanding in chemistry, physics, engineering, and materials for photonics, electronics, and quantum sciences.

Light-emitting materials are key materials for displays, lighting, and other optoelectronic applications. New classes of emitters such as organic-inorganic hybrid perovskite emitters, inorganic quantum dots, carbon-based quantum dots, inorganic semiconductor nanocrystals, and other low-dimensional emitters are increasingly proposed for displays, lightings, lasers, and other optoelectronic applications including solar cells, quantum light sources, and infrared photodetectors. In recent years particularly, metal halide perovskite emitters are emerging as promising candidates for the next generation high color-purity, high efficiency, and low-cost emitters that are applicable to solution-processed displays.¹⁻³

Perovskites, quantum dots, and other light-emitting materials covered in this MRS meeting are applicable to various army technologies such as virtual reality (VR) and augmented reality (AR) displays, infrared photodetectors for night vision goggles, efficient solar cells for energy sources, and quantum light sources for secure communication systems. Especially, AR/VR technologies in which the emerging light emitters covered in this MRS meeting hold the key to the realization are becoming the key technologies in modern army training to win modern battle combats. Therefore, we believe that our symposium on emerging light emitters from MRS is deeply related to the ARO program, and as a result contribute to the reinforcement of U.S. army combat capabilities.

Discussions in the proposed symposium covered the synthesis, characterization, physics, and device engineering comprising emerging light-emitting materials. Our symposium was conducted in connection with the ARO program, oriented to fundamental knowledge and the understanding of the chemistry, physics, engineering, and materials for photonics, electronics, and quantum sciences. In order to effectively conduct related discussions, our symposium consisted of 13 sub-sessions.

Detailed On-site program is described below.

EQ09. 01. Low-Dimensional Perovskite Light-Emitting Materials and Optoelectronics I

EQ09. 02. Low-Dimensional Perovskite Light-Emitting Materials and Optoelectronics II

EQ09. 03. Photophysics of Low-Dimensional Perovskite Materials

EQ09. 04. EQ08/EQ09 Joint Keynote Session

EQ09. 05. Quantum Dot Emitting Materials and Lasers

EQ09. 06. Perovskite Lasers

EQ09. 07. Poster Session

EQ09. 08. Surface Passivation and Molecular Additives in Perovskite Light-Emitting Devices I

EQ09. 09. Surface Passivation and Molecular Additives in Perovskite Light-Emitting Devices II

EQ09. 10. Perovskite Photovoltaics and Other Applications
 EQ09. 11. Physics of Perovskite Materials
 EQ09. 12. Quantum Dots and Emerging Emitting Materials and Devices I
 EQ09. 13. Quantum Dots and Emerging Emitting Materials and Devices II

A total of 13 sub-sessions were conducted for 5 days at Honolulu Hawaii in person. In order to have a broader discussion and extend the application of emerging light emitters, EQ09. 03 Keynote session was held as a joint session with “EQ08, *Quantum Dot Optoelectronics and Low-Dimensional Semiconductor Electronics*”. 16 outstanding invited speakers, 46 oral presentation speakers and 13 poster presentation speakers participated in our symposium. Among these participants, we selected the two best oral presentations and three best poster presentations to encourage research by students and scientists in related fields and to nurture young scientists. The best presentation was each awarded with a prize of \$100.

Also, in this session, we had dinner among the symposium speakers to promote relationships between related researchers and to discuss related fields. 13 of the outstanding speakers including our symposium organizers participated to discuss perovskite and other next generation light emitters. A total of \$1254.35 was used for the dinner budget.

We also organized virtual sessions from May 23rd to May 25th, considering the pandemic situation. 11 outstanding invited speakers, 7 oral speakers, and 1 poster presentation speaker participated in the virtual program.

Detailed Virtual program is described below.

EQ09.14: Perovskite Light-Emitting Diodes and Lasing
 EQ09.15: Low-Dimensional Perovskite Light-Emitting Materials and Devices
 EQ09.16: Perovskite and Low-Dimensional Light-Emitting Materials and Devices I
 EQ09.17: Perovskite and Low-Dimensional Light-Emitting Materials and Devices II

Detailed budget used in our symposium is as shown below.

	Price	Number	Total
Best oral/poster presentation travel grant	\$100-\$106.38	5	\$506.38
Invited speaker travel expense	\$150-\$200	11	\$1720
Total	-	-	\$2226.38

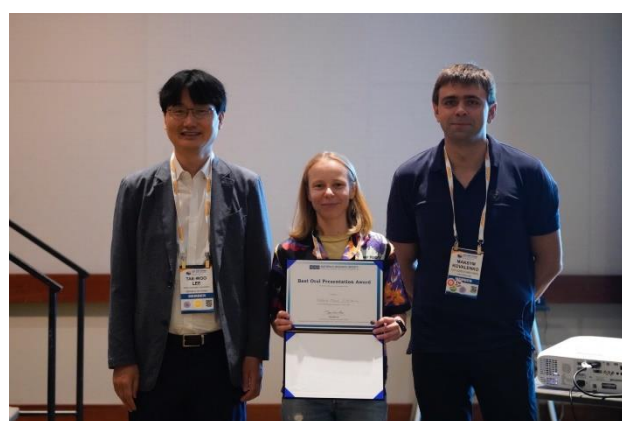
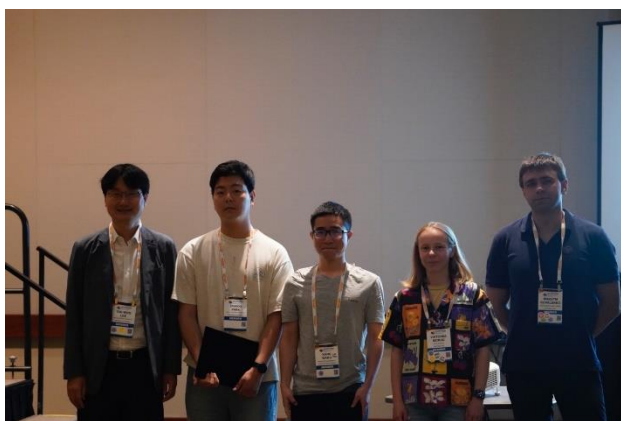
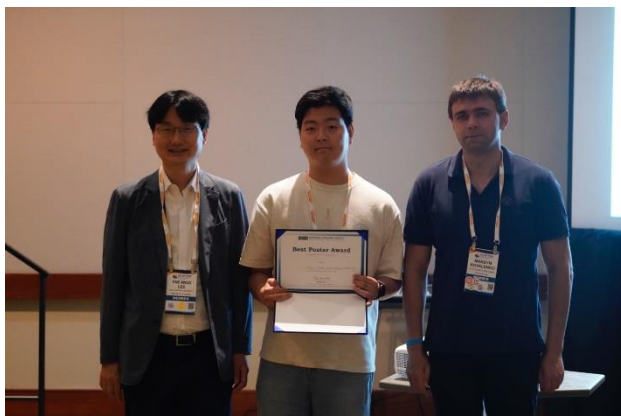
Reference:

1. H. Cho, T.-W. Lee et al., *Science*, 350, 1222–1225, 2015.
2. Y.-H. Kim, T.-W. Lee et al., *Nature Photonics*, 15, 148–155, 2021.
3. S.-J. Woo, J.S. Kim, T.-W. Lee, *Nature Photonics*, 15, 630-634, 2021

<2022 MRS Spring Symposium EQ09>



<2022 MRS Spring Oral & Poster Award>



1. Best Oral Presentation Award

- (1) Viktoriia Morad, ETH Zurich, Switzerland
- (2) Kang Wang, Purdue University, United States

2. Best Poster Award

- (1) Junho Kim, KAIST, The Republic of Korea
- (2) Seongmin Park, Sungkyunkwan University, The Republic of Korea
- (3) Jinwoo Park, Seoul National University, The Republic of Korea

<2022 MRS Spring dinner at 22.05.10>



Participant List

1. Tae-Woo Lee
2. Maksym Kovalenko
3. Aditya Mohite
4. Song Jin
5. Maria Antonietta Loi
6. Zhu Xiaoyang
7. Victor Klimov
8. Barry Rand
9. Song Myoung Hoon
10. Letian Dou
11. Yan Yanfa
12. Matthew Beard
13. Bin Hu
14. Giulia Pacchioni

FINAL REPORT TO ARMY RESEARCH OFFICE

NM05 Symposium Title: Advances in Nanodiamonds for Sensing, Biomedical and Other Novel Applications

Organizers:

Shery Chang, University of New South Wales, Australia

Olga Shenderova, Adamas Nanotechnologies, Inc. USA

Edward Chow, National University of Singapore, Singapore

Jean-Charles Arnault, CEA, France

Objectives

This symposium provides a forum for the presentation of recent advances of nanodiamonds in quantum sensing, diagnostic and biomedical applications as well as addressing fabrication and characterisation advances needed for the new applications. The fast developing quantum sensing and communication, as well as developing nanodiamonds as new diagnostic and therapeutic materials, gather leading scientists, industry, young researchers and students from the USA and across the world to this symposium. The symposium presentations cover topics from fabrication, applications, clinical trial progress of nanodiamonds. Continuing the tradition of the nanodiamond symposium since it was first established in 2012, the symposium in 2022 again successfully bridges the scientists in industry and academia across all aspect of nanodiamond together, creating new collaborations that are critically needed to further developing fluorescent nanodiamond for the increasingly important sensing applications.

Presentations

This symposium features 3 day in-person as well as one day virtual presentations. It hosted 15 invited speakers from 8 countries (Asia, USA, central/south America, Europe and Australia), 3 industry presentations, 37 contributed oral presentations and 3 poster presentations. The presentations were grouped into 6 topic areas of (1) Synthesis and functionalization; (2) Biosensing for disease detection; (3) Nanoscale sensing; (4) Characterisation: structure and properties; (5) Medical applications and (6) Fluorescent nanodiamond fabrication. The design of the topic areas and the schedules woven the researchers in fabrication and application on the same day so that the researchers can mingle and promote deeper collaborations.

Highlight

- **Nanoscale quantum sensing in biology, diagnostics and chemical radicles**

We are seeing remarkable progress in the application of fluorescent nanodiamonds as nanoscale sensors, particularly in biology and diagnostic fields. Prof. Rachel McKendry (substituted by her postdoc) highlighted her research in the highest sensitivity reported in detecting virus on flow-chip using the spin properties of fluorescent nanodiamond. Prof Oliver Williams presented his new research in using the positive charged nanodiamond for effective virus filtering. This has a tremendous potential in medical filtering applications including dialysis, blood filtering that requires biocompatible, safe, small and effective nanomaterials.

- **Therapeutic and drug delivery applications**

The fast growing interest in nanodiamonds has been largely driven by applications in nanotherapies (antibacterial agents, implantation coating, bone implant, etc), drug delivery (cancer treatment, vaccination, stem cell therapy, etc) and medical imaging. Recent years

have seen nanodiamonds transition from preclinical development to clinical trials. The large breadth of research has demonstrated that nanodiamonds are non-toxic, biocompatible nanomaterials that can be used as a multi-modal platform for diagnostics and delivery of both traditional and emerging therapeutic molecules. The industry presentation by Dr. Nishikawa from Daicel, Inc, Japan, showed their latest research in using nanodiamond for boron neutron capture therapy (BNCT) that is the state-of-the-art in the delivery of tumor cell selective radiotherapy. Contributed presentations from young researchers and students also demonstrate the vibrant research activities in using nanodiamond for gene therapy delivery (Jingru Xu, the best student oral presentation from National University of Singapore), as smart dressing materials for wound healing (Khalid Asma from Royal Melbourne Institute of Technology, Australia), and as dental implant coating.

- **Industry advancement in multi-modal, ultrasmall fluorescent nanodiamond fabrications**

Three industry researchers presented their latest development in multi-color fluorescent nanodiamond fabrications and applications. Daicel, Inc demonstrated their latest ~5nm nanodiamond with SiV centers. Adamas Nanotechnologies, Inc showed their continued improvement in scale up multi-color HPHT nanodiamond. Megadiamond, the company in diamond production branching into the fabrication for the first time, showed their exciting new development in blue color HPHT nanodiamond.

Contribution to the disciplines

The NM05 nanodiamond symposium at the MRS Spring Meeting is a biennial symposium established in 2012. It is the only dedicated nanodiamond meeting in the USA, gathering leading scientists, industry, young researchers and students from the USA and across the world. The symposium presents a unique and important forum for the fabrication and applications of nanodiamonds. The distribution of the topic areas promotes deep and broader collaborations between scientists in different application disciplines, for example, in medical field, to have deeper engagement with chemists and material scientists and industry that fabricate and synthesize nanodiamond. We, the organizers, believe that our symposium is the best forum that not only showcase the cutting edge research in nanodiamond applications in quantum/biosensing, but also presenting fundamental research in nanodiamond synthesis, structure and properties.

Future Directions

This symposium has shown a huge advancement of nanodiamond as unique, sensitive and nanoscale sensors. As the community continue to explore the applications of nanodiamond sensors, the opportunity to expand this symposium will grow. Since the establishment of nanodiamond symposium in 2012, we are constantly seeing the growth of the community, particularly the rapid expansion in the biosensing and diagnostics areas. Therefore the value of this symposium is not only in providing a biannual forum of the nanodiamond research, but also and more importantly in the introduction of new cutting-edge applications that demonstrate how advancement in nanodiamond can address new challenges that cannot be solved using other material systems.

How the ARO fund is used

The symposium organizers used the ARO grant (\$2226) to pay partial registrations to three Best Young Researchers, three Best Student Oral Presentations and one Best Student Poster Presentation.

Best Young Researchers: \$350 travel reimbursement

1. Ben Miller (UK) Nanodiamond diagnostics: improving sensitivity by spin manipulation.
2. Bethany Hudak (USA) Locating NV centers in nanodiamond using simultaneous STEM-EELS/EDS
3. Jack Hart (UK) Nanoscale sensing of temperature and viscosity inside single cells

Best Student Oral Presentations: \$320 travel reimbursement

1. Jingru Xu (Singapore) Enhanced penetrative siRNA delivery by nanodiamond drug delivery platform against hepatocellular carcinoma 3D models
2. Nicholas Nunn (USA) Impact of ultra-long high temperature annealing on color centers and color center spin properties of particulate diamonds
3. Erin Grant (Australia) In-solution quantum sensing using nanodiamond ensembles

Best Student Poster Presentations: \$216 travel reimbursement

1. Liqiu Yang (USA) Atomistic and electronic structures of MoO_x on hydrogenated diamond

Acknowledgement

The organizers wish to thank the support of the Army Research Office (ARO) that is critical for the success of the nanodiamond symposium in 2022. This is particularly important for us this time as our long term industry partners were not able to support us due to their financial difficulties from the pandemic. We would also wish to thank the MRS staff for their help in the ARO block grant applications.

Program

https://www.mrs.org/meetings-events/spring-meetings-exhibits/past-spring-meetings/2022-mrs-spring-meeting/symposium-sessions/symposium-sessions-detail/2022_mrs_spring_meeting/nm05

Report to Army Research Office (ARO)

2022 MRS Spring Meeting & Exhibit

Symposium QT09 – Light-Matter Strong Coupling in the Infrared and THz – Materials, Methods and New Phenomena

Organizers: Joshua Caldwell, Vanderbilt University; Lauren Buchanan, Vanderbilt University; Hatice Altug, EPFL; Thomas Folland, University of Iowa

Summary:

Symposium QT09 was held in person on Thursday afternoon and all-day Friday (May 12th and 13th) along with one virtual session the following week. This provided an forum bringing together researchers across the globe including 10 invited speakers from Asia, Australia, North and South America and Europe to discuss their work investigating strong coupling phenomena and how this influences chemical reactivity, optical nonlinearities among other effects. This symposium featured 16 live presentations and 5 virtual, along with 2 poster presentations.

Objectives:

This symposium addresses the reinvigorated topic of strong coupling between light and matter in the infrared and THz spectral ranges (frequency range 1-300 THz), including the emergence of novel quantum interactions. In the strong coupling regime, two or more modes coherently interact and exchange energy at a rate much faster than the energy decay in either material. Under these conditions, the modes take on a hybrid character with properties and information shared between the constituent components. Thus, strong coupling can enable one system to adopt the beneficial properties of another. As such, strong coupling promises advances in quantum optics, control of chemical and biological reaction pathways, and, tailoring of emission properties of infrared emitters.

Strong coupling has been demonstrated in a wide range of materials (including two-dimensional materials, metamaterials, and biological and molecular systems). At its heart, strong coupling relies heavily upon the material properties that can couple to light, and thus investigations of strong coupling require the development of a concerted materials-centric understanding of light-matter interactions. Currently, however, strong coupling phenomena are viewed as interesting phenomenon observed within a variety of research fields, limiting cross-pollination of ideas and concepts between different research communities. It is the intent of this symposium to bring together leaders in strong coupling research across research disciplines. We hope a unified approach will allow us to advance our fundamental understanding of the transition from weak to ultra-strong coupling and from classical to quantum behavior, among other topics.

Research highlights:

The symposium presentations were divided into the following topic areas:

- 1) Vibrational Strong Coupling, featuring both experimental and computational studies of strong coupling phenomena between IR-active molecular vibrations and light. Prof. Herrera discussed quantum mechanical descriptions of such vibrational polaritons, while Dr. Blake Simpkins

discussed ground breaking results seemingly demonstrating the first realization of modified chemical reactivity from vibrational polariton formation. Prof. Joel Yuen-Zhou discussed theoretical efforts towards observing vibrational polariton condensation, illustrating the strong potential for such an approach. Additional talks in infrared nanophotonics via hyperbolic polariton formation in hexagonal boron nitride were also discussed by Prof. Siyuan Dai, along with a discussion of advances in nano-optic probe techniques by Dr. Artem Danilov.

- 2) Electronic Strong Coupling featured talks focusing on strong coupling between light and electronic particles, excitons or metasurfaces. These results highlighted the potential of such structures for next generation optical emitters and nonlinear optical structures. Specifically, Prof. Vinod Menon described a series of exciton polariton dynamics within a variety of transition metal dichalcogenides, while Dr. Biswajit Datta described nonlinear optical phenomena resulting from interlayer interactions between such two-dimensional materials. Prof. Claudia Climent described theoretical to describe the dynamics of singlet fission into triplet states through control of strong light-matter interactions.
- 3) Strong Coupling and Nanoscale Cavities offered a session highlighting the role of nanoscale cavities in inducing strong coupling phenomena. This featured two invited talks, one which was scheduled to be given by Prof. Sang-Hyun Oh was instead given by Mr. Mingze He, a collaborator on that work. This talk featured the realization of ultrastrong coupling between vibrational modes of dielectrics and proteins within coaxial nanocavities featuring coax gaps as small as 2-nm wide, yet could be made in arrays at wafer scale. Prof. Simone De Liberato highlighted numerical methods describing how ultrastrong coupling can be employed to engineer electronic wavefunctions through nanostructure designs.

Contributions to the Discipline:

This symposium (QT09) brought scientists from multiple disciplines including chemists, material scientists, physicists, electrical and mechanical engineers together to share results and develop new collaborations for employing strong coupling in the control of chemical reactions, light emission and detection and on-chip photonics. This symposium featured multiple students and postdocs, who were given direct access to leading researchers in theory, fabrication and experiments, while also giving them a platform to discuss their recent results. Through a symposium lunch and happy hour, along with multiple impromptu get togethers during the conference, multiple collaborations were instigated and new experiments were conceived. The organizers strongly believe that these collaborative efforts resulting from this symposium will identify new directions in strong coupling research, enable new advances that otherwise might not have been considered or would have been significantly delayed.

Symposium QT09 organizers used the ARO grant (\$2226) to pay registration fees for two invited speakers (one postdoc and one student) and one co-organizer who is a young faculty member (\$825 + \$175 + \$900 = \$1900). Partial reimbursement for another pre-tenure co-organizer (\$166) and one international foreign speaker (\$160) were also provided, with the remainder of the support for these two coming from other symposium funding.

Supported Invited Speakers (or Co-Organizers)

Prof. Thomas Folland, University of Iowa, co-organizer

Prof. Lauren Buchanan, Vanderbilt University, co-organizer

Dr. Claudia Climent, University of Pennsylvania, invited speaker

Mr. Mingze He, Vanderbilt University, invited speaker

Prof. Simone De Liberato, University of Southampton, invited speaker

Future Directions:

The role of that light matter interactions can play in driving and controlling physical phenomena has long been a key focus of symposia within the Materials Research Society meetings. Extending such interactions from plasmonic behaviors towards effects where novel excitations coupled to light through strong coupling offer new functionality and new behaviors was at the heart of this symposium. Looking forward, identifying if and to what degree chemistry can be controlled through strong coupling, how such effects can be used for enhanced chemical sensing and identification, while also advances in novel optical devices such as emitters and metasurface optics will be key foci for this symposium going forward in addition to the topics covered in the subject symposia. Further conference symposia of this theme will serve to accelerate our efforts.

Program:

https://www.mrs.org/meetings-events/spring-meetings-exhibits/past-spring-meetings/2022-mrs-spring-meeting/symposium-sessions/symposium-sessions-detail/2022_mrs_spring_meeting/qt09

Acknowledgements:

The organizers gratefully appreciate the support from the US Army Research Office (ARO), which was critical to the success of this symposium. We also want to thank MRS staff for supporting the application of this ARO grant, and ensured that ARO, along with all of our symposium sponsors were thanked at the start and finish of all sessions.

Session Information

SESSION TITLE: QT09.01: Poster Session: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

SESSION TYPE: Poster

SESSION DAY & DATE: Wed 5/11/2022 5:00 PM

SESSION DURATION: 120

SESSION LOCATION: Hawai'i Convention Center, Level 1, Kamehameha Exhibit Hall 2 & 3

SESSION HOST: Session Chair: Hatice Altug
Session Chair: Lauren Buchanan

SESSION TOPIC: QT09: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

Control ID	Final ID	Title	Presenting Author	PRESENTER (COUNTRY ONLY)	Start/end time	SESSION ABSTRACT DURATION	Presentation Type
<u>3672209</u>	QT09.01.01	Vibrational Strong Coupling in Nanoscale Hyperbolic Phonon Polariton Cavities	Shmidt, Alisa	United States	5:00 PM 7:00 PM	0	Poster Presentation Preferred
<u>3708329</u>	QT09.01.02	Exploring the Effects of Vibrational Strong Coupling on Supramolecular Chemistry—Perylene Crystallization in a Fabry-Perrot Cavity	Modesti, Federico	Germany	5:00 PM 7:00 PM	0	Poster Presentation Preferred

Session Information

SESSION TITLE: QT09.02: Vibrational Strong Coupling
 SESSION TYPE: Oral
 SESSION DAY & DATE: Thu 5/12/2022 1:30 PM
 SESSION DURATION: 195
 SESSION LOCATION: Hawai'i Convention Center, Level 3, 305A
 SESSION HOST: Session Chair: Joshua Caldwell
 Session Chair: Lauren Buchanan
 SESSION TOPIC: QT09: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

Control ID	Final ID	Title	Presenting Author	PRESENTER (COUNTRY ONLY)	Start/end time	SESSION ABSTRACT DURATION	Presentation Type
<u>3705534</u>	QT09.02.01	Semi-Empirical Quantum Optics for Mid-Infrared Molecular Nanophotonics	Herrera, Felipe	Chile	1:30 PM 2:00 PM	30	Invited Speaker
<u>3669243</u>	QT09.02.02	Vibrational Strong Coupling in Direct Laser Printed Plasmonic MIM Nanopatch Antennas	Proscia, Nicholas	United States	2:00 PM 2:15 PM	15	Oral Presentation Preferred
<u>3673878</u>	QT09.02.03	The Investigation of Polariton Reflection Phase in Hexagonal Boron Nitride	Dai, Siyuan	United States	2:15 PM 2:30 PM	15	Oral Presentation Preferred
		BREAK			2:30 PM 3:00 PM	30	
<u>3667522</u>	QT09.02.05	Molecular Polaritons—Modulation, Impact on Chemistry and Modeling Their Density of States	Simpkins, Blake	United States	3:00 PM 3:30 PM	30	Invited Speaker
<u>3648069</u>	QT09.02.06	Cavity-Modified Unimolecular Dissociation Reactions via Intramolecular Vibrational Energy Redistribution	Wang, Derek	United States	3:30 PM 3:45 PM	15	Oral Presentation Preferred
<u>3711062</u>	QT09.02.07	s-SNOM Imaging and Spectroscopy for Nanoscale Characterisation of Light-Matter Strong Coupling in the Infrared	Danilov, Artem	Germany	3:45 PM 4:00 PM	15	Oral Presentation Preferred
<u>3758446</u>	QT09.02.08	Vibrational Polaritonics: Nonlinear Optics and Prospects of Condensation	Yuen-Zhou, Joel	United States	4:00 PM 4:30 PM	30	Invited Speaker
<u>3677018</u>	QT09.02.09	Spectroscopy and Imaging of Strongly-Coupled Plasmon-Phonon Modes Using EELS	Lagos, Maureen Joel	Canada	4:30 PM 4:45 PM	15	Oral Presentation Preferred

Session Information

SESSION TITLE: QT09.03: Electronic Strong Coupling
 SESSION TYPE: Oral
 SESSION DAY & DATE: Fri 5/13/2022 8:30 AM
 SESSION DURATION: 135
 SESSION LOCATION: Hawai'i Convention Center, Level 3, 305A
 SESSION HOST: Session Chair: Joshua Caldwell
 Session Chair: Lauren Buchanan
 SESSION TOPIC: QT09: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

Control ID	Final ID	Title	Presenting Author	PRESENTER (COUNTRY ONLY)	Start/end time	SESSION ABSTRACT DURATION	Presentation Type
<u>3680751</u>	QT09.03.01	Highly Non-Linear Interlayer Exciton-Polaritons in Bilayer MoS ₂	Datta, Biswajit	United States	8:30 AM 8:45 AM	15	Oral Presentation Preferred
<u>3659008</u>	QT09.03.02	Cooperativity and Ultrastrong Coupling in Terahertz Metasurfaces	Chase, Zizwe	United States	8:45 AM 9:00 AM	15	Oral Presentation Preferred
<u>3675085</u>	QT09.03.03	Singlet Fission Dynamics Under Strong Light-Matter Coupling	Climent, Clàudia	United States	9:00 AM 9:30 AM	30	Invited Speaker
		BREAK			9:30 AM 10:00 AM	30	
<u>3670836</u>	QT09.03.04	Nonequilibrium Spin-Orbital Dynamics in Mott Insulator YTiO ₃	Curtis, Jonathan	United States	10:00 AM 10:15 AM	15	Oral Presentation Preferred
<u>3673314</u>	QT09.03.05	Exciton-Polaritons in 2D Semiconductors	Menon, Vinod	United States	10:15 AM 10:45 AM	30	Invited Speaker

Session Information

SESSION TITLE: QT09.04: Strong Coupling and Nanoscale Cavities

SESSION TYPE: Oral

SESSION DAY & DATE: Fri 5/13/2022 1:30 PM

SESSION DURATION: 75

SESSION LOCATION: Hawai'i Convention Center, Level 3, 305A

SESSION HOST: Session Chair: Joshua Caldwell
Session Chair: Lauren Buchanan

SESSION TOPIC: QT09: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

Control ID	Final ID	Title	Presenting Author	PRESENTER (COUNTRY ONLY)	Start/end time	SESSION ABSTRACT DURATION	Presentation Type
<u>3673901</u>	QT09.04.01	Ultrastrong Coupling Phenomena in Extreme-Scale Resonant Nanocavities	He, Mingze	United States	1:30 PM 2:00 PM	30	Invited Speaker
<u>3668937</u>	QT09.04.02	Development of an On-Chip THz Spectrometer with Metamaterial Waveguides	Seddon, James	United Kingdom	2:00 PM 2:15 PM	15	Oral Presentation Preferred
<u>3675361</u>	QT09.04.03	Ultrastrong Light-Matter Coupling—Engineering Electronic Wavefunctions with Single Photons	De Liberato, Simone	United Kingdom	2:15 PM 2:45 PM	30	Invited Speaker

Session Information

SESSION TITLE: QT09.05: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

SESSION TYPE: Oral

SESSION DAY & DATE: Wed 5/25/2022 4:00 PM

SESSION DURATION: 120

SESSION LOCATION: QT09-Virtual

SESSION HOST: Session Chair: Thomas Folland

SESSION TOPIC: QT09: Light-Matter Strong Coupling in the Infrared and THz—Materials, Methods and New Phenomena

Control ID	Final ID	Title	Presenting Author	PRESENTER (COUNTRY ONLY)	Start/end time	SESSION ABSTRACT DURATION	Presentation Type
3669711	QT09.05.01	Enhanced Interactions Between Exciton-Polaritons in Semiconductor Microcavities	Parish, Meera	Australia	4:00 PM 4:30 PM	30	Invited Speaker
3677397	QT09.02.04	Nanoparticle Supercrystals for (Ultra)Strong Light-Matter Coupling	Reich, Stephanie	Germany	4:30 PM 5:00 PM	30	Invited Speaker
3673032	QT09.05.03	Strong Light-Matter Interaction and Its Applications in Nonlinear and Quantum Optics	Welakuh Mbangheku, Davis Dave	United States	5:00 PM 5:15 PM	15	Oral Presentation Preferred
3670770	QT09.05.04	Adiabatic Compression of Mid-IR Through THz Light in Diamond-Metal Campanile Probe for Ultrawide Spectral Range Nanospectroscopy	Medapalli, Rajasekhar	United Kingdom	5:15 PM 5:30 PM	15	Oral Presentation Preferred
3677162	QT09.05.02	Excitons and Polaritons in van der Waals Heterostructures	Deng, Hui	United States	5:30 PM 6:00 PM	30	Invited Speaker

[2022 MRS Spring Meeting and Exhibit](#)

Symposium SB03: Robotic Materials for Advanced Machine Intelligence

Summary:

Symposium SB03 was held in-person and virtually at the 2022 Spring MRS Meeting and Exhibit in Honolulu, Hawai'i. The symposium attracted an international and interdisciplinary audience to discuss latest research activities in soft robotics, bioinspired robotics, soft multifunctional materials, and robotic matter. The in-person sessions took place from Wednesday, May 11, to Friday, May 14, 2022, and the virtual session was held on Wednesday, May 25, 2022. The 3-day in-person sessions featured 10 invited speakers, 18 oral presentations, and 9 poster presentations. The invited speakers (2 women, 8 men) were from Germany, Switzerland, the United States, and the United Kingdom. Several invited speakers were not able to attend due to COVID-related circumstances. The virtual session had one invited speaker and 9 oral presentations. Altogether, symposium contributors represented North America, Europe, and Asia. The symposium was organized by four experts (2 women and 2 men representing North America, Europe, and Asia) in the topic areas, with three organizers at the early-career stage.

Objectives:

The natural world motivates the advancing of machine intelligence by way of new materials for robot bodies, where material properties provide advanced capabilities and autonomous behaviors akin to those of living organisms. Soft robotics has exemplified how a materials-driven approach to robotics has expanded robots' abilities, opened new avenues for wearable and biomedical machines, and transformed our ideas of what a robot is and can be. However, continued advances are needed to address fundamental limitations in fabrication, power, and control. To address these interdisciplinary challenges, Symposium SB03 brought together researchers from soft and microscale robotics, stretchable electronics, active matter, mechanics, and chemistry to share research that advances robotics by way of new "robotic materials."

The objective of Symposium SB03 was to attract contributions around three key research themes. The first theme - *robotic components from soft and architected materials* – focused on new materials for actuation, perception, power, and control capabilities in soft robots and robotic materials. This theme focused on electrically-driven soft actuators, self-powered components, chemical power strategies, and ionotronic devices. The second theme - *integrated design and fabrication strategies for robotic materials* – focused on progress in soft robotic and robotic material manufacturing. Methods of particular interest were those methods that facilitated distributed actuation and sensing capabilities in material systems, multi-material fabrication, assembly across scales, and paths towards the end-to-end design, fabrication, and evaluation of robotic materials. The third theme - *advances in the modeling and control of materials for physical machine intelligence* - featured theoretical contributions for improve robotic material design, fabrication, and control.

Collectively, all invited and contributed talks covered the following topics of interest for our objectives:

- Actuators for soft robots and devices, including liquid crystal elastomers, dielectric elastomer composites, and shape-memory and shape-morphing materials
- Soft robotic electronics and sensors from hydrogels, liquid metals, and ionic
- Strategies for power and energy management in soft devices
- Additive and digital fabrication methods for soft robots and robotic materials
- Architected materials for robots
- Materials for self-healing, growing, learning, and other adaptive robotic functions
- Bioinspired and biohybrid design in robotic materials
- Modeling, simulation, and control of robotic materials
- Robotic materials for innovations at the human-robot interface
- Autonomous soft/microscale robots and active matter

Symposium Highlights:

Based on our objectives and the contributions received in our Call for Papers, the in-person component of Symposium SB03 was organized into several sessions:

1. SB03.01: Bioinspired Actuators – This session focused on bioinspired actuators and shape changing materials. The invited speaker in this session was Prof. Andreas Lendlein of the University of Potsdam (Germany), who began this section with a presentation on the use of shape memory polymers for building soft robotic actuators inspired by plants and their shape changing capabilities. These included, for example, the use of shape memory and mechanical design to replicate fast actuation inspired by Venus flytraps. Prof. Shu Yang of the University of Pennsylvania (USA) also gave a contributed talk on photoresponsive liquid crystal elastomer actuators for soft robots.
2. SB03.02: Shape Morphing and Mechanics – The two invited presentations in this session were Prof. Jordan Raney of the University of Pennsylvania and Prof. Herbert Shea of the Swiss Federal Institute of Technology Lausanne (EPFL, Switzerland). Prof. Jordan Raney’s presentation was given by a postdoctoral scholar in his lab, Dr. Qiguang He, who presented their work on novel electronics-free control strategies for soft robots through changes in bodily mechanics. Their “control modules” used stimuli responsive liquid crystal elastomers, hydrogels, and silicones to change how an actuating soft robot could navigate an environment based on stimuli it encountered. Prof. Shea presented on reconfigurable soft actuators that respond to heat and magnetic fields and novel hybrids of electrostatic and shape memory polymer actuators. Two contributed presentations in the section were given by early-career researchers Prof. Michael Bartlett (Virginia Tech, USA) and Prof. Jeffrey Lipton (University of Washington, USA). Prof. Bartlett presented his group’s latest research in shape morphing mechanical metamaterials using liquid metals, and Prof. Lipton presented his group’s efforts in designing novel motorized auxetics for robot actuation.
3. SB03.03: Poster Session – Our poster session was held with a general MRS-wide poster session one evening. We awarded one Best Poster Award. Poster presentations covered topics including liquid crystal elastomer actuators, volumetric actuators based on phase transitions, 3D printed soft robots, magnetically steered devices for drug delivery, soft sensing, and more.

4. SB03.04: Small Scale Robotic Materials – Our invited speaker for this section was unable to attend due to COVID-related issues. However, in this short section, one contributed talk was given by Prof. Emma Fan of The University of Texas at Austin (USA). She presented her recent research efforts to control steerable microrobot swarms using light and electric fields.
5. SB03.05: Design and Fabrication – This three-talk section had two invited speakers, Prof. Rebecca Kramer-Bottiglio of Yale University (USA) and Prof. Robert Shepherd of Cornell University (USA). Prof. Kramer-Bottiglio presented her latest work on designing stiffness-tuning soft robotic materials for amphibious locomotion of turtle-inspired soft robots. She also presented a strategy for fabricating granular actuators that actuation with large volumetric changes through phase transitions of embedded solvents. Prof. Shepherd reviewed his latest progress in embodied energy principles in soft robots and soft robotic sensing.
6. SB03.06: Robotic Material Systems – The first of two invited talks in this section was given by Prof. Kris Dorsey of Northeastern University (USA). Prof. Dorsey presented on her latest work in using kirigami and origami-inspired designs to improve distributed sensing and actuation capabilities in soft robotic materials. Prof. Dorsey was one of our early-career invited speakers. The section was closed by our second invited speaker, Prof. Mirko Kovac from Imperial College London (UK) and the EMPA Material Science Institute in Switzerland, where he is Head of the Materials and Technology Centre of Robotics. Prof. Kovac reviewed a number of his group's research projects, including soft robotic materials for aerial robots, manipulation in drones, environmental sensing via sensor-launching UAVs, and more.
7. SB03.07: Plant-inspired Robotic Materials – This section also lost a speaker due to COVID-related circumstances. We originally planned to open this section with Prof. Bilge Baytekin from Bilkent University (Turkey). She was one of our planned early-career invited speakers and was scheduled to give a talk titled, "Solar Tracking Plant Robots—The Soft and the Softer." Our other invited speaker in this section was Prof. Thomas Speck of the University of Freiburg (Germany). Prof. Speck reviewed the physiology and anatomy of motion in plants, showed how his team is translating plant behaviors into bioinspired and sustainably built soft robots, and discussed his ongoing efforts with one of the symposium's co-organizers, Dr. Barbara Mazzolai, to make robots that can grow.
8. SB03.08: Electroprogrammable Robotic Materials – Our final in-person section had two invited speakers. The first was Prof. Ryan Hayward of the University of Colorado at Boulder (USA). He presented his research on ionoelastomer heterojunctions as electromechanically-active, multifunctional materials for soft robots, soft electronics, wearable devices, and energy generation. The foundation of his talk was based on his latest work in designing ionic liquid-based composites whose spatially programmed fixed and mobile charges enable ionic diode-like devices and electroresponsive adhesives. The second invited presentation was given by Prof. Ravinder Dahiya of Glasgow University (UK). Prof. Dahiya presented on printed electronic devices for soft wearable electronics and artificial skin-inspired devices.
9. Our final invited talk was given at the virtual component of Symposium SB03 by Prof. Hani Nagueib of the University of Toronto (Canada). He presented progress on thermomechanically responsive shape-changing materials and devices for soft robots and morphing devices.

Contributions to the Materials Community and Beyond:

Symposium SB03 successfully brought interdisciplinary researchers from around the world together to highlight and discuss the latest research and developments in soft robotics and robotic materials. The symposium contributors and invited speakers included materials scientists and engineers, biologists, mechanical engineers, electrical engineers, physicists, and chemists, who all work on efforts to advance machine intelligence through material design. The symposium was well attended by postdoctoral researchers, graduate students, and even undergraduates (one of our contributed talks was presented by an undergraduate student researcher from Korea), who were able to learn about recent developments in this interdisciplinary field. The breaks throughout allowed for informal discussion and continued Q&A sessions that we believe will drive new, multidisciplinary, and international research efforts.

Symposium SB03 organizers used the ARO grant (\$2,226.37) to pay for partial registration fees for 4 of our invited speakers and two co-organizers ($\$370 \times 4 = \$1480$) and the full registration of one organizer (\$685).

Supported Invited Speakers (or Organizers)

Our symposium organizers raised financial support from several organizations. Those Symposium SB03 speakers or organizers supported by funds generously provided by the ARO Grant include:

- Prof. Rebecca Kramer Bottiglio, Yale University, USA
- Prof. Robert Shepherd, Cornell University, USA
- Prof. Kris Dorsey, Northeastern University, USA
- Prof. Ryan Hayward, University of Colorado at Boulder, USA
- Prof. Ryan Truby, Northwestern University, USA (Lead Organizer)

Future Directions:

Today's state-of-the-art robots are having rapid and expansive impact on our society. However, their capabilities are still unmatched to those we have long observed in living organisms. Soft robotics and emerging efforts in robotic materials represent an opportunity to greatly expand robot capabilities and machine intelligence through materials design to bring robots into new real-world, people-centric environments. However, many challenges in the design, fabrication, and control of these systems remains. For over a decade, MRS has recognized through the acceptance of many related symposia that soft robotics is a research area of growing interest and important to the materials science and engineering community. SB03 is a first symposium dedicated to robotic materials. The organizers have planned follow-up symposia for future meetings, and the lead organizer is working with one of the invited speakers to organize a similar symposium at the Fall 2023 MRS Meeting.

Program

https://www.mrs.org/meetings-events/spring-meetings-exhibits/past-spring-meetings/2022-mrs-spring-meeting/symposium-sessions/symposium-sessions-detail/2022_mrs_spring_meeting/sb03

Acknowledgements:

The organizers are grateful for the support from the US Army Research Office (ARO). This supporting grant was essential for Symposium SB03's success. We also to thank the Staff at the Materials Research Society who assisted with submitting and supporting the ARO Grant Application.

2022 MRS Spring Meeting – Final Report, Block Grant Army Research Office (ARO): Grant Number: W911NF-22-1-0049

SF05, Final Report, Block Grant, Army Research Office (ARO):

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1. Symposium Objectives

An autonomous function is the ability to perform the cycle of sensing, communicating, computing, and reacting to stimuli. Nature provides us with engineered examples of autonomous systems; investigating the governing mechanisms of such provides the fundamental principles for realizing autonomous function at the material, device, and system levels.

The goal of Autonomous Materials is to create a new vision for material composites. These composite materials will encompass effort from the "Smart Materials" and "Smart Systems" community (PZTs, for example), as well as new work in soft structural sensing (e.g., stretchable photonic networks), structural energy, dynamic mechanical energy (electrohydraulic energy storage), material computation (e.g., BZ reactions), self-healing, ionotronics, stretchable electronics, etc. One specific difference in our goals from prior topics, such as Smart Materials, is that we will prioritize research at scales and properties that allow for processing as materials (e.g., injection molding, 3D printing, layup, etc).

In many ways, the underlying principles of material embodied autonomy are parallel to those currently employed in robotic artificial intelligence systems. AI-driven robots interact with their environment based on information previously gathered and processed from their surroundings via onboard sensors. This closed sense-decide-response loop relies on a continuous synergy between the sensors, processors, actuators, and collected data; the same is true for the energy harvesting-storage-delivery loop in robots. Embedding autonomy in the material level in the form of energy, actuation, and control functions is a foundation for creating new age robotics that more seamlessly interface with their own environments.

†E-mail: ym279@cornell.edu

In this symposium we focus the utility of this topic towards applications; as such, we expect a broad span of technology readiness levels represented in our space (robots, medical devices, analytical chemistry, rheology, additive manufacturing, etc). Essentially, this symposium aims to bring together an interdisciplinary group of researchers from chemistry, materials science, physics, robotics, biology and engineering to discuss recent developments in autonomous materials, devices and systems, and their applications. We aim to reinstitute autonomous systems at the forefront of material science and innovation, emphasizing the potential for industrial applications.

2. Presentations

Here we provide a list of the invited speakers, by order of appearance, who contributed to the symposium and whose influence in the field of autonomous and functional materials contributed significantly to the symposium's success (full abstracts are provided in Appendix A).

1. *Collective Cell Behavior in 3D Cell Assemblies—3D Printed Structures, Random Aggregates and Perfectly Precise Arrays*

Thomas Angelini, University of Florida.

2. *Designing Robotic Materials from Sensorized Soft and Architected Matter*

Ryan Truby, Northwestern University

3. *Power Amplification of Soft Artificial Muscles for Rapid Actuation*

Michael Tolley, University of California, San Diego.

4. *2D, 3D and 4D Printing of Smart Materials*

Shlomo Magdassi, Hebrew Univ of Jerusalem.

5. *Programming Tangible World*

Jiyun Kim, Ulsan National Institute of Science and Technology.

6. *Robust Collective Locomotion with and Without Coordination*

Daniel Goldman, Georgia Institute of Technology.

7. *Embodied and Distributed Energy Circulation, Powering and Computing Network for Soft Robots*

Hyeon Seok An, Cornell University, U.S. Army Research Laboratory

8. *Mechanics-Based Material Computing using Physical ReLU Spring Networks*

Phil Buskohl, UES, Inc.¹, Air Force Research Laboratory.

9. *Triboelectric Nanogenerator for Self-Powered Sensors and Systems*

Zhong Lin Wang, Georgia Institute of Technology.

10. *Electrochemistry for Autonomous Navigation of Small Vehicles and Healing of Metal Parts*

James Pikul, University of Pennsylvania.

11. Biomimetic Approaches with Stretchable Ionics

Jeong-Yun Sun, Seoul National University.

12. Smart Contact Lenses for Wireless Medical Diagnosis

Jang-ung Park, Yonsei University¹, Institute for Basic Science (IBS).

13. Printable Robots Integrated in a Robot-Ecosystem for Measuring the Oceanic Margins of Ice Sheets

Markus Nemitz, WPI¹, University of California, Los Angeles.

3. Highlights

1.1. Phil Buskohl (Keynote: Air Force Research Laboratory)

Mechanics-Based Material Computing using Physical ReLU Spring Networks

Phil Buskohl, UES, Inc.¹, Air Force Research Laboratory.

Abstract

Dynamic movement and shape change are key enablers for living systems to sense, assess and respond to environmental stimuli. For example, actuating mechanisms are utilized in natural systems for diverse operations, such as arms and legs for locomotion, skin wrinkling for camouflage, or multistable snapping to catch prey. Nonlinear mechanical dynamics can also serve as a computing resource to directly process the environmental cues into complex mappings between the input and output dynamics of a mechanical system. To explore this concept, we numerically investigated the computing capacity of 2D nonlinear spring networks using a reservoir computing approach. Reservoir computing is a class of recurrent neural networks that trains only a readout layer of the network dynamics in contrast to tuning all the internal parameters of the network. We introduce a mechanical analog for the rectified linear unit (ReLU) activation function from neural network community and benchmark the memory capacity, nonlinearity and output tasks of mechanical ReLU networks sampled from a distribution of spring properties. Preliminary results indicate that the stiffness ratio of the ReLU spring (ie. ratio of the bilinear slopes) is a key driver of the nonlinearity score of the network, even more so than the incidence of activating the spring nonlinearity. In addition, spring networks with a mixture of linear and ReLU springs exhibit a marked loss in memory capacity even at low ReLU springs fractions. Collectively, the results highlight the potential to harness computing capacity from the intrinsic dynamics of a material or mechanical system and motivates further study on how to leverage unconventional materials and physics for information processing.

1.2. Daniel Goldman (Keynote: Georgia Institute of Technology)

Robust Collective Locomotion with and Without Coordination

Daniel Goldman, Georgia Institute of Technology.

Abstract

I will discuss examples from our recent work on leveraging the power of collectives to function as robust locomoting units. At one extreme, I will discuss our studies of myriapod locomotion; in biological experiments on centipedes, we use advances in neural network trackers (e.g. DeepLabCut) to extract kinematics of limb and body postures vs time. We analyze these dynamics using a geometric formulation of locomotion and show how these animals can optimally coordinate body bending and limb stepping patterns. When instantiated in a robophysical centipede model consisting of repeated two-legged units whose limbs display directional compliance and whose body segments are joined with soft elements, the geometric scheme for coordination of limb and body undulation creates a robot that can traverse diverse complex terrain in open loop. As a counterpoint to tightly coordinated units, I will discuss how groups of worms (worm blobs) can make decisions to avoid environmental threats without presumed system-wide coordination. In particular, the blobs can collectively crawl away from heat sources, which we hypothesize results from an uncoordinated interaction of leading-edge pulling worms and trailing edge lifters, whose individual dynamics are dominated by local heat responses. Implementing analogous control schemes in collections of robots (smarticles) that sense local conditions (light levels) but do not coordinate this information, we demonstrate robust translation without unit-wide coordination. We expect that future robot swarms could move along the (un)coordination axis to flexibly perform complex tasks which might require individual or collective actions.

4. Contribution to Discipline and Use of ARO Funding

It is our intention to draw attention to this field and affirm the positive effects of collaboration between the military, industry, and academia. The program included three speakers affiliated with the United States Military, Yoav Matia, U.S Army Research Laboratory, and Hyeon Seok An, Cornell University, both affiliated with the ARL under the direction of Dr. Nathan Lazarus (U.S Army Research Laboratory) as well as Phil Buskohl an Air Force Research Laboratory researcher. For full affiliate abstracts, see appendix B.

In addition, to advance future collaborations and drive excellence; participants at the symposium were informed in advance of the three ARO excellence presentations to increase participant engagement:

- Travel Reimbursement for Keynote speaker – Robert Shepherd, registration reimbursement. Funds used: 390\$.
- Travel Reimbursement for Contributing speaker – awarded to Yoav Matia, registration reimbursement. Funds used: 510\$.
- Best Poster presentation– Hyeonseo Song. Funds used: 500\$.
- Best Invited Speak – Heon Seok An. Funds used: 826.37\$.

5. Future Directions of Symposium

Following the success of this year's symposium and the significant interest it showed. In coordination with the MRS steering committee, we organizers have coordinated the continuation of this year's symposium to become a reoccurring feature in future MRS conferences – The next being the 2023 MRS fall Meeting at Boston. The Boston meeting, just as this one, will focus with emphasis on utility and applications broadening the span of technological readiness levels represented in the field, as per ARO interests.

Below is the symposium abstract for Boston 2023 with a list of the invited speakers.

From Robotic Towards Autonomous Materials

Organizers:

Robert Shepherd, Ph.D., Cornell University, USA

Ryan L. Truby, Ph.D., Northwestern University, USA

Yoav Matia, Ph.D., Army Research Lab and Cornell University, USA

Over the last twenty years, progress in soft robotics has motivated the materialization of physical intelligence through new forms of soft actuators, sensors, and control strategies. But the challenges of power, performance, and control in soft robotics remain limited by available materials. The natural world is inspiring a new generation of materials design paradigms, where multifunctionality not only tightly integrates multiple robotic capabilities, but enables truly autonomous behaviors. The next-generation of autonomous agents should be indistinguishable from materials, as they must truly integrate distributed actuation, perception, control, and energy capabilities. To enable this interdisciplinary vision, this symposium aims to bring several communities together – from materials science and soft robotics, to chemistry and mechanics – to build beyond visions of robotic materials to truly autonomous ones.

Our symposium is structured around three core tracks. The first – robotic materials – will feature new materials for actuators, sensors, controllers, and energy. Research themes of interest are electrically-driven and chemically powered actuators, new soft material sensing and control strategies, and materials for robotic power. The second track – design and fabrication – will highlight innovations in multifunctional material fabrication, directed assembly of materials across multiple lengths scales, and modeling. The third track – autonomous materials – will explore the emergence of autonomous, self-regulatory, and intelligence in material systems, while exploring emerging areas of embodied energy, distributed sensorimotor capabilities. Overall, the three tracks will collectively explore new applications for robotic or autonomous materials, including devices for wearables and biomedicine, untethered bioinspired robots, food security, environmental monitoring, and beyond.

Proposed Invited Speakers (roughly in order of research theme, with non-USA speakers in italics and women in bold)

- Ryan Hayward, University of Colorado Boulder, USA
- Timothy White, University of Colorado Boulder, USA
- **Jennifer Lewis, Harvard University, USA**
- **Joanna Aizenberg, Harvard University, USA**
- Jordan Raney, UPenn, USA

- Samuel Stupp, Northwestern University, USA
- Monica Olvera De La Cruz, Northwestern University, USA
- **Kirstin Petersen, Cornell University, USA**
- Xuanhe Zhao, MIT, USA
- *Christoph Keplinger, Max Planck Institute for Robotic Materials, Germany*
- **Zeynep Temel, Carnegie Mellon University, USA**
- **Yan Ji, Tsinghua University, China**
- **Rebecca Kramer-Bottiglio, Yale University, USA**
- *Metin Sitti, Max Planck Institute for Intelligent Systems, Germany*
- *Mirko Kovac, Imperial College London, UK, and Swiss Federal Laboratories for Materials Science (EMPA), Switzerland*
- **Bilge Baytekin, Bilkent University, Turkey**
- **Chiara Daraio, California Institute of Technology, USA**
- *Kyujin Cho, Seoul National University, Korea*
- *Shingo Meada, Shibaura Institute of Technology, Japan*
- *Shlomo Magdassi, The Hebrew University of Jerusalem, Israel*
- James Pikul, University of Pennsylvania, USA
- **Nancy R Sottos, University of Illinois at Urbana-Champaign, USA**
- *Amir Gat, Technion – Israel Institute of Technology, Israel*

Topics

- Stimuli-responsive hydrogels, liquid crystalline materials, and composites
- Materials with distributed sensorimotor behaviors
- Soft material logic, memory, and computation
- Multifunctional materials for programmed shape-change, adaptability, and embodied intelligence
- Self-healing, self-regulatory, and homeostatic materials
- Biohybrid, autonomous materials
- Application- and data-driven design of robotic and autonomous materials
- Materials for energy scavenging and embodied energy
- Autonomous soft, bioinspired, and/or microscale robots
- Additive and digital fabrication of autonomous materials
- Architected materials for robots
- Modeling, simulation, and control of autonomous materials

Keywords: Autonomous Material, bioinspired, Electronic material, Energy harvesting and storage, Material computation, Robotics, Soft material logic, Self-healing, Additive and digital fabrication.

Appendix A – Invited speakers abstracts

List of invited speakers and full abstract details by order of appearance,

1. *Collective Cell Behavior in 3D Cell Assemblies—3D Printed Structures, Random Aggregates and Perfectly Precise Arrays*

Thomas Angelini, University of Florida.

Abstract

The remarkable differences between cells grown on plates and cells in vivo or in 3D culture are well-known. At the physical level, cell shape, structure, motion, and mechanical behavior in 3D are totally different from those in the dish and are far less explored. At the molecular level, cells grown in monolayers exhibit gene expression profiles that do not correlate or are anticorrelated with those of cells grown in 3D culture or xenograft animal models. However, our understanding of cell biology has been heavily shaped by the culture plate, whether viewed through the lens of gene expression profiles, signaling pathways, morphological characterization, or mechanical behaviors. Closing this major gap between 2D in vitro culture and in vivo biology requires a tunable and flexible method for creating 3D cell assemblies and performing experiments on cells in 3D environments. Critically, studying collective cell behavior in 3D assemblies is needed to gain understanding of the relationship between the detailed cellular structure found within tissues and emergent tissue function. In this talk I will describe how we use 3D biofabrication tools in combination with a 3D culture medium made from jammed microgels to perform a wide range of 3D experiments. I will demonstrate this experimental platform's ability to print structures made from multiple cell types or extracellular matrix with predictable feature sizes down to the scale of a few cell bodies. I will also present data from numerous types of experiments performed in 3D, designed to explore collective cell behavior and cell-cell interactions. For example, I will discuss recent results on collectively driven mechanical instabilities in 3D printed structures, collective cell migration in 3D printed immunotherapy models, cell aggregation in random 3D cell dispersions, and biofabrication with single-cell precision.

2. *Designing Robotic Materials from Sensorized Soft and Architected Matter*

Ryan Truby, Northwestern University

Abstract

Recent advances in autonomous material systems – from adaptive materials to soft, bioinspired robots – motivate the design of novel multifunctional composites with distributed actuation and perception capabilities. These functionalities are required for addressing long-standing challenges in autonomous material control and achieving more sophisticated bioinspired behaviors. However, continued progress towards this vision is stymied by limitations in current materials and manufacturing methods. I will present approaches for designing and fabricating material systems with distributed sensorimotor capabilities as robotic materials. Two classes of robotic materials based on sensorized fluidic elastomer actuators and motorized auxetic actuators be discussed. I will present the novel materials, 3D printing-based fabrication methods, and sensing approaches we have developed for both. Finally, I will discuss how these integrated design and fabrication strategies for sensorizing soft and architected matter can be broadly adapted to engineer other embodiments of autonomous robotic materials.

3. Power Amplification of Soft Artificial Muscles for Rapid Actuation

Michael Tolley, University of California, San Diego.

Abstract

Robots composed of soft materials can passively adapt to unstructured environments and can mitigate damage due to impact. Given these features, previous work has explored the design of soft robots capable of jumping. However, for mesoscale jumping robots, lightweight and compact actuation is an outstanding challenge. Previous work has focused on systems powered by fluids, combustion, electromagnetic, or electrostatic motors; each of which requires one or more of the following: large rigid components, external power, and components available only in discrete sizes. While compact actuation via smart materials has also been proposed, it is challenging to achieve rapid motions with continuously tunable performance (e.g., speed, jump height). In this work, we propose an approach to the design and fabrication of an electrically powered soft amplification mechanism (motor-spring-latching system) to enable untethered mesoscale systems with continuously tunable performance. We used the tunable geometry of a liquid crystal elastomer (LCE) actuator, an elastic hemispherical shell, and a soft pouch for active latching, to achieve rapid motions for jumping despite the slow contraction rate of the actuator. In a tethered experiment, we demonstrated a system capable of amplifying the power output of an LCE actuator by a factor of 8.12×10^4 to jump to a height of 55.6 mm while carrying a payload of 30 g. This approach offers a promising pathway towards continuously tunable and untethered mesoscale soft robotic systems capable of rapid motions.

4. 2D, 3D and 4D Printing of Smart Materials

Shlomo Magdassi, Hebrew Univ of Jerusalem.

Abstract

Additive manufacturing, which is the process of fabrication through printing, brings new opportunities in the fields of material science and industrial manufacturing. 3D printing is based on sequential printing of 2D images, and 4D printing results from 3D objects that can change their structure due to external triggers. Many of these processes utilize polymers and monomers, that together with embedded particles may enable fabrication of shape morphing structures, including actuators. For example, embedding gold nanoparticles within stretchable polymers enable remote localized heating, that result in controlled shape morphing of 3D objects. New materials and processes for 2D and 3D printing will be presented, for fabrication of objects composed of shape memory polymers, elastomers and hydrogels, mainly by light-activated printing processes. Examples of applications of these materials will be presented, such as in soft robotics, energy harvesting and responsive optical and electrical connectors, towards utilization in autonomous materials.

5. Programming Tangible World

Jiyun Kim, Ulsan National Institute of Science and Technology.

Abstract

Virtual intelligence has been dramatically advancing these days, catching up with or even surpassing the functional and cognitive capability of human, by the advances in computing power and new operation methodologies. On the other hand, tangible objects or machines in physical world try to mimic forms and functions of specific living organisms, such as human, cheetah, octopus, etc., but still lag behind them in terms of intelligent and adaptive functions necessitating to overcome traditional mechanisms and approaches.

Therefore, our group aims to develop integrated robotic platform capable of programming its morphology, physical property, interface and function *in situ*. This paradigm of robot requires the innovation in all levels of system including materials, components, architectures to integrate them, manufacturing process, data processing, and operation. In this talk, I introduce recent research outcomes in our group, such as autonomous magnetic material for robotic applications, tensegrity metamaterial capable of synergistically integrating rigid and soft materials, 4D printing method directly transforming 2D pen drawing into 3D structure, flexible robotic components and sensor group interface, novel robotic platform with the corresponding operation, etc., and try to share our visions to blur the boundary between virtual and tangible world, and more importantly between human and environment.

6. Robust Collective Locomotion with and Without Coordination

Daniel Goldman, Georgia Institute of Technology.

Abstract

I will discuss examples from our recent work on leveraging the power of collectives to function as robust locomoting units. At one extreme, I will discuss our studies of myriapod locomotion; in biological experiments on centipedes, we use advances in neural network trackers (e.g. DeepLabCut) to extract kinematics of limb and body postures vs time. We analyze these dynamics using a geometric formulation of locomotion and show how these animals can optimally coordinate body bending and limb stepping patterns. When instantiated in a robophysical centipede model consisting of repeated two-legged units whose limbs display directional compliance and whose body segments are joined with soft elements, the geometric scheme for coordination of limb and body undulation creates a robot that can traverse diverse complex terrain in open loop. As a counterpoint to tightly coordinated units, I will discuss how groups of worms (worm blobs) can make decisions to avoid environmental threats without presumed system-wide coordination. In particular, the blobs can collectively crawl away from heat sources, which we hypothesize results from an uncoordinated interaction of leading-edge pulling worms and trailing edge lifters, whose individual dynamics are dominated by local heat responses. Implementing analogous control schemes in collections of robots (smarticles) that sense local conditions (light levels) but do not coordinate this information, we demonstrate robust translation without unit-wide coordination. We expect that future robot swarms could move along the (un)coordination axis to flexibly perform complex tasks which might require individual or collective actions.

7. Embodied and Distributed Energy Circulation, Powering and Computing Network for Soft Robots

Hyeon Seok An, Cornell University, U.S. Army Research Laboratory

Abstract

Living system has embodied nervous, muscular, and circulatory networks that can react and adapt to external stimuli and environmental changes. Through the circulatory system, energy is transported throughout the body and supplied to the muscular system. The nervous system responds to external stimuli by controlling the muscular system. By combining various systems, all living organisms realize automatic functions that control the body in response to feedback. Modern robots lack the multifunctional interconnected system found in living organisms and are consequently unable to reproduce their efficiency and autonomy. Here, we present a multi-functionalized energetic vascular system, which can be used as energy

storage and actuation system by coupling redox flow batteries (RFBs) and elastomeric solenoid pumps (ESPs). RFB itself can act as an energy storage device and actuator simultaneously by integrating it into the fluidic elastomer actuator (FEA). The ESP was incorporated into the RFB to circulate the electrolyte and generate the hydraulic force required to operate the actuator. The ESP is comprised of a permanent magnet coated with a hydrogel layer (sealing layer). The magnet is then inserted into a stretchable tube. The tube is externally coiled with thin liquid metal wire in successive sections to produce a train of solenoids along the length of the tube. Upon activation, the magnets will be pulled continuously along the length of the tube to generate hydraulic force. In addition, the ionic conductivity imparted by the ions of the electrolyte can be used as a conductive substrate for sensing external strain and transmitting data. Therefore, the RFB network can serve as a network responsible for sensing and communicating like a nervous system.

The RFB-ESP network can be utilized to implement a multifunctional network (vascular, muscular, and nervous) of a living organism and enhance the efficiency and autonomy of the robot.

8. *Mechanics-Based Material Computing using Physical ReLU Spring Networks*

Phil Buskohl, UES, Inc.¹, **Air Force Research Laboratory.**

Abstract

Dynamic movement and shape change are key enablers for living systems to sense, assess and respond to environmental stimuli. For example, actuating mechanisms are utilized in natural systems for diverse operations, such as arms and legs for locomotion, skin wrinkling for camouflage, or multistable snapping to catch prey. Nonlinear mechanical dynamics can also serve as a computing resource to directly process the environmental cues into complex mappings between the input and output dynamics of a mechanical system. To explore this concept, we numerically investigated the computing capacity of 2D nonlinear spring networks using a reservoir computing approach. Reservoir computing is a class of recurrent neural networks that trains only a readout layer of the network dynamics in contrast to tuning all the internal parameters of the network. We introduce a mechanical analog for the rectified linear unit (ReLU) activation function from neural network community and benchmark the memory capacity, nonlinearity and output tasks of mechanical ReLU networks sampled from a distribution of spring properties. Preliminary results indicate that the stiffness ratio of the ReLU spring (ie. ratio of the bilinear slopes) is a key driver of the nonlinearity score of the network, even more so than the incidence of activating the spring nonlinearity. In addition, spring networks with a mixture of linear and ReLU springs exhibit a marked loss in memory capacity even at low ReLU springs fractions. Collectively, the results highlight the potential to harness computing capacity from the intrinsic dynamics of a material or mechanical system and motivates further study on how to leverage unconventional materials and physics for information processing.

9. *Triboelectric Nanogenerator for Self-Powered Sensors and Systems*

Zhong Lin Wang, Georgia Institute of Technology.

Abstract

Self-powered system is a system that can sustainably operate without an external power supply for sensing, detection, data processing and data transmission. Nanogenerators (NG) were first developed for self-powered systems based on piezoelectric effect and triboelectrification effect for converting tiny mechanical energy into electricity, which have applications in internet of things, environmental/infrastructural monitoring, medical science, environmental science and security. We will present the applications of the NGs for harvesting all kind mechanical energy that is available

but wasted in our daily life, such as human motion, walking, vibration, mechanical triggering, rotating tire, wind, flowing water and more. Then, we will show that NGs as self-powered sensors for actively detecting the static and dynamic processes arising from mechanical agitation using the voltage and current output signals.

10. Electrochemistry for Autonomous Navigation of Small Vehicles and Healing of Metal Parts

James Pikul, University of Pennsylvania.

Abstract

Organisms often make autonomous decisions using electrochemical systems, such as neurons, that transmit information and respond to environmental cues. These capabilities provide exciting alternatives to classic control systems and would enable powerful tools for robots and smart materials. In this work, we show how materials that use electrochemical systems can enable autonomous navigation in small vehicles and room temperature repair of damaged metal parts. In both cases, electrochemical potentials mediated by the environment trigger autonomous behavior. Autonomous swimming driven by electrochemistry has been studied in microswimmers and active colloids where energy in the surrounding liquid is large relative the energy need for transportation, but there are no devices that can provide sufficient power from environmental chemicals to move and steer larger scale robots and vehicles in dry environments. We overcome this limitation with an environmentally controlled voltage source (ECVS) that, when directly attached to electric motors on a vehicle, can increase the energy available to the vehicle and provide computer-free autonomous navigation toward chemical fuels in the environment and away from hazards. Two ECVSs can also be arranged in series or parallel to perform logical functions based on the chemicals in contact with the ECVSs. This presents a new method to simultaneously steer and power vehicles and robots without computers by directly responding to a wide variety of chemical fields in their environment using electrochemistry.

Healing metallic materials involves high temperatures and large energy inputs. This work demonstrates rapid, effective, low-energy, and room-temperature healing of cellular metallic materials by using electrochemistry to mimic the transport-mediated healing of bone. A polymer coating enables selective healing only at the fracture site and the cellular structure of the metal allows facile ion transport to healing sites and effective recovery of strength and toughness when the cellular metal is damaged. Using this strategy, samples fractured in tension and by scission recover 100% of their tensile strength in as little as 10 and 4 h of healing. This electrochemistry-based approach enables the first demonstration of room-temperature healing of structural metallic materials and requires several orders of magnitude less energy than many previously reported metal healing techniques.

11. Biomimetic Approaches with Stretchable Ionics

Jeong-Yun Sun, Seoul National University.

Abstract

As many devices for human utility target fast and convenient communications with users, superb electronic devices have been demonstrated as hardware for Human-Machine Interface (HMI) in wearable forms. Wearable devices for daily health-cares and self-diagnosis desire more human-like properties unconstrained to deformation. In this sense, stretchable ionics based on flexible and stretchable hydrogels is on the rise as another field to develop wearable devices for bio-applications due to two major reasons; i) ionic currents, choosing the same signal carriers with biological areas, and ii) the adoption of hydrogel ionic conductors which are intrinsically stretchable materials with

bio-compatibility. Here, the current status of stretchable ionics as well as future applications whose positive effects can be magnified by stretchable ionics are going to be introduced.

12. Smart Contact Lenses for Wireless Medical Diagnosis

Jang-ung Park, Yonsei University¹, Institute for Basic Science (IBS).

Abstract

Recent progress in optoelectronic devices for wearable electronics demands their outstanding mechanical deformability for versatile systems in daily life. Especially, smart contact lenses are one of the promising candidates to provide real-time, noninvasive medical diagnostics from the physiological information on the eye and tear fluid. The eyes contain the tear fluid, so the contact lenses can monitor the physiological status of human body continuously. Previous smart contact lenses have exploited opaque and rigid device components for the operations of these electronic integration systems. Therefore, these devices could interfere with the user's vision and be potentially dangerous to the eyes. Furthermore, the bulky equipment with an excessive cost to monitor the signals from the smart contact lens could restrict the user's activities. These limitations reduce the convenience and features of the smart contact lenses. Therefore, we propose soft smart contact lenses which can detect the biomarker concentrations in tear fluid. For the superior stretchability and transparency, the smart contact lenses are fabricated using metal nanowires and graphene which have stretchable and transparent properties. Therefore, the resulting smart contact lens can provide a clear vision. In addition, the stretchable antenna enables the wireless communication, so the results of biosensors in smart contact lens could be wirelessly monitored. These sensor platforms can be exploited as not only smart contact lenses but also internet of things (IoTs) for the environment monitoring. Furthermore, the smart contact lens integrated with wireless display can exhibit the sensing results through the display pixel and exclude the use of bulky measurement equipment which reduces user convenience. Therefore, we believe that the smart contact lenses suggest a promising strategy towards wearable electronics for the diagnosis of diseases.

13. Printable Robots Integrated in a Robot-Ecosystem for Measuring the Oceanic Margins of Ice Sheets

Markus Nemitz, WPI¹, University of California, Los Angeles.

Abstract

The Greenland and Antarctic ice sheets are melting at a rapidly accelerating rate, increasing by ~700% compared to the 1990s. This has important implications for global sea level, which is expected to rise 26 to 77 cm by 2100 if the global temperature increase can be limited to 1.5 deg. C, which is a limit we are expected to exceed. This is a huge range in sea level uncertainty, because as little as 0.1 meter of sea level difference may affect upwards of 10 million people. Recent observations have provided circumstantial but not definitive evidence that this recent acceleration of ice sheet mass loss is caused by the warming ocean that comes into contact with the glaciers at the periphery of these ice sheets. However, there is a lack of spatial and temporal resolution of data in these areas, which are vital to improve the accuracy of models and improve climate predictions. In addition, many factors such as sea ice, calving icebergs, hurricane force winds, etc. make in-situ observations and ongoing monitoring difficult or unsafe for human observers. Therefore, we propose to employ a robot eco-system that can drastically improve the spatiotemporal sampling of ocean properties that drive the melting of these ice sheets, specifically in fjords that connect marine-terminating glaciers to the open ocean. Robot eco-systems consist of teams of conventional robots

and printable, disposable diving robots. The printable robots are numerously deployed from unmanned aerial vehicles and unmanned underwater vehicles, allowing for automated monitoring missions. Our diving robots are printed from TPU using FDM printers, integrate fluidically-driven actuators, sensors, and logic gates based on mechanical instabilities, and oscillate between predefined hydrostatic pressures. Minimalistic electronics is incorporated into our 3D printed vessels to monitor conductivity, temperature, and depth and communicate measurements when they surface. We will end this talk with an outlook for printable robots for real-world applications and their vast potential for robotics education.

Appendix B – U.S. Military affiliated Research Abstracts

1. *Magnetohydrodynamic Levitation for High-Performance Flexible Pumps*

Yoav Matia^{1,2}, Hyeon An², Robert Shepherd², Nathan Lazarus¹

U.S. Army Research Laboratory¹, Cornell University²

Abstract

We use magnetohydrodynamic levitation as a means to create a soft elastomeric solenoid pump. We present a theoretical framework and fabrication of a pump designed to address the unique challenges of soft robotics. Using a permanent magnet as a piston, and ferrofluid as a liquid seal, we model and construct a deformable displacement pump. The magnet is driven back and forth along the length of a flexible tube by a series of solenoids made of thin conductive wire. The magnet piston is kept concentric within the channel by Maxwell stresses within the ferrofluid, and magnetohydrodynamic levitation as viscous lift pressure is created due to its forward velocity. The centering of the magnet reduces shear stresses during pumping and improves efficiency. We provide a predictive model and capture the transient nonlinear dynamics of the magnet during operation, leading to a parametric performance curve characterizing the elastomeric solenoid pump (denoted ESP), enabling goal-driven design. We show the pump integrated at the center of an elastomeric chassis can be pushed through a tortuous pathway while providing continuous fluid pressure and flow rate, and emerge at the other end to complete a swimming task. We demonstrate the utility of this ESP integrated soft machine by squeezing it through a tortuous obstacle course and then causing it to swim on the other side.

We report a shut-off pressure of 2-8 [kPa] and a flow rate of 50-325 [ml/min] while subject to deformation of its own length scale, drawing a total of 0.17 [watts]; thus presenting ESP systems as readily scalable devices with reported performance curves under deformation, providing the golden standard of pressure and flow rates for 'human scale' soft robotics.

2. *Embodied and Distributed Energy Circulation, Powering and Computing Network for Soft Robots*

Hyeon Seok An, Cornell University, U.S. Army Research Laboratory

Abstract

Living system has embodied nervous, muscular, and circulatory networks that can react and adapt to external stimuli and environmental changes. Through the circulatory system, energy is transported throughout the body and supplied to the muscular system. The nervous system responds to external stimuli by controlling the muscular system. By combining various systems, all living organisms realize automatic functions that control the body in response to feedback.

Modern robots lack the multifunctional interconnected system found in living organisms and are consequently unable to reproduce their efficiency and autonomy.

Here, we present a multi-functionalized energetic vascular system, which can be used as energy storage and actuation system by coupling redox flow batteries (RFBs) and elastomeric solenoid pumps (ESPs). RFB itself can act as an energy storage device and actuator simultaneously by integrating it into the fluidic elastomer actuator (FEA). The ESP was incorporated into the RFB to circulate the electrolyte and generate the hydraulic force required to operate the actuator. The ESP is comprised of a permanent magnet coated with a hydrogel layer (sealing layer). The magnet is then inserted into a stretchable tube. The tube is externally coiled with thin liquid metal wire in successive sections to produce a train of solenoids along the length of the tube. Upon activation, the magnets will be pulled continuously along the length of the tube to generate hydraulic force. In

addition, the ionic conductivity imparted by the ions of the electrolyte can be used as a conductive substrate for sensing external strain and transmitting data. Therefore, the RFB network can serve as a network responsible for sensing and communicating like a nervous system.

The RFB-ESP network can be utilized to implement a multifunctional network (vascular, muscular, and nervous) of a living organism and enhance the efficiency and autonomy of the robot.

3. Mechanics-Based Material Computing using Physical ReLU Spring Networks

Phil Buskohl, UES, Inc.¹, **Air Force Research Laboratory.**

Abstract

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Symposium SF09 Title: High Entropy Materials II

- From Fundamentals to Potential Applications

As a new generation of materials, the High-entropy materials (HEMs) design concept shifts the focus away from the corners of phase diagrams toward their centers, allowing compositions beyond the scope of traditional materials, offering distinctive properties, challenges, and opportunities for a wide range of structural and functional applications. The objective of this symposium is to share the latest research advances in materials with high configurational entropy, including high-entropy and complex concentrated alloys, high-entropy oxides/ nitrides, high-entropy metallic glasses, etc. and discuss primary materials issues for HEMs from property-targeted design to process optimization, from structures to properties, and from the fundamental science to viable industrial applications. In this symposium, we hope to deepen understanding of why HEMs attract such intensive interest, as well as highlight some challenging issues awaiting resolution to provide viable paths to widespread application and adoption of HEMs.

From the perspective of fundamental science and structural analysis, the research on the short-range order and stacking fault energy in HEMs, which has been a significant issue recently, was actively discussed based on experimental approaches such as TEM and 4D-STEM and computational approaches such as first-principles energy density method. In addition, the effect of this unique atomic-scale microstructure on mechanical properties was also discussed. Furthermore, in terms of substantial improvement of the mechanical property of HEMs, studies related to the phase transformation mechanisms and control of second phase distributions were presented, which were published in reputable journals such as Nature and Applied Physics Letters. In addition, this symposium opened a forum for discussion in the field

of new materials such as high entropy oxide, and the results from in-depth structural analysis to potential applications were actively discussed.

At the 2022 MRS spring meeting, the ARO fund was used to encourage the best oral and poster presenter in the symposium. We hope to continue the international networking and active collaborative research based on this support even after the 2022 MRS spring meeting. In addition, since the HEM symposium is also scheduled to be held at the 2023 MRS spring meeting, we will continue to update the latest research and contribute to the active growth of the HEM field.

Symposium Highlights

► **SF09.01.04 | Short-Range Order and the Evolution of Deformation Mechanisms in the CrCoNi Medium Entropy Alloy | Andrew M. Minor, University of California, Berkeley, United States**

This talk shows the results of direct imaging and quantitative analysis of SRO in CrCoNi medium entropy alloy using energy-filtered TEM and HRSTEM. In addition, the effect of SRO on the multiscale deformation phenomena was studied by using in situ TEM nanomechanical testing, and the obtained diffraction patterns are used to identify defects and map relative strain.

► **SF09.02.02 | Pathways for Plastic Deformation in Refractory Multi-Principal Element Alloys | Daniel S. Gianola, University of California, Santa Barbara, United States**

The talk shows a study of multi-planar, multi-character dislocation slip in a ternary MPEA, MoNbTi at low homologous temperature, which is studied by using a combination of in situ dislocation observations, microstructural investigations, and atomistic calculations.

► **SF09.03.01 | Insights on Phase Formation from Thermodynamic Calculations and**

Machine Learning of 2436 Experimentally Measured High Entropy Alloys | Ji-Cheng

Zhao, University of Maryland, United States

In this study, both CALPHAD and machine-learning (ML) approaches were employed to analyze the phase formation in 2,436 experimentally measured high entropy alloy (HEA) compositions consisting of various quinary mixtures of Al, Co, Cr, Cu, Fe, Mn, and Ni. The high accuracy of phase prediction method will be very valuable for designing HEAs with targeted crystal structures.

► **SF09.01.03 | Collective Dislocation Motion and Localization of Slip in an HEA |**

Robert Maass, University of Illinois at Urbana-Champaign, United States

The authors focused on the collective dislocation motion of a fcc single-phase solid solution of the well-known AlCoCrFeNi alloy with the aim of revealing how lattice distortions may affect depinning and subsequent motion of dislocations. By comparing to pure single element metals, they conclude that differences primarily are found in the fine details of the time-resolved velocity signature rather than in the averaged quantities, suggesting at the coarse-grained level a very similar collective dislocation velocity in the investigated pure and compositionally complex metals.

► **SF09.06.01 | Novel Precipitate Strengthening Mechanism in a Medium-Entropy Alloy**

| Easo P. George, Oak Ridge National Laboratory, United States

The authors focused on the fact that precipitates can suppress the formation of thermal martensite during processing and heat treatment but allow martensite to form during

subsequent deformation which can lead to high work hardening, strength and ductility. As a results, they shows that by carefully controlling the precipitate characteristics (size and spacing) and matrix composition, it is possible to call upon specific deformation mechanisms precisely when needed.

► **SF09.08.01 | Computational Discovery of Co-Existence of Multiple Short-Range Orders in Si-Ge-Sn Medium-Entropy Alloys | Tianshu Li, George Washington Univ, United States**

In this study, the authors show by combining statistical sampling and large-scale ab initio calculations, that SRO can bear complex forms in SiGeSn MEA, which is a promising material for mid-infrared technology. They identify an unexpected, spontaneous occurrence of two types of SROs, the R-SRO and E-SRO. This study suggests an inherent structural heterogeneity of SiGeSn medium-entropy alloy structure at the nanoscale and even more broadly, the possible ubiquity of such structural heterogeneity in other MEAs/HEAs.

► **SF09.09.01 | FCC-HCP Phase Stability and Grain Refinement Behavior in $\text{Cr}_{20}\text{Mn}_{20}\text{Fe}_{20}\text{Co}_{40-x}\text{Ni}_x$ High-Entropy Alloys | Koichi Tsuchiya, National Institute for Materials Science, Japan**

Present study elucidates the effect of phase stability on deformation behavior and on grain refinement by severe plastic deformation in FCC high-entropy alloys. For the FCC stable alloys with 15~20Ni, HPT led to a drastic increase in H_v after HPT process since nanoscale lamellar accelerates an increase in dislocation density and led to the formation of equiaxed nanograins (~50 nm) by continuous dynamic recrystallization.

Best Oral Presentation

SF09.01.08	Ordering and Magnetism of Cr in FCC Solid Solutions	Flynn Walsh	Lawrence Berkeley National Laboratory, United States
SF09.02.08	ULtrahigh TEMperature Refractory Alloys (ULTERA) Database	Adam M. Krajewski	The Pennsylvania State University, United States
SF09.05.02	Tuning Phase Transformations in Epsilon- Martensite - Pathways to Extend the Limit of Metastability Engineering	Shaolou Wei	Massachusetts Institute of Technology, United States
SF09.05.03	Influence of Co/Ni Ratio on the Shape Memory Effect in the CrMnFeCoNi Alloy System	Je In Lee	Pusan National University, Republic of Korea
SF09.08.04	Corrosion Properties and Protective Oxide Film Characteristics of CrMnFeCoNi High Entropy Alloy and CrCoNi Medium Entropy Alloy	Annica Wetzel	Bundesanstalt für Materialforschung und - prüfung, Germany
SF09.08.07	Crystal Growth and Phase Composition of High-Entropy Rare-Earth Sesquioxides	Matheus Pianassola	University of Tennessee, Knoxville, United States

Best Poster Presentation

SF09.04.01	Asymmetry of Element-Specific Lattice Distortion in 3D Transition Metal-Based Complex Concentrated Alloys	Hyunseok Oh	Massachusetts Institute of Technology, United States
SF09.04.02	Atomic-Scale Measurement of Chemical Short-Range Order (C-SRO) in CrMnFeCoNi High Entropy Alloys and Its Effect on the Deformation Behaviors	Kooknoh Yoon	Seoul National University, Republic of Korea
SF09.04.03	Short Range Order Correlated with Hardening and Softening Behavior of High Entropy Brasses and Bronzes	Anna M. Soper	Harvey Mudd College, United States
SF09.04.09	A Study of Ideal Glass State via High Entropy Metallic Glasses	Ji Young Kim	Seoul National University, Republic of Korea
SF09.04.11	Exploring M ₃ O ₄ Spinel High-Entropy Oxide Nanoparticles for Emissions Catalysis	Sreya Paladugu	University of Tennessee, Knoxville, United States

Program

https://www.mrs.org/meetings-events/spring-meetings-exhibits/past-spring-meetings/2022-mrs-spring-meeting/symposium-sessions/symposium-sessions-detail/2022_mrs_spring_meeting/sf09

2022 MRS Spring Meeting & Exhibit

Symposiums SF13: From Actuators and Energy Harvesting Storage Systems to Living Machines

Organizers: Kris Dorsey, Renee Zhao, Pablo Valdivia y Alvarado, and Andreas Lendlein

Symposium Summary & Objectives:

Technological innovations and requirements of modern applications have driven research toward active materials, capable of performing functions in specific system environments. The realization of directed movement has increased the attention paid to polymeric materials, such as liquid crystalline elastomers or shape-memory hydrogels. Fascinating advances in materials science, including multifunctional soft materials, energy harvesting, and actuation schemes opened up innovative paths to design and operate appliances and robots. Autonomous systems like soft robots can be realized by integrating multiple functions including energy generation, harvesting, storage, sensory functions, as well as actuation. Furthermore, nature, from plants to animals and bacteria, has served as a great source of inspiration for scientists and engineers to design and develop many innovative technologies.

This multi-disciplinary symposium aimed to cover a variety of advances in the design and fabrication of “living” machines as a new generation of robots, and in increasing the efficiency, autonomy, and lifespan of these systems. It also aimed to bring together speakers and audiences from materials science, chemistry, biology, robotics, and computation (among others) to share their perspectives and ideas for the future challenges of this exciting field.

Topics Covered:

- Energy harvesting and storage in multifunctional systems
- Soft robotics and electrically conductive soft or stretchable materials for force sensing, actuating, and electronics
- Application-driven design of multifunctional materials with capabilities of intelligent systems
- Life-like technologies inspired by the scientific investigation of biological systems
- Bionic principles for multifunctionality, bio-inspired design, and biomorphous materials design e.g. biologically derived adhesives
- Self-sensing and self-healing materials
- Stimuli-responsive polymer-based systems that respond to e.g. pH, temperature, (bio)molecules, light, electrical, strain
- Liquid-crystalline elastomers, shape-memory polymers, adaptive polymers
- Ferroelectric, magnetostrictive, and magnetoelectric materials
- Characterization methods for functions and structures
- Integrated Multi-material Fabrication 3D/4D Printing
- Virtual material design, computational design, multiscale modelling and simulation

Presentations:

Monday, May 9		
Soft Actuators I		
invited	Michael Dickey	Soft Energy Harvesters and Actuators Using Liquid Metal
regular	Renee Zhao	Multifunctional magnetic origami robots
invited	Shu Yang	Programming Intelligence in Liquid Crystal Elastomer Composites: From Actuation to Energy Harvesting
Soft Actuators II		
invited	Christopher Lynch	Applications of Large Strain Near Phase Instabilities in Relaxor Ferroelectric Single Crystals
regular	Daehwan Park	Light-Triggered Temperature-Responsive Hydrogel Actuator Reinforced with Bacterial Cellulose for Soft Robotics
regular	Geonoh Choe	Printable and self-healing gelatin conductive ink for dielectric elastomer actuators and strain sensors
regular	Marc Behl	Sequential Coupling of Functions in Hydrogels Enables Shape-memory Hydrogels with pH, Enzyme- or an Inverse Temperature Sensitivity
regular	Saewoong Oh	Nanowire-Forest Grown Shape Memory Alloy for Fast Actuation and its Application to Bio-inspired Robotics
regular	Michael Leveille	Sensitive Multi-Stimuli Responsive Actuating Films Driven by Submolecular Switching
Tuesday, May 10		
Biomaterials / Devices		
invited	David H. Gracias	Smart 3D Microtechnologies for biology and human health
regular	Erfan Pourshaban	Motion-Activated Zn-Air Battery As A Power Supply To Smart Contact Lenses
regular	Benjamin C. Baker	Soft matter actuators for muscle-replacement applications
regular	Huaizhi Li	Manipulation and Assembly of Anisotropic Nanoparticles with Ultrahigh Precision and Versatility in Both Position and Angle Control applications
invited	Victoria Webster-Wood	Biodegradable and Biocompatible Actuators for Soft and Biohybrid Robotics
Biomaterials / Devices and Energy harvesting		
invited	Sung Hoon Kang	Bone-Inspired Autonomously Reinforcing and Damage-Mitigating Materials
regular	Minsoo Kim	Polarization-induced polymer dielectric layers for multifunctional triboelectric applications with self-healing and high-performance
regular	Jonghyeon Yun	Advanced traffic and security systems with facile spray-coating based triboelectric nanogenerator
invited	Philippe Poulin	Piezoelectric Fibers
regular	Hyesu Han	Hybrid energy harvester utilizing dual stimulus of temperature and humidity enabled by thermoelectric and hydrons
Wednesday, May 11		
3D/4D-printing		
invited	Jerry Qi	Multimaterial 3D/4D Printing for Functional Composites
regular	Theo Calais	Freeform Liquid 3D-Printing of Silicone/Epoxy Hybrid Resins for the Fabrication of Functionally Graded Materials Applied to Soft Robotics
regular	Andreas Walker	Spinodal Metamaterials as Pneumatic Actuators for Complex Shape Morphing
invited	Shlomo Magdassi	New materials and approaches for 2D and 3D printing of responsive objects
regular	Rigoberto Castillo Advincula	Nanostructured Layers and 4D Printed Materials: Scalable Stimuli-responsive Functionality
regular	Joël Nicolas Chapuis	Computational Design of 4D Printed Tunable Pneumatic Valves
regular	Theo Calais	Tunable Silicone/Epoxy Hybrid Resins for the Fabrication of Functionally Graded Materials Applied to Flying Devices
Plants		
invited	Patricia Soffiatti	Developmental Themes of a Climbing Cactus: a Bio-Inspired Approach for New Actuator Technologies
invited	Hongli Zhu	Nature-derived Multifunctional Materials and Nature-inspired Designs
invited	Barbara Mazzolai	From plants and soft animals: lessons for a new generation of living machines
regular	Akira Kudo	Micropatterned 2D Pyrolytic Carbon Microlattices Fabricated via Stereolithography
Poster Session		
Nicholas Boynton - Programmable Mechanical Properties in Dynamic Reaction-Induced Phase Separated Thia-Michael Networks		
Youngsu Kim - Shear thickening fluid-based robust and flexible triboelectricity-based harvesting system for impact force sensor		
Kim Tae Bin - Self-Powered Finger Motion-Sensing Structural Color Display		
Aoife Gregg - Light-Actuated Anisotropic Microactuators from CNT/Hydrogel Nanocomposites		
Takuya Paul Wise - Working Fluid Enhancement for a Solar Water Heater System towards Hawaii with Nanofluids		
Kyle Schlafmann – Retention and Deformation of the Blue Phases in Liquid Crystalline Elastomers		

Shuang Cui – Solid-State Tunable Thermal Energy Storage for Building Envelopes		
Monday, May 23 (Virtual)		
Tutorial		
Muhammad Farhan, Andreas Lendlein, Yue Liu, Fabian Meder	Soft Actuators and Robotic Systems for Living Machines	
Tuesday, May 24 (Virtual)		
General Session I		
invited	Sung-Hoon Ahn	Material-Form-Scale Effects of Shape Memory Alloy (SMA) Actuators
invited	Huichan Zhao	Long-Life-Cycle and Damage-Recovery Artificial Muscles via Controllable and Observable Self-Clearing Process
regular	Pravin Varade	Synthesis and Characterisation of Multifunctional Ba0.95CaO.05SnO.09TiO.91O3 Ceramic
Regular	Hyunwoo Kim	Improving the Durability of Soft EPIC Actuators by Modifying Their Viscoelastic Properties by Using Skin-Inspired Hybrid Polymer Film
invited	Peer Fischer	Fabrication of 4D Multifunctional Living Systems
regular	Minje Kim	High Piezoelectric Characteristic of SnS2/SnS Heterostructure for Piezoelectric Nanogenerator
Wednesday, May 25 (Virtual)		
General Session II		
invited	Carmel Majidi	Soft Matter Transducers for Wearable Energy Harvesting & Power
regular	Yue Liu	Actuating Micro-Bowls with a Temperature-Memory
regular	Muireann de h-Ora	Magnetoelectric Coupling in Inorganic/Organic Hybrid Composite Thin Films
regular	Muhammad Farhan	Origami Hand for Soft Robotics Driven by Thermally Controlled Polymeric Fiber Actuators
invited	Thao (Vicky) Nguyen	Computational Design of Thermo-Responsive Hydrogel Crawlers

Highlights:

Workshop highlights included: two dinners organized for the invited speakers, where lively academic conversation helped spark ideas for future work and potential collaborations, a wonderful poster session where young researchers displayed promising new discoveries, and finally a very engaging tutorial on “Soft Actuators and Robotic Systems for Living Machines” that catered for an audience with a varied set of interests.

Contributions to discipline:

The topics covered during the symposium were of great relevance to various active areas of research in advanced fabrication and applications such as soft robotics and “living machines”. Both fundamental and applied studies were showcased covering novel actuation, biomaterials and devices, energy harvesting, 3D/4D printing, and Plant bio-inspiration.

In particular, the nature of the symposium enabled researchers working on both fundamental and applied problems to gain new perspectives on challenges and enabling technologies.

During the symposium, 12 researchers delivered invited talks. Four researchers presented posters and 24 delivered oral presentations.

Future direction for this symposium:

The organizing committee will look for new opportunities in MRS to continue covering themes related to advanced fabrication, multifunctional materials, and novel applications to robotics and intelligent systems.

Items supported with ARO funds:

Seven early career researchers (three PhD students, two postdoctoral researchers, and two assistant professors) received travel grants for their registration from ARO funds. These travel grants were delivered on the basis of the following categories:

1. Best invited presentation: Novel actuators and sensors 1: Ben Baker, University of Bristol, "Soft matter actuators for muscle-replacement applications".
2. Best invited presentation: Novel materials or fabrication: Hongli Zhu, Northeastern University, "Nature-derived Multifunctional Materials and Nature-inspired Designs".
3. Best invited presentation: Novel actuators and sensors 2: Victoria Webster-Wood, Carnegie Mellon University, "Biodegradable and Biocompatible Actuators for Soft and Biohybrid Robotics".
4. Best presentation for novel actuators and sensors: Michael Leveille, University of California Merced, "Sensitive Multi-Stimuli Responsive Actuating Films Driven by Submolecular Switching".
5. Best presentation for novel materials or fabrication: Theo Calais, Singapore University of Technology and Design, "Freeform Liquid 3D-Printing of Silicone/Epoxy Hybrid Resins for the Fabrication of Functionally Graded Materials Applied to Soft Robotics".
6. Best presentation for energy harvesting or storage: Huaizhi Li, University of Texas Austin, "Manipulation and Assembly of Anisotropic Nanoparticles with Ultrahigh Precision and Versatility in Both Position and Angle Control applications".
7. Best poster: Aoife Gregg, University of Cambridge, "Light-Actuated Anisotropic Microactuators from CNT/Hydrogel Nanocomposites".

Federal Financial Report

(Follow form Instructions)

OMB Number: 4040-0014

Expiration Date: 02/28/2025

1. Federal Agency and Organizational Element to Which Report is Submitted

Army Research Office

2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment)

3. Recipient Organization (Name and complete address including Zip code)

Recipient Organization Name: Materials Research Society

Street1: 506 Keystone Drive

Street2:

City: Warrendale

County:

State: Pennsylvania

Province:

Country:

ZIP / Postal Code: 15086

4a. UEI

MFPJGRD1NWE3

4b. EIN

31-1037979

5. Recipient Account Number or Identifying Number
(To report multiple grants, use FFR Attachment)

2022 MRS Spring Meeting

6. Report Type

- ☐ Quarterly
☐ Semi-Annual
☐ Annual
☒ Final

7. Basis of Accounting

- ☒ Cash
☐ Accrual

8. Project/Grant Period

From:

5/1/22

To:

12/31/22

9. Reporting Period End Date

12/31/22

10. Transactions

Cumulative

(Use lines a-c for single or multiple grant reporting)

Federal Cash (To report multiple grants, also use FFR attachment):

a. Cash Receipts

15,523.00

b. Cash Disbursements

15,523.00

c. Cash on Hand (line a minus b)

0.00

(Use lines d-o for single grant reporting)

Federal Expenditures and Unobligated Balance:

d. Total Federal funds authorized

20,037.00

e. Federal share of expenditures

15,523.00

f. Federal share of unliquidated obligations

g. Total Federal share (sum of lines e and f)

15,523.00

h. Unobligated balance of Federal Funds (line d minus g)

4,514.00

Recipient Share:

i. Total recipient share required

j. Recipient share of expenditures

k. Remaining recipient share to be provided (line i minus j)

0.00

Program Income:

l. Total Federal program income earned

m. Program Income expended in accordance with the deduction alternative

n. Program Income expended in accordance with the addition alternative

o. Unexpended program income (line l minus line m or line n)

11. Indirect Expense						
a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
g. Totals:				0.00	0.00	0.00

12. Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:

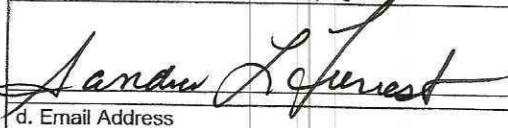
13. Certification: By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

a. Name and Title of Authorized Certifying Official

Prefix: First Name: Middle Name:

Last Name: Suffix:

Title:

b. Signature of Authorized Certifying Official 	c. Telephone (Area code, number and extension) 7247792712
d. Email Address forrest@mrs.org	e. Date Report Submitted 2/13/23

14. Agency use only: