MATERIAL
NEWS

Materials Science & Engineering
University of California, San Diego

CONTENT

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Cover Figure:
Moire patterns in graphene

Image courtesy:
N. Sarkar (Dr. Prab Bandaru's Research Group)

LETTER
FROM THE DIRECTOR

It has been a year since normal life as we knew it has been upended. There seems to be a light at the end of the tunnel though as we eagerly await the After Pandemic (A.P.) era! However, research has continued behind masks and with the participants six feet apart, in the Materials Science Program (MATSE) at UC San Diego. In this newsletter, we highlight representative work of five of the five score faculty associated with the program. The program is wide-ranging and encompasses engineering (Mechanical and Aerospace, Electrical, Structural, Nanoengineering, and Bioengineering), and the science departments (Physics, Chemistry and Biology), and the School of Medicine. Indeed, MATSE is dynamic proof of the pervasiveness of materials science and on a continual upward trajectory of growth and development.

You will find, in the newsletter, samples of the work by faculty in the program, ranging over optical bioimaging, nanoparticle-based valves for electron spins, batteries that work at low temperatures, mechanical metamaterials, and extending to dynamically programmable neural trees for AI and neuromorphic computing.

A few significant faculty honors, e.g., with respect to innovations in biomedical materials engineering, are highlighted. A seminal award named after a pioneering ex-colleague, the late Prof. Gareth Thomas (who worked at both UC Berkeley and UC San Diego), was given to Kevin Kaufmann, an innovative graduate student whose work included the application of machine learning based algorithms to the discovery of novel materials, such as high entropy alloy systems.

We were also glad to welcome more than 50 new graduate students this year with far reaching diversity and scientific and technological range. In addition to regarding the accomplishments of our students, we take immense pride, and follow the career trajectories of our alumni. Dr. Irene Chen, who worked at both Intel and Lockheed Martin, discusses how harnessing programming skills may be invaluable for work in industry. Dr. Byung Kim, who is presently working in Korea advises attending seminars over campus "as much as you can" for broad understanding. The award of a new MRSEC (Materials Research Science and Engineering Center) from the National Science Foundation with emphasis on (a) predictive assembly of materials, and (b) engineered living materials, is expected to further bolster the outreach of the MATSE program.

We hope you enjoy reading the newsletter and always welcome your feedback, support and good wishes.

Sincerely yours,

Prab R. Bandaru

Perovskite Neural Trees

Artificial intelligence (AI) and machine learning are poised to impact every aspect of society. Major research efforts are being devoted to developing artificial neurons and synapses. One key requirement for AI to be sustainable is to create artificial synapses, those structures in the brain that enable memory and learning, and operate (that is, remember and learn) over extended time spans. Electrical synapses encode memory by adapting their resistance (known as their "weight") to electrical stimuli. Although the resistance of a synapse increases or decreases with stimuli over the life of the host, the resistance will not change so much that it catastrophically breaks the neural circuit. Evolution has provided a slow saturation point, beyond which the circuit is stable and so continues to learn throughout the life of the host.

This remarkable weight-limiting memory mechanism can be visualized in a tree structure, similar to decision-tree algorithms in mathematics. Over a period of time, in response to a sequence of identical stimuli, the weight of a synapse evolves along a certain self-limited trajectory, creating a "branch." If the stimuli then change in pulse, intensity, or duration, the trajectory changes into another branch. After many such changes of the stimuli, the synaptic weight trajectory has many branches and thus many "learned" states, as shown below.
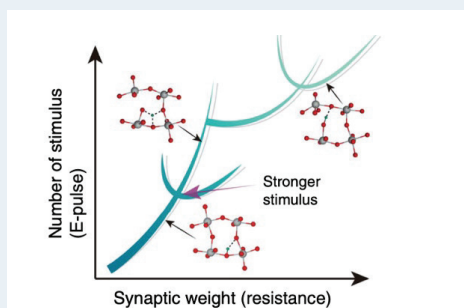
Trees, in fact, are a mathematical concept in number theory that was used to develop the original neural network theories nearly 40 years ago. Up to now, creating tree-based memory in real materials has proven impossible. They have only existed in software algorithms or cartoon drawings describing hypothetical materials. The difficulty has been in finding real materials that can host multiple states that can each be uniquely identified electrically and are capable of learning.

These problems—that the material host multiple states that can be identified and learn—have foiled researchers. Until now. We've solved these problems via atomic-scale control over proton migration in a nickel-oxide thin film subject to nanosecond electric pulses, as shown below.
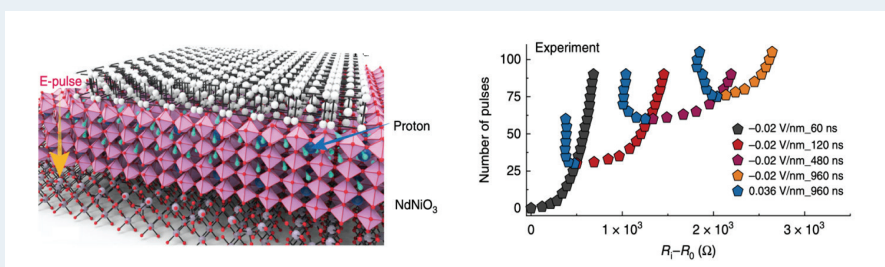
The resistance of these materials is highly sensitive to proton doping (one proton addition per chemical formula leads to ~10 orders of magnitude change in electrical resistance) and electric field pulses (the resistance changes upon applying electric field pulses). The latter occurs through the migration of protons due to the electric field. Together, these aspects form the basis of neuromorphic hardware synapses. Moreover, the resistance state of the material saturates after many pulses, mimicking the self-limiting behavior of synapses which also generate other trajectories upon stimuli of different characteristics. Therefore, we have demonstrated the ability to generate tree-like trajectories of the electrical resistance (see below). The quantum mechanical amplification effect from proton drift enables a vast number of tree memory states that are dynamically programmable. We show they can operate safely without catastrophic breakdown and they can learn. The results open up a new dimension of safe hardware for AI and neuromorphic computing.

Hai-Tian Zhang1,2,#, Tae Joon Park1,#, Ivan A. Zaluzhnyy3,#, Shakti Nagnath Wadekar4, Sukriti Manna5,6, Robert Andrawis4, Peter O. Sprau3, Yifei Sun1, Qi Wang1, Zhen Zhang1, Hua Zhou7, Zhan Zhang7, Badri Narayanan8, Gopalakrishnan Srinivasan4, Nelson Hua3, Evgeny Nazaretski9, Xiaojing Huang9, Hanfei Yan9, Mingyuan Ge9, Yong S. Chu9, Mathew J. Cherukara5, Martin V. Holt5, Muthu Krishnamurthy10, Oleg Shpyrko3, Subramanian K.R.S. Sankaranarayanan5,6, Alex Franó3, Kaushik Roy4, and Shriram Ramanathan1

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ALEX FRAÑÓ

Alex Frañó is Assistant Professor at the University of California, San Diego. He obtained his Bachelor's degree in Physics from the National University of Honduras in Tegucigalpa. Then, after pursuing a career in music in Mexico City and other places, he returned to Physics to work on his Master's degree at the University of Stuttgart. He did his PhD research with Prof. Bernhard Keimer the Max Planck Institute for Solid State Research stationed at the synchrotron facility in Berlin. He won the Ernst-Eckhard-Koch Prize and the Springer Outstanding PhD Research Prize. He was later awarded the University of California (UC) Presidential Postdoctoral Fellowship to work at UC Berkeley with emeritus Chancellor Robert Birgeneau. Now he is an Assistant Professor and he has recently won the Sloan Research Award 2020 and the Cottrell Scholar Award 2021. He is also the Assistant Director of an "Energy Frontier Research Center" funded by the Department of Energy to study "Quantum Materials for Energy Efficient Neuromorphic Computing"; with the goal of developing a new materials' platform for a computing paradigm inspired by the brain. His other research interests include strongly correlated electron systems, design and growth of transition-metal oxide heterostructures, and various forms of x-ray scattering tools to probe their properties.

Transition Waves in Metamaterials with Spatio-temporal Potentials

Solitons[1] are spatially localized, large-amplitude solutions to non-linear equations which describe a variety of processes within materials science, e.g., transformation phenomena which impact material performance. Recently, mechanical metamaterials[2] characterized by multi-stable internal architectures have exhibited similar behavior, extending atomic-scale physics to the readily-accessible structural level. However, strategies for soliton management in metamaterials are few and often "lock in" performance, preventing spontaneous adjustments to the transformation kinetics and phase distribution desired for applications.

At the atomic scale, the environment in which a soliton propagates is hardly ideal: external fields, thermal noise, and impurities each affect the soliton dynamics and have been utilized as instruments of control. Inspired by these results, in a recently published article[3], we propose a strategy for soliton management in metamaterials with space-time variable potentials, enabling on-demand, post-fabrication control of the associated phase transformation kinetics and distribution. The results contribute to the theoretical understanding of soliton dynamics in multi-stable metamaterials, facilitating the integration of these systems into applications.

As a continuum approximation of the discrete lattice dynamics, Eq. (1) describes the evolution of the displacement field, u:

$$u_{,tt} - u_{,xx} + \psi'(u) = f(x,t) - \eta u_{,t}, \quad (1)$$

where $\psi(u)$ represents the local bi-stability and $f(x,t) = g(x,t)u_{,xx} + h(x,t)\psi'(u)$ is the forcing emerging form the spatio-temporal potential function. In the context of the physical metamaterial, coefficients $g(x,t)$ and $h(x,t)$ stem from, e.g., prescribed external fields on stimuli-responsive elastic constituents. For analysis, in Ref. 4, we adopt the (Newtonian) particle description for supported solitons with q and $\dot{q}$ the particle position and velocity, respectively. For a slow-moving soliton, we formulate the soliton governing equation:

$$\ddot{q}(t) = \frac{1}{m_0} I(t) - \eta \dot{q}(t) \quad (2)$$

where

$$I(t) = \int_{-\infty}^{\infty} f(x,t)u_{,x} \, \mathrm{d}x$$

To demonstrate the effectiveness of our strategy as well as to validate our theoretical predictions, we consider soliton dynamics in 1D/2D systems. Figure 1b compares the predicted [Eq. (2)] and simulated [Eq. (1)] response of an initially static soliton in the static, linear potential grading of a 1D metamaterial where excellent agreement is observed. For vanishing initial conditions and $\bar{\eta} \neq 0$ Eq. (2) gives the steady-state velocity as $\dot{q}_{ss} = I/m_0\bar{\eta}$. Within a 2D system, we initiate a circular phase which, subsequently, tends to collapse inward and vanish due to an energy-minimizing, "surface tension" effect related to the wave-front curvature (Fig. 1c). However, we show that a radially directed spatio-temporal potential modulation is able to stabilize an open phase phase by repelling the wave front. Moreover, by directing the modulation along specific axes, the shape of the wave front can be deformed away from circular on demand.
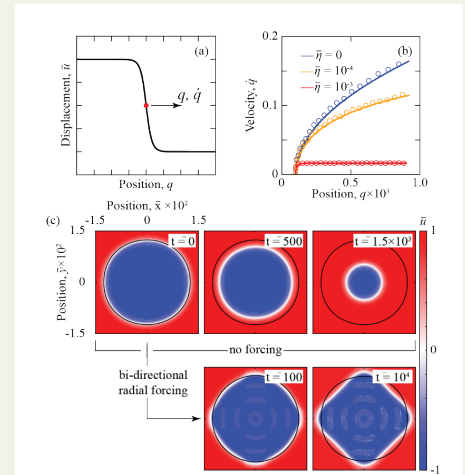
FIG. 1. (a) Soliton profile. (b) Soliton response in a static, linear potential grading in a 1D lattice: theory (solid line) and simulation (dots). (c) (top row) The collapse of a circular wave front in a 2D lattice in the absence of a potential variation; (bottom row) the stabilization and shaping of the same wave front by a spatio-temporal potential variation.

[1] M. Remoissenet, Waves called solitons: concepts and experiments. 2013.
[2] D. M. Kochmann and K. Bertoldi Appl. Mech. Rev., 2017.
[3] V. Ramakrishnan and M. J. Frazier Appl. Phys. Lett., 2020.

Michael Frazier joined the Department of Mechanical and Aerospace Engineering at UC San Diego in the Fall of 2017 after completing his postdoctoral fellowship at the California Institute of Technology, where his research focused on the dynamics of materials with engineered nonlinear and multistable responses. He received his Ph.D. from the University of Colorado, Boulder in the Fall of 2015 where his research (supported by an NSF Graduate Research Fellowship) investigated the impact and potential functionality of vibrational wave propagation in dissipative architected materials for which he received the 2013 John A. Vise Graduate Student Excellence Award. He earned his bachelor's degree from Embry-Riddle Aeronautical University."

MICHAEL FRAZIER

Shi Lab-Laboratory of Optical Bioimaging and Spectroscopy

Research in Shi Lab

Our goal is to develop and apply new ultrafast laser scanning optical imaging and spectroscopic technologies, such as stimulated Raman scattering (SRS) spectroscopy and imaging, and multiphoton microscopy (MPM) imaging for studying metabolism, neurodegenerative diseases, cancer, drug delivery, development, and aging processes in living organisms.

We are applying bioorthogonal labelling SRS imaging techniques and MPM for directly visualizing complex molecular events in brain, cancer, and metabolic diseases at sub-cellular scale in situ, which offering powerful tools potentially for disease detection, diagnosis and treatment, as well as for mechanistic understanding of scientific fundamentals.
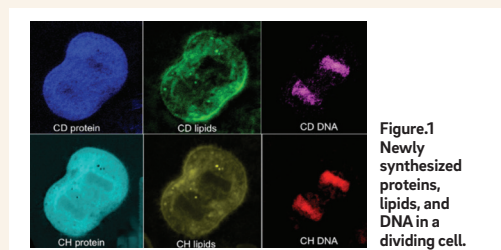
Figure.1 Newly synthesized proteins, lipids, and DNA in a dividing cell.

Deep Imaging of Drug Delivery

Small bioorthogonal Raman probes can be attached onto small drug solutes and imaged by SRS, making them ideal for drug-delivery imaging in brain.

For example, by labeling small drugs with deuterium or alkyne tags and injecting them into animal vascular system, the SRS imaging platform can visualize drug delivery across the BBB and diffusion into the brain parenchyma at subcellular resolution.

We apply bioorthogonally labeled SRS combined with multiphoton fluorescence microscopy to investigate the structure and function of BBB in vivo by assessing the relationship between BBB permeability and neural activity-regulated signaling in vascular endothelial cells.

Development of an optimal systemic drug delivery strategy to the brain will require noninvasive or minimally invasive methods to quantify the permeability of the cerebral microvessel wall or blood-brain barrier (BBB) to various therapeutic agents and to measure their transport in the brain tissue. Dr.Shi has used multiphoton microscopy to determine BBB permeability. The quantitative transport parameters measured can be used to develop better strategies for brain drug delivery.
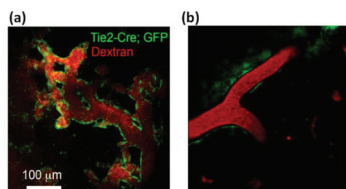
Figure.4 Mouse brain blood vessel filled with dextran (red). Green: endothelial cell (left), and Gcamp 6 labeled astrocyte (right).

Deep Tissue Imaging Platform

One of the major challenges in biomedical imaging is to visualize deep in an intact tissue with desired cellular resolution. Optical microscopy is still the only method for in situ imaging at a sub-micrometer scale.

Our study discovered that light at certain near-infrared (NIR) regions would significantly increase the tissue imaging depth. Specifically, the highest imaging depth is reached at the "Golden Window" (window III, 1600-1870 nm), with the maximum transmittance (percentage of light passes through the tissue) and minimum absorbance (percentage of light absorbed in the tissue), which is superior to windows I (650-950 nm), II (1100-1350 nm) and IV (centered at 2200 nm).

We are developing novel deep tissue imaging technologies for different imaging modalities such as SRS and MPF microscopy to obtain a better understanding of the structural functional interactions in biological systems.

We are developing a novel isotope-probed multiplex stimulated Raman scattering (ipm-SRS) microscopy imaging platform for visualizing deep tissue metabolism and drug delivery in living organisms. It combines (1) bioorthogonal labeling to examine the uptake and synthesis activity in tissues, and (2) label-free SRS and MPF of endogenous signals to examine cell structure, chemical composition, and biomolecular trafficking.

We developed a new nonlinear process - enhanced stimulated Raman scattering (ESRS) that proposes a new promising approach for improving SRS signals.

Above imaging tools allow us to conduct metabolic imaging on cells, tissues, live animals, and more.

Cells organize to form intricate 3D biological structures that are closely related to their physiological functions. It is critical to assess their structural and functional correlations at an organ-wide scale when study metabolic activities.

Large-scale volumetric SRS imaging techniques are necessary for in-depth understanding of whole-organ metabolic heterogeneity. A new and effective tissue-clearing approach is also required that is compatible with SRS imaging and can better reveal morphogenesis and chemical changes in normal and pathological conditions.

We are also developing and applying a tissue clearing assisted general optical microscopy platform for volumetric SRS imaging that can visualize both the chemical composition and the metabolic activities in large-scale biological specimens.
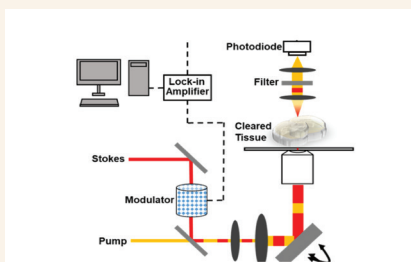

Figure.2 Experimental deep tissue imaging system

Deep Imaging of Metabolism

Many neurodegenerative disorders, such as Alzheimer's Disease and Multiple Sclerosis, and cancer usually have coexisting metabolic dysfunction. The SRS imaging platform can be used to identify early stage in situ metabolic changes during the progression of aging, obesity, development, neurodegenerative diseases, cancer, and more.

Direct visualization of metabolic dynamics in living animals with high spatial and temporal resolution is essential to understanding many biological processes. We design a platform that combines D2O probing with stimulated Raman scattering(DO-SRS) microscopy to image in situ metabolic activities. Enzymatic incorporation of D2O-derived deuterium into macromolecules generates C−D bonds, which track biosynthesis in tissues and can be imaged by SRS in situ. Within the broad vibrational spectra of C−D bonds, we discover lipid-, protein-, and DNA-specific Raman shifts and develop spectral unmixing methods to obtain C−D signals with macromolecular selectivity. DO-SRS microscopy enables us to probe de novo lipogenesis in animals, image protein biosynthesis without tissue bias, and simultaneously visualize lipid and protein metabolism and reveal their different dynamics. DO-SRS microscopy, being noninvasive, universally applicable, and cost-effective, can be adapted to a broad range of biological systems to study development, tissue homeostasis, aging, and tumor heterogeneity.
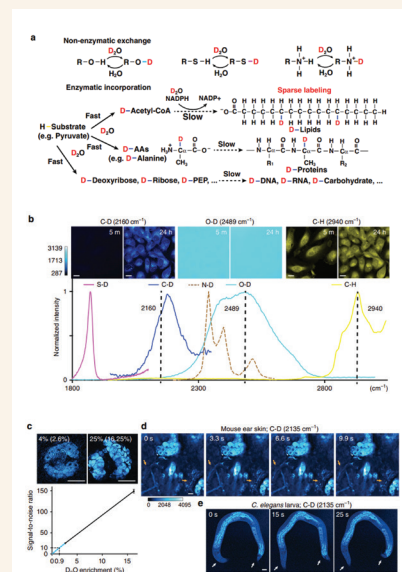
Figure.3 SRS microscopic imaging of biosynthetic incorporation of deuterium from D2O into macromolecules in living cells and animals

Dr. Shi is an Assistant Professor in the Department of Bioengineering at the UC San Diego Jacobs School of Engineering. She received her Ph.D. in Biomedical Engineering from the City College of New York (CCNY). She was a postdoc at the Institute for Ultrafast Spectroscopy and Lasers at CCNY. She then moved to the Department of Chemistry at Columbia University for her second postdoctoral training in biophotonics, prior to her joining UC San Diego. Dr. Shi major scientific contributions include the discovery of the "Golden Optical Window" for deep brain imaging, and the development of a breakthrough platform that combines deuterium probing with stimulated Raman scattering microscopy for optical imaging of metabolic dynamics in living organism in situ. Dr. Shi won the Blavatnik Regional Awards for Young Scientists in 2018. Her primary research interests focus on developing and applying novel optical techniques for studying neuroscience, cancer, and metabolism."

LINGYAN SHI

# Low-T Battery: Batteries That Can Work In Extreme Temperatures

The current temperature operating range and energy density provided by commercial lithium-ion batteries is insufficient for supporting advanced electronic devices in extreme environments, such as the arctic, deep sea, and outer space. Furthermore, state-of-the art cells have been historically limited in low-temperature charging capability, where cells must be heated during the charge process, necessitating additional warming equipment which further reduces the energy density and efficiency of these devices. To address the concerns regarding energy density, lithium metal batteries have attracted growing interest as a next-generation battery technology, however their operation and limitations at ultra-low temperature have just begun to be understood.

Kinetic limitations in batteries are broadly thought of as attributed to impedance associated with bulk transport through the electrolyte, ion migration through the solid-electrolyte interphase, and charge-transfer. While at room temperature these factors have all been seen to play a role, it has been previously observed that the charge-transfer impedance is the overwhelming contributor for low-temperature performance fade. While charge-transfer is a relatively complicated physical process, at low-temperatures this process has been

Ultra-Cold Cycling

Strong Li⁺/Solvent Binding — Dendritic Li Plating

Homogenous Li Plating — Weak Li⁺/Solvent Binding

hypothesized to be dominated by desolvation, a process in which the lithium ion sheds its coordinating solvent in the electrolyte at the electrode. Despite this, design strategies to reduce the desolvation penalty are in their early stages, which severely limits the advancement of low-temperature battery electrolytes.

Professor Zheng Chen's group shows that the structure of the Li+ ion in the electrolyte plays a defining role in the desolvation kinetics, and set out to demonstrate this in order to pave the way for the development of lithium metal batteries that can be both charged and discharged at extremely low temperatures. In doing so we identified and demonstrated a system in which the low-temperature interphasial kinetics are vastly improved due to an alteration of the Li+ solvation environment featuring weak Li+/solvent interactions. This improved kinetics resulted in a transformative effect on the low temperature Li metal plating efficiency as compared to a typical control electrolyte, despite a reduction in bulk transport and a comparable SEI composition.

The investigation and development of these systems were fueled by an effective collaboration between the Chen group, Professor Ping Liu and the theory expertise of Professor Tod Pascal. The produced results indicate that effective strategies for improving the interphasial kinetics in batteries exist, and require an effective integration of both computational theory and experimental study in order to probe system properties that are not readily apparent. The results presented in our work (Nature Energy, 2021, 6, 303-313.) will prompt a deeper examination of electrolyte properties, and lead the field to a more robust view of charge transfer in Lithium batteries under various operating conditions.
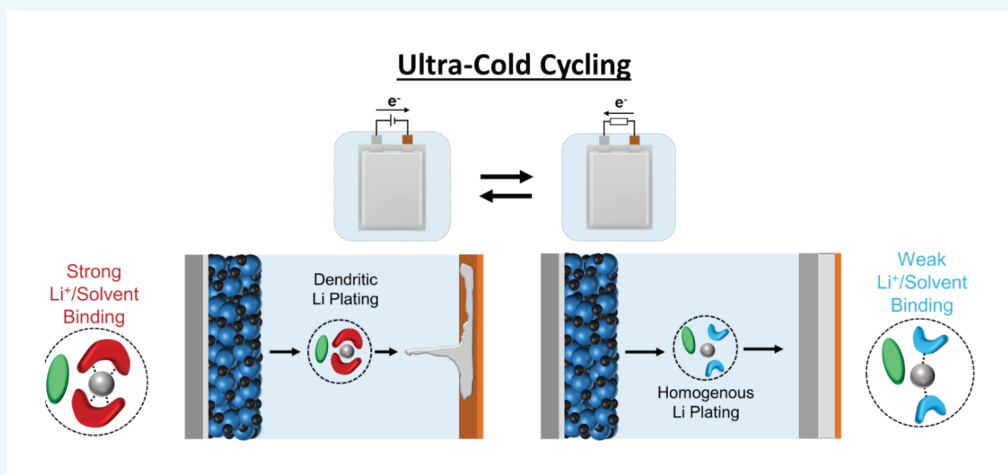
Zheng Chen is an Assistant Professor in the NanoEngineering Department at the University of California, San Diego. Zheng Chen received his Ph.D. at UCLA in 2012 under the supervision of Prof. Yunfeng Lu in the Department of Chemical and Biomolecular Engineering. His Ph.D. work mainly related to design and synthesis of nanostructured materials for electrochemical energy storage devices. From 2013-2016, he was a postdoctoral associate working with Prof. Zhenan Bao in Chemical Engineering and Prof. Yi Cui in Materials Science and Engineering at Stanford University, where his work focused on functional polymer materials for enhanced energy density, longer cycling lifetime and improved safety of batteries.

ZHENG CHEN

Pseudo Spin Valve Behavior in Colloidally Prepared Nanoparticle Films

Magnetoresistance sensors are based on composite materials whose resistance varies with magnetic field. These composite materials have traditionally been epitaxially grown multilayers of magnetic thin films. The alignment of adjacent layers' magnetic moments with or against each other leads to a low or high resistance state, respectively. This basic concept can be realized in nanogranular materials, where the magnetic alignment of adjacent grains determines the resistance of the material as a whole. The use of colloidal nanoparticles to form these nanogranular materials is attractive because of the precision of modern colloidal nanoparticle synthesis, the tunability of these nanoparticles' properties, and the ease of their solution-processing.

Colloidally prepared magnetoresistance devices have been limited by the intrinsic magnetic response of the nanoparticles: a gradual shift from high to low resistance with increasing magnetic field. The Rinehart group has demonstrated a simple solution to this issue by making composite nanoparticle films to mimic the spin valve used to increase the sensitivity of multilayer thin film magnetoresistance sensors. In a spin valve a 'hard'
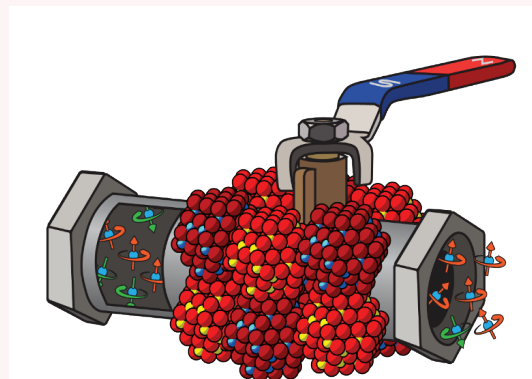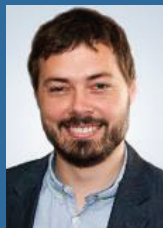

Figure 1 - Conceptual illustration of a composite magnetic nanoparticle spin valve
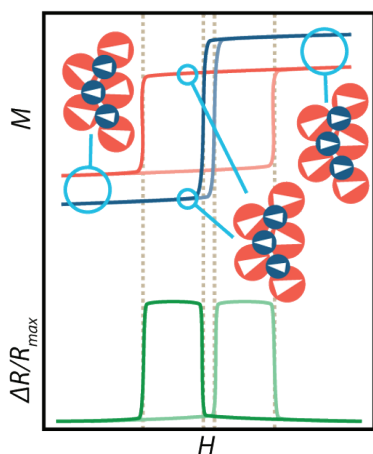
magnetic layer has its moment fixed, while the 'soft' layer's moment is free to rotate. Thus, only a small change in magnetic field can switch the sensor between low and high resistance. In his PhD work, UCSD Materials Science graduate student Benjamin Zhou has demonstrated that composite films of colloidally-prepared 'hard' $CoFe_2O_4$ and 'soft' Fe_3O_4 magnetic nanoparticles can be tuned to enhance sensitivity through a spin valve mechanism. As predicted by the model, it is crucial to have two types of nanoparticles with maximized mixing and minimized magnetic exchange interaction, allowing the 'soft' nanoparticles to rotate their magnetic moments freely.

The non-interaction between the two types of nanoparticles means that the composite nanoparticle films can be modularly designed with predictable electronic properties. A series of variable-ratio films shows that different magnetoresistance behaviors can be selected by varying the hard/soft material ratio. For example, 100% and 75% $CoFe_2O_4$ films have bistable magnetoresistance, while the 25% $CoFe_2O_4$ film has the greatest responsivity. As Benjamin Zhou works to complete his dissertation in the Rinehart group, he hopes to leverage this modularity to create a set of nanoparticle films with a wide scope of nanoparticle starting materials, thereby generating magnetoresistance behaviors optimized over a broad range of conditions. Currently, much promise has been shown in the use of improved 'hard' magnetic nanoparticles as well as the incorporation of antiferromagnetic components to further improve the spin valve behavior of these composite nanoparticle films.

Figure 2 - A schematic of the magnetic state (M) and resulting magnetoresistance ($\Delta R/R_{max}$) of a composite hard/soft magnetic nanoparticle material at varying magnetic fields (H)

Jeffrey Rinehart completed his PhD at the University of California, Berkeley. His research focuses on bottom-up design of molecular and nanoscale magnetic materials. He is currently an Associate Professor in the Department of Chemistry and Biochemistry and affiliate of the Materials Science and Engineering Program at the University of California, San Diego.

JEFFREY RINEHART

MATSE ALUMNI INTERVIEWS

BYUNG WOOK KIM

PhD. 2014, Bandaru group

Presently working at Hyundai Motors, Korea on vehicular thermoelectric generator prototypes. His daily work consists of synthesizing thermoelectric materials for both performance and reliability.

What was the thesis topic? How did the related work impact your future career trajectory?

My thesis topic was thermal transport in nanostructures. During graduate school while the research purpose was to understand how each element/factor affects thermal properties of nanocomposites, the research work spanned from A to Z, which is a philosophy of my advisor, such as synthesizing materials, building measurement apparatus, analysis, and modeling. These diverse work experiences gave me strength to start a research project from scratch and flexibility to contribute related ongoing projects as well.

Could you briefly describe your career path from UCSD to now?

After getting Ph.D., I have worked to develop performance and reliability of thermoelectric materials and to apply TE generators to vehicles at Hyundai Motor Group for about 5 years.

In retrospect, what were the highlights of MATSE program?

Most of all, interdisciplinary nature. Regardless of department any graduate students in UCSD could join the program which matched their research interests and gave them opportunities to collaborate with other researchers of different majors and labs.

Any interesting memories (both good and bad) of the MATSE program?

Supposedly like most graduate students, I felt some relief when passing exams and sense of accomplishment when receiving acceptance letters of journal publication. But I have struggled to enhance research outcomes.

What were the suggestions/advice for MATSE students who would like to get into industry?

Set time lines to achieve your goals and try to be on time. Try to drive your project yourself sometimes! No matter how you are familiar with the subject, try to attend seminars as much as you can, and learn how they present their works and discuss with audiences.

IRENE CHEN

My Thesis title is:
Flexible Dermal Armor:
Designs Learned from Nature.

What was your thesis topic in UCSD? How did the related work impact your future career trajectory?)

2015-2017 - Intel - Module and Device Yield Engineer - I was working as a Module engineer with my Materials Science and Engineering background.
2017-present - Lockheed Martin - Stress Analysis Engineer - Mostly using Finite element software (LS-DYNA and NX/Nastran) to analyze structural stress on spacecraft launching components.

In retrospect, what were the highlights of the MATSE program?)

I enjoyed the classes in the MATSE program, in particular, the solid-state diffusion, thermodynamics of material and electronic properties of materials. These classes really helped with my work at Intel. With my current work, mostly the classes from undergrad helped. Because of the PhD program, I was able to study and catch up to speed on a particular subject fairly quickly, for example, I picked up the book Solid Mechanics and was able to study and learn it on my own. The defense of the dissertation itself was able to sharpen my mind and allow me to think critically which I thought as a Scientist is a must-have and learnable quality.

Any interesting memories (both good and bad!) of the MATSE program?

The most memorable highlights were being able to embrace myself in a highly intellectual environment and knowing lots of smart people and learning from them. I wished I could learn some programming skills on the side while I was in the program to brush up my skill set to prepare me for the industry.

What are your suggestions/advice for MATSE students who would like to get into industry?

Enjoy your time in the program and learned as many diversified subjects as possible. It will all be useful at some point. For example, I was able to connect with all sorts of engineering disciplines (renewable energy, Bioengineering in terms of genome sequencing, Mechanical engineering and even Quantum physics) grad students on campus and learning what top-notch research topic they are working on. Those were valuable knowledge and keep in touch with them.

SUNMI SHIN WINS 2020 CHANCELLOR'S DISSERTATION MEDAL

The University of California San Diego 2020 Chancellor's dissertation medal was awarded for my PhD research in Active Thermal Engineering Using Nanostructures. The dissertation presents my work aiming to actively manipulate heat transport in multidisciplinary approaches, including thermo-electric and thermo-photonic engineering.

Heat conduction process is often difficult to control due to its diffusive nature. The feature is distinct from optical and electrical energy transport with highly advanced technologies. If one could engineer the transport of thermal energy as well, arguably the most ubiquitous form of energy, a variety of energy transport and conversion technologies can be improved. Active control of thermal transport is of significant interest for a wide range of applications, such as thermoregulation of individuals, buildings, vehicles and batteries, renewable energy conversion, bio/chemical sensing, and micro/nanomanufacturing. The scope of my study ranges from the fundamental nanoscale heat transfer beyond the classical limit to personal thermoregulation applications.

RESEARCH SUMMARY

Thermo-Electric Engineering: High-Efficient Printable Thermoelectric Materials

The former part of the dissertation discusses the strategy for active thermoregulation of individuals using flexible thermoelectric devices. The ongoing effort to reduce the energy consumption of climate control systems has mainly focused on the development of more efficient thermoregulation technologies. In particular, interests in personalized thermoregulation devices have inspired studies on high-performance flexible thermoelectric materials for integration with emerging wearable electronics. Towards this end, I have developed a generic screen-printing strategy using nanostructured thermoelectric materials with optimized printing ink formulation.

Thermo-Photonic Engineering: Radiation and Conduction Heat Transfer Mediated by Surface Phonon Polaritons
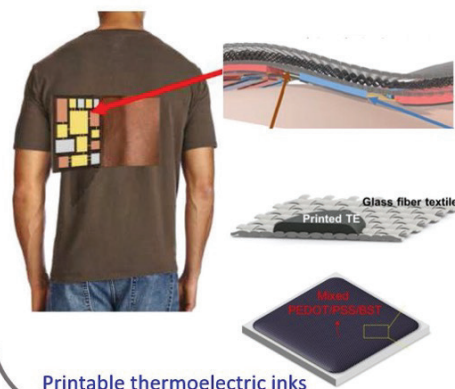
The second part of the dissertation introduces a thermo-photonic engineering approach to manipulate nanoscale thermal transport by using surface phonon polaritons (SPhP). Thermal radiation, as described by Planck's law, is generally considered incandescent in classic textbooks. However, as Planck himself originally noted in his book "The theory of heat radiation," the broadband nature of the emitting energy distribution no longer holds at a length scale smaller than the thermal wavelength, which is around 10 microns at room temperature. This feature can be utilized to alter the traditional concept of broadband thermal emission from a blackbody to create a coherent, near monochromatic heat source.

Foremost, this interdisciplinary work combines two interesting worlds: heat transfer and photonics. The systematic study of thermal transport medicated by phonon polaritons will lead to new understanding of heat conduction beyond the common regimes of electronic and phononic heat conduction and will potentially offer new approaches to engineer thermal properties in nanostructures. These new concepts are especially attractive in that heat can be guided along the surface, and this feature mimics optical wave guides. It greatly extends the degree of freedom to engineer heat transfer.
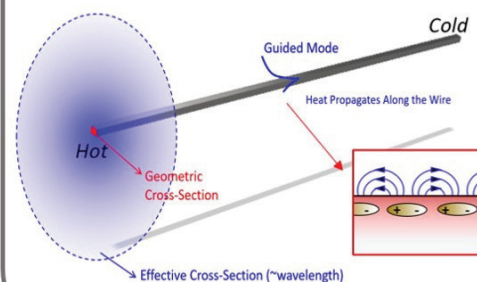
Thermo-Electric

Personalized Thermoregulator

Glass fiber textile
Printed TE

Mixed PEDOT:PSS/BST

Printable thermoelectric inks

Thermo-Photonic

Super-Planckian Heat Transport

Cold
Guided Mode
Heat Propagates Along the Wire
Hot
Geometric Cross-Section
Effective Cross-Section (~wavelength)

UC SAN DIEGO MATERIALS RESEARCH SCIENCE AND ENGINEERING CENTER

The National Science Foundation has awarded University of California San Diego researchers a six-year $18 million grant to fund a new Materials Research Science and Engineering Center (MRSEC).

These research centers are transformative for the schools that earn them, putting their materials science research efforts into the global spotlight. In addition to research and facilities funding, MRSEC centers provide sustained research opportunities for both graduate and undergraduate students, and resources to focus on diversifying the pool of students studying materials science.

The UC San Diego labs funded by this new MRSEC will focus on two important, emerging approaches to build new materials aimed at improving human lives.

The first research theme is all about developing new ways to control the properties of materials during their synthesis by controlling how they transition, from the smallest atomic building blocks to materials that are large enough to see with the human eye.
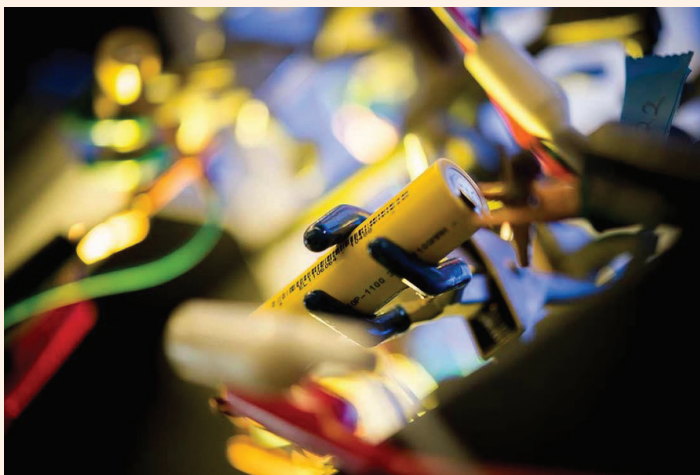
Improved materials for batteries and other technologies that help societies increase renewable energy use will emerge from UC San Diego MRSEC center projects.

The UC San Diego professors who make up the leadership team of the UC San Diego MRSEC center are, left to right: Tod Pascal, Andrea Tao, Jon Pokorski, Nicole Steinmetz, Michael Sailor, Shirley Meng and Stacey Brydges.

The new materials developed at UC San Diego will be used to improve the speed and accuracy of medical diagnostic tests, enable more effective therapeutics for disease treatment, quickly and efficiently decontaminate chemical or biological hazards, improve batteries, and reduce the cost of key industrial processes.

"This MRSEC grant is a wonderful affirmation of what we've known all along—that UC San Diego is a world-class research and education powerhouse in materials science. This grant is going to enable researchers and students from different disciplines to work together and chart the course for important new avenues for innovation in materials science," said UC San Diego Chancellor Pradeep K. Khosla.

At the heart of the new MRSEC are student programs designed to diversify materials science and a strong partnership with the educational arm of San Diego's Fleet Science Center.

The team weaves 19 UC San Diego faculty members and their labs from the Division of Physical Sciences, the Jacobs School of Engineering and the Division of Biological Sciences into a large community of computational and materials science researchers.

"Our MRSEC capitalizes on three specific strengths at UC San Diego—our leadership in materials science, our leadership in the life sciences and our position as a national resource in high performance computing," said Michael Sailor, professor of chemistry and biochemistry at UC San Diego and the leader of the center. "We are weaving the life sciences and high performance computing into materials science. That really makes our center unique."

"Many of tomorrow's life-changing discoveries will happen at the intersection of engineering, physical sciences and biological sciences. This is why we pursue such interdisciplinarity here at UC San Diego, and this MRSEC is a tangible result of that effort. It is a tribute to the vision of Mike Sailor, Shirley Meng, Andrea Tao and Jon Pokorski to make the connections necessary to build this world-class team across such varied disciplines," said Albert P. Pisano, dean of the UC San Diego Jacobs School of Engineering.

The MRSEC is the first big win for the UC San Diego Institute for Materials Discovery and Design (IMDD), which focuses on bridging the gap between physical scientists and engineers on the campus to enable cross-disciplinary research.
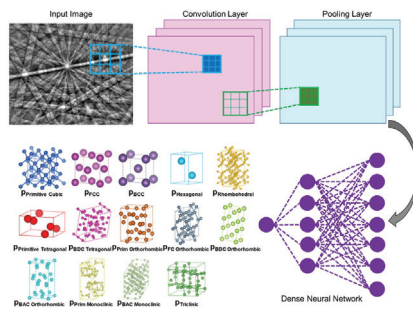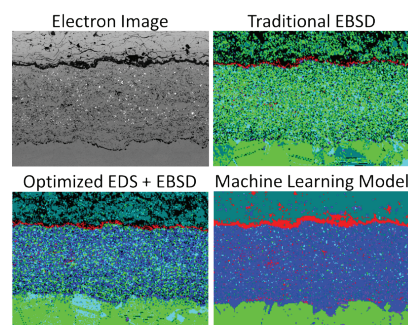
GARETH THOMAS
AWARD RECIPIENT
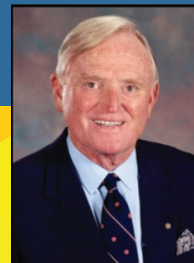
A convolutional neural network analyzes a diffraction pattern and computes the probability it belongs to one of 14 Bravais lattices.
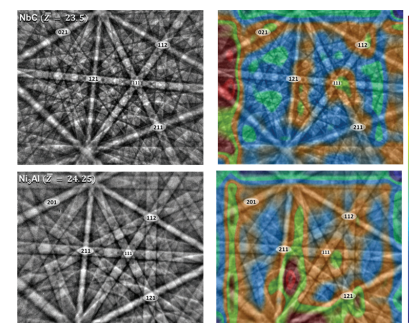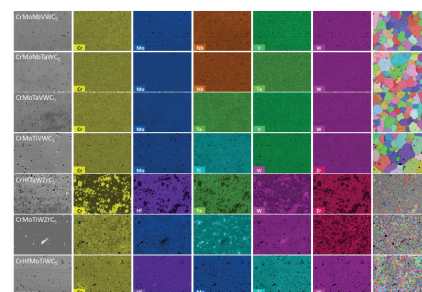

Analysis of the information a deep neural network finds important in the electron backscatter diffraction patterns.

A machine learning model outperforms state-of-the-art EBSD systems at classifying electron diffraction patterns.

Successful prediction of whether a high entropy ceramic would be single-phase (top four) or multi-phase (bottom three) using machine learning. The predictions took days instead of months to years.

Kevin Kaufmann

*Winner of the
Gareth Thomas Award*

Describe your research interests.

I am primarily interested in the application of artificial intelligence (AI) to accelerate material discovery and analysis. The goal is to enable high-throughput materials research by reducing the burden on scientists having to analyze mountains of data and automating key tasks. The AI companion agents I have been developing are either designed to (i) assist with selection of compositions most likely to meet target properties or to (ii) extract information from electron diffraction patterns captured in a scanning electron microscope. A recent example of the material design work is the prediction and subsequent fabrication of novel high entropy ceramics, a class of materials that are likely to help enable hypersonic flight. On the material analysis side, our work has enabled the determination of crystal symmetry from electron backscatter diffraction patterns.

What have been your experiences in the MATS program?

Being a graduate student researcher working with Dr. Kenneth Vecchio has provided me the opportunity to work with a phenomenal interdisciplinary team developing solutions to real world problems. The diverse skill set of the team gives us the advantage of looking at a problem through many different lenses. Here at UC San Diego in general, we have unprecedented access to cutting-edge compute resources, material fabrication and processing equipment, and analytical instruments. This experience has provided me with the opportunity to expand my skill set, deepen my understanding of material development, and improve my experimental design abilities.

Where do you see yourself in the future?

In the future, I would like to be an expert in the industry that others consult for ideas and strategy. I plan to continue developing and applying my expertise in computational and experimental material design and analysis to achieve this goal.

NEW FACULTY

Chunhui Du
Assistant Professor, Physics
Ph.D. Ohio State University

Focuses on developing quantum sensing and imaging techniques to study various properties (spin, charge, and heat, etc) of novel materials in the nanometer scale.

Seth Cohen
Professor, Chemistry and Biochemistry
Ph.D. U.C. Berkeley

The design, synthesis, characterization, and evaluation of new metal-organic frameworks (MOFs) is the goal of our current research. Our focus is on the development of postsynthetic methods for the functionalization of MOFs.

Joshua Figeroa
Professor, Chemistry and Biochemistry
Ph.D. Massachusetts Institute of Technology

Design and synthesis of highly tailored and reactive transition metal complexes for small molecule activation chemistry.

Michael Frazier
Assistant Professor, Mechanical and Aerospace Engineering
Ph.D. University of Colorado, Boulder

Understanding the dynamic behavior of architected materials (e.g., metamaterials) with an emphasis on nonlinear and multi physical effects.

Michael Burkart
Professor, Chemistry and Biochemistry
Ph.D. Scripps Research Institute

Biosynthetic chemical and structural biology. Metabolic engineering and renewable fuels/materials. Drug discovery and medicinal chemistry

Lingyan Shi
Assistant Professor, Bioengineering
Ph.D. City College of New York

Ultrafast laser scanning microscopy, Stimulated Raman Scattering (SRS), multiphoton fluorescence, Brain, metabolism, cancer, bioorthogonal labeling, Raman probe, subcellular resolution, in situ.

Nicholas Boechler
Assistant Professor, Mechanical and Aerospace Engineering
Ph.D. California Institute of Technology

The study wave propagation in complex materials and the design of materials with extraordinary properties.
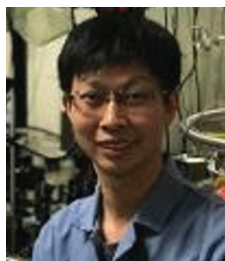
Shaowei Li
Assistant Professor, Chemistry and Biochemistry
Ph.D. University of California, Irvine

Combines optical techniques with scanning probe microscopy to explore the quantum properties of single molecules and low dimensional materials in both real and temporal spaces.

Lisa Poulikakos
Assistant Professor, Mechanical and Aerospace Engineering

Nanophotonics, optical materials, nanomaterials, electromagnetism, biophotonics, biomaterials, diagnostics

NEW STUDENTS IN 2020-2021

DOCTORAL STUDENTS

Albelo, Isabel Victoria
Bai, Shuang
Cai, Ruilin
Eshraghi, Kassra Daniel
Gupta, Varun
He, Dong
Hopkins, Emma Jane
Kapoor, Ashish
Kashyap, Harshil

Kaur, Jasleen
Le, Dong Vu Thu
Parab, Saurabh Anil
Shin, Chanho
Song, Keqi
Soulen, Charles Edward
Yin, Guoxin
Yuan, Ying

MASTER'S STUDENTS

Bilyk, Jake Johnson
Casper, Nadia
Chen, Cong
Cheng, Tung-Yu
Chung, Donna Daye
Dalman, Michael Edward
Ding, Yujia
Fu, Yunpengfu
Furmidge, Allison Michelle
Heinzmann, Trevor Thomas
Huang, Chung-Wei
Huang, Wei-En
Kim, Kangwoon

Lawrence, Travis Buchanan
Li, Xiang
Li, Yu Ming
Liao, Hao-Chi
Mishra, Aditya
Oswald, Sarah Lynn
Rose, James Y
Shukla, Shreyas
Tsai, Wei-Che
Wu, Yonghan
Zhang, Zizhe
Zhou, Jin

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Materials Science and Engineering Program
University of California, San Diego
9500 Gilman Drive, Dept. 0418
La Jolla, California 92093-0418

Copper pillar on Lithium Niobate

Aperture Size = 30.00 µm   WD = 8.4 mm   EHT = 3.00 kV   10 µm   Display Mag = 534 X
Date :8 Oct 2020   Stage at T = 0.0 °   Detector = SE2   Image Pixel Size = 208.9 nm

Figure: Bandaru Lab, Waveguide for surface acoustic waves
Image courtesy: Y. Zhao

mae.ucsd.edu/matsci