

Program

2:30 – 3:00 pm	Refreshments
3:00 – 4:00 pm	Keynote Address Dr. Tim Hendry, Vice President, Technology and Manufacturing Group (ret.), Intel Semiconductor Industry Trends and Implications on the Electronic Materials Supply Chain
4:00 – 4:10 pm	Break
Graduate student presentations	
4:10 – 4:25 pm	Sandra Murcia The Natural Armors of Fish: A Comparison of the Lamination Pattern and Structure of Scales
4:25 – 4:40 pm	Matthew Lim Rapid Sol-Gel Synthesis of Graphene Aerogels for Supercapacitor Applications
4:40 – 4:55 pm	Trevor Martin Chalcogen Polymers for Completely Solution-Processed Inorganic Photovoltaics
4:55 – 5:10 pm	Deniz Yucesoy Dentomimetics: Peptide-Enabled Remineralization Strategies for Novel Dental Health Care
5:10 – 5:20 pm	Break
5:20 – 5:35 pm	Spencer Williams Bringing Perovskite Photovoltaics to Scale through Material Engineering
5:35 – 5:50 pm	Mike Jeon Magnetic Nanoparticles for Targeted Theranostics
5:50 – 6:05 pm	Bo Zhao From Lab to Fab: How Academic Experience and Industrial Internship Benefit Each Other
6:05 – 6:30 pm	Break. Room will be flipped so please briefly leave the room.
6:30 – 8:30 pm	Poster, networking, wine reception

Abstracts

Oral Presentations

1. Sandra Murcia (Advisor: Dwayne Arola)

The natural armors of fish: A Comparison of the Lamination Pattern and Structure of Scales

Co-author: Ossa, E.A.; Production Engineering, EAFIT University

In the search for advanced structural materials, scientists are finding inspiration from structural biological composites in nature that exhibit exceptional properties. In regards to armor materials, a combination of flexibility, puncture resistance and capacity for energy dissipation is highly desirable. This rare combination of properties is found in the armored skin of modern fish, where flexibility is achieved by overlapping scales with specific strength and toughness. Recent research on these materials has focused on analyzing their mechanical properties, but neglected their microstructure and the potential spatial variations over the fish body. If fish scales will serve to inspire future generations of flexible wearable armor, a better understanding of the relationships between scale design as a laminated system and its contribution to performance is essential. Here the armor of fish with different manner of locomotion, size and protection needs were analyzed. Scales from the Arapaima gigas, the tarpon (*Megalops atlanticus*) and the carp (*Cyprinus carpio*) were compared in terms of the stacking sequence of individual plies and their microstructure. The scales were also compared with respect to anatomical position to distinguish site-specific functional differences. Results show that the lamination sequence of plies for the carp and tarpon exhibit a Bouligand structure with relative rotation of 75° between consecutive plies. The *A. gigas* scales exhibit a cross-ply structure, with 90° rotation between adjacent plies. In addition, results indicate that the volume fraction of reinforcement, the number of plies and the variations in thickness with anatomical position are unique amongst the three fish and contribute to the mechanical behavior. These characteristics should be considered in future evaluations focused on the mechanical behavior of natural armors and are presently being used in the development of prototype bioinspired material systems for various applications.

2. Matthew Lim (Advisor: Peter Pauzauskie)

Rapid Sol-Gel Synthesis of Graphene Aerogels for Supercapacitor Applications

Co-authors: Manandhar, Sandeep; Hu, Matthew; Materials Science and Engineering, University of Washington
Sakshaug, Avery; Strong, Adam; Riley, Leah; EnerG2 Technologies Inc.

Graphene, a 2D structure of carbon atoms bonded in a hexagonal lattice, has attracted widespread attention for its extraordinary physical properties. The realization of a chemically cross-linked, macroscopic 3D assembly of graphene sheets would significantly

enhance prospects for the commercial success of this remarkable material. One solution-based strategy toward this end is to polymerize resorcinol–formaldehyde (RF) in the presence of graphene oxide (GO), followed by supercritical CO₂ drying and pyrolysis to create a porous “graphene aerogel”. The huge surface area characteristic of the aerogel matrix, combined with the outstanding electronic transport properties of the graphene network, makes such materials particularly suitable as electrodes for supercapacitors. Unfortunately, the conventional base-catalyzed, aqueous synthesis of the wet precursor gels is time-consuming, requiring >12 hours at elevated temperature and posing a bottleneck to large-scale manufacture. In this study, we demonstrate an alternative hydrochloric acid-catalyzed synthesis using acetonitrile as the solvent, whereby wet GO–RF gels are realized within only two hours at near-ambient temperatures. The process hinges on two successive half-hour ultrasonications, first with GO and acetonitrile only, then after adding RF and HCl, to achieve the rapid gelation. Spectroscopic analysis of the aerogels following pyrolysis confirms graphitization of the samples with no residual carbon–nitrogen bonds from acetonitrile or its derivatives. Furthermore, electrochemical tests attest to the positive effect of graphene on the supercapacitor performance of RF-derived aerogels, with the pyrolyzed GO–RF aerogels exhibiting 25% greater capacitance per unit area, superior rate capability up to applied currents of 8 A/g, faster current response in voltammetric operation, and lower series resistance compared to aerogels of pyrolyzed RF alone. These results, viewed in light of the unprecedented rapidity of our synthetic technique, represent a major step toward mass production of high-power electrodes for electrochemical energy sources in a timely and cost-effective manner.

3. Trevor Martin (Advisor: Christine Luscombe)

Chalcogen Polymers for Completely Solution-Processed Inorganic Photovoltaics

Chalcopyrite materials such as CuInS_xSe_{2-x} (CISSe), the gallium alloy variant CuIn_xGa_{1-x}S_ySe_{2-y} (CIGSSe), and the earth-abundant kesterite material Cu₂ZnSnS_xSe_{4-x} (CZTSSe) possess a range of properties that are ideally suited for thin-film photovoltaics (PV) applications. However, these materials are conventionally manufactured using expensive and complicated vapor-phase reaction procedures or high-temperature, vacuum-based deposition methods. Furthermore, these materials frequently require a post-selenization or post-sulfurization step, which involves the use of harmful gases such as H₂Se and H₂S. Although these materials are beginning to see some commercial success, these production methods require an exorbitantly large capital investment to create new manufacturing facilities, which severely hampers the widespread and rapid deployment of these emerging solar energy technologies.

This work focuses on developing novel chalcogen polymers to synthesize nanocrystals and crystalline thin films for printed photovoltaics applications. Typical polymers contain carbon atoms within the polymeric chain, however we have developed polymers that consist of linear chains of sulfur or selenium atoms. To our knowledge, polymeric materials with this chalcogen backbone structure have not been previously demonstrated and therefore there are many opportunities for important discoveries within this field.

For example, our preliminary work has shown that chalcogen polymers can also be functionalized to directly coordinate with metal cations. This resulting hybrid organic-inorganic polymer can be printed onto a substrate and heated to initiate a chemical reaction that produces a metal-chalcogenide material such as CISse. This new synthesis method provides a pathway towards making PV materials via a completely solution-processed, low-temperature fabrication procedure. If successful, this technique would constitute the first viable means to produce low-bandgap chalcogenides without additional vapor-phase reactions or high-temperature sputtering depositions. Therefore, this process can potentially be implemented to rapidly and cheaply manufacture printed chalcopyrite and kesterite photovoltaics.

4. Deniz Yucesoy (Advisor: Mehmet Sarikaya)

Dentomimetics: Peptide-Enabled Remineralization Strategies for Novel Dental Health Care

Co-authors: Gresswell, Carolyn; Materials Science and Engineering, University of Washington
Saadat, Sanaz; School of Dentistry, University of Washington
Fong, Hanson; Materials Science and Engineering, University of Washington
Dogan, Sami; Restorative Dentistry

Incipient carious lesions on enamel surfaces, dentin hypersensitivity, and wear of cementum are the clinical outcomes for tooth demineralization. If left untreated, demineralization can progress and may cause complex restorative procedures or even tooth extraction which permanently destroys the surrounding soft and hard tissues as a consequence of connective tissue and bone loss. Current clinical practices are insufficient in treating such diseases. A long-standing practical challenge associated with demineralization related to dental diseases is incorporating a functional mineral microlayer which is fully integrated into the molecular structure of the tooth in repairing damaged dental tissue.

Small peptide domains derived from native protein amelogenin can be utilized to construct mineral layer on damaged human enamel in vitro and in vivo in a variety of formulations such as solution, gel or paste. Using a novel protocol, the team identified peptide sequences from native amelogenin, the key protein in the construction of enamel, and demonstrated the repair of damaged dental tissues by biomimicking HAp biomineralization. Specifically, among these amelogenin-derived peptides, a short peptide ADP5 was shown to facilitate cell-free and fast formation of a mineral layer on demineralized human root dentin. The ADP's epitomize the unique features of the natural proteins in tooth formation especially in enzymatic function of capturing constituent ions, synthesizing mineral and controlling morphology on the surface of the tooth. The resulting mineralized biogenic layer was demonstrated to be structurally and mechanically integrated into the underlying enamel, dentin or cementum, resembling natural tooth as well as mechanically and chemically durable. The extensive R&D carried

out by the Team in GEMSEC Labs could eventually form the foundation of developing clinical treatments for the restoration of dental diseases from early stage cavities, e.g., incipient caries and white spot lesions, to more advanced lesions such as hypersensitivity and gingivitis. The ADP-enabled remineralization approaches have the potential to disruptively alter future clinical implementation as a new, biomimetic remineralization treatment in dental health care.

5. Spencer Williams (Advisor: Alex Jen)

Bringing Perovskite Photovoltaics to Scale through Material Engineering

Co-authors: Rajagopal, Adharsh.; Jo, Sae B.; Chueh, Chu Chen; Tang, Tiffany F. L.;
Materials Science and Engineering, University of Washington

Organic-inorganic hybrid perovskite photovoltaics (PVSCs) are poised to push toward technology translation, but significant challenges complicating commercialization remain. While J-V hysteresis and ecotoxicity are uniquely imposing issues at scale, $\text{CH}_3\text{NH}_3\text{PbI}_3$ degradation is by far the sharpest limitation to the technology's potential market contribution. We offer a perspective on the practical market potential of PVSCs, the nature of fundamental PVSC challenges at scale, and an outline of prospective solutions for achieving module scale PVSC production tailored to intrinsic advantages of $\text{CH}_3\text{NH}_3\text{PbI}_3$. Through research directed at fundamental material design, we show the important role of each aspect of the approach we lay out in creating scalable solutions for perovskite fabrication.

6. Mike Jeon (Advisor: Miqin Zhang)

Magnetic Nanoparticles for Targeted Theranostics

Co-authors: Stephen, Zachary R.; Gebhart, Rachel N.; Materials Science and
Engineering, University of Washington

Nanotechnology has given scientists new tools for the development of advanced materials for the detection, diagnosis, and treatment of disease. Superparamagnetic iron oxide nanoparticles (SPIONs) in particular have drawn significant interest due to favorable magnetic properties, biodegradability, and flexible surface chemistry that allow improved in vivo kinetics and multifunctionality for targeted drug delivery. SPIONs' favorable intrinsic properties have driven extensive investigation as promising theranostic agents, which combine imaging and therapeutic capabilities in a single vector. The combination of imaging and therapy could allow real-time monitoring of drug delivery, which could be used to tailor treatments for individual patients to improve clinical outcomes. This presentation will address the limitations of conventional clinical cancer treatment and how we use SPIONs to overcome these limitations to specifically target and kill cancer cells, while monitoring the treatment via magnetic resonance imaging (MRI).

7. Bo Zhao (Advisor: Fumio Ohuchi)

From Lab to Fab: How Academic Experience and Industrial Internship Benefit Each Other

To a Ph.D. student who has experience only in academia, experience in industry might seem irrelevant until graduation nears. However, from my own summer internship in the semiconductor industry, I gained a new perspective. On the one hand, I realized years of academic research has shaped many of the skills that are responsible for success in industry: solid analytical skills, problem solving strategies, and confidence in facing complex technical issues are directly transferable and practiced every day in industry. On the other hand, the many business skills needed during an internship, such as communication on a large scale, and result-driven mentality, are best learned in industry. These skills, too, can enhance the way we do our academic work. Moreover, seeing technologies similar to my research in school being used in mass production in the industry and impacting numerous people's lives really provided me with a greater sense of purpose and dedication to my academic work. This presentation aims to help students/advisors recognize the value of an internship experience. At the same time, it aims to show industry representatives the benefit of taking in students with high-caliber training from Materials Science and Engineering at University of Washington.

Poster Presentations

1. Genevieve Clark (Advisor: Xiaodong Xu)

Atomically Thin Light Emitting Diodes based on Monolayer Semiconductors

Co-author: Liu, Chang-Hua; Physics, University of Washington
Fryett, Taylor; Electrical Engineering, University of Washington
Majumdar, Arka; Electrical Engineering, University of Washington

The development of nanotechnology and advanced fabrication methods has driven traditional electronic and photonic circuits towards the nanoscale limit, allowing fabrication of increasingly compact and multi-functional electronics. To continue this progress beyond the limits of traditional materials, there is an immediate demand for new materials combining advantages of traditional semiconductors in dimensions compatible with atomic-scale electronics. Atomically thin, layered semiconductors known as Transition Metal Dichalcogenides (TMD's) are uniquely suited to address this challenge. They can be scalably grown via chemical vapor deposition (CVD), and assembled both laterally and vertically to form heterostructures and atomically thin field effect transistors. Their large direct band-gap also makes them ideal for use in optoelectronic devices and photonic circuits. This presentation will discuss recent work on fabrication of atomically thin light emitting diodes using monolayer TMD materials grown via scalable CVD processes, and coupling of the electroluminescence with photonic crystal cavities.

2. Gaurav Gulati (Advisor: Bruce Hinds)

Programmable carbon nanotube membrane-based transdermal nicotine delivery with microdialysis validation assay

Co-author: Berger, Lily; Materials Science and Engineering, University of Washington, Seattle

Purpose: Transdermal nicotine patches have low success rates in smoking cessation therapy due to the need for variable flux/dose for treatment and relapse events. Ideal is to have a low power switchable nicotine delivery device that can couple psychological counseling over a wireless device to enhance counseling and mitigate relapse events. Variable delivery by a switchable transdermal nicotine delivery device based on carbon nanotube (CNT) membrane can improve smoking cessation therapy due to its low power usage and ability to be switched by small applied biases. However, a new transdermal assay need to be developed to show switching events of such devices. Thus, in present study, the performance of switchable carbon nanotubes membrane devices for transdermal nicotine delivery was evaluated by a novel in-vitro microdialysis method that allow us to detect variable transdermal fluxes of nicotine through CNT devices and can be applied directly to in-vivo studies.

Methods: In-vitro nicotine transdermal delivery (TDD) through CNT membrane was carried out using flow cell geometry with microdialysis membrane directly under dermatomed skin. This system allows for the measurement of both the nicotine flow into the small microdialysis tubule and across the entire skin area into the larger permeate flow cell.

Results: Microdialysis membranes were placed beneath the porcine skin and its nicotine levels increased 6-8 times when the CNT membrane on skin was turned from OFF to ON state by application of bias. Fluxes in the ON state were approximately 3 times that of commercial Nicoderm patches and switching times were less than two hours, thus suggesting the improved therapeutic potential of our device.

Conclusions: This study for the first time demonstrates the feasibility of a microdialysis method for demonstrating switchable transdermal drug delivery devices. These blue-tooth enabled TDD devices along with smart phone app based tools for behavioral support are highly promising for smoking cessation therapy.

3. Ryan Hufschmid (Advisor: Kannan Krishnan)

Observing Colloidal Dynamics with in-situ (Scanning) Transmission Electron Microscopy

Co-authors: Teeman, E; Materials Science and Engineering, University of Washington, Seattle

Mehdi, BL; Pacific Northwest National Laboratory

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Recent developments in in-situ Transmission Electron Microscopy (TEM) techniques and instrumentation enable direct nanoscale imaging and spectroscopy in relevant environments. For example, by encapsulating a solution between electron-transparent silicon nitride membranes the liquid sample can be introduced into the TEM column without compromising vacuum. This allows for dynamic phenomena to be directly

observed at high spatial and temporal resolution, under controlled electron dose conditions for imaging and chemical analysis.

In this work we observe magnetite (Fe_3O_4) nanoparticles in solution and alter surface chemistry to systematically study colloidal stability at the nanoscale. Iron oxides are ubiquitous in natural systems and serve as a platform for many engineered applications, for example, Magnetic Particle Imaging (MPI). Interactions between iron oxides, solvents, minerals, small molecules, and tissues are fundamental to the dynamics of these diverse systems.

Here we use in-situ liquid (S)TEM techniques to directly observe the behavior of Fe_3O_4 nanoparticles with different surface chemistries in organic and aqueous solutions. The electron beam interacts with water, producing charged species and reducing the pH of solution. Aqueous iron oxide nanoparticles typically dissolve even under relatively low dose conditions of $<1 \text{ e}^-/\text{\AA}^2\text{s}$. The dissolution can be controlled, as it is proportional to the e-beam dose delivered to the sample during the experiment and dependent on surface chemistry of the functionalized nanoparticles. For example, functionalizing with a polycationic peptide promotes growth at the particle surface. For certain surface functionalization the growth and dissolution reactions are reversible. We show that colloidal stability depends strongly on surface chemistry and local solution conditions, while bulk indicators of stability such as zeta potential may not predict all behavior of individual nanoparticles. For systems that depend on nanoscale phenomena, in-situ TEM characterization is therefore an important complement to conventional analyses. With increasingly widespread application, in-situ methods will enable direct observation of dynamic systems at unprecedented length and time scales in materials science and beyond.

4. Rita Taitano Johnson (Advisor: Brian Flinn)

Improving Adhesive Bonding of Composites Through Surface Characterization Using Inverse Gas Chromatography (IGC) Methods

Co-authors: Blohowiak, Kay; Osborne, John; Wilson, Ryan; The Boeing Company

Surface preparation is essential in the adhesive bonding process for composite materials. Methods are needed to inspect prepared surfaces for optimal surface conditions for bonding. Surface energy measurement is one promising technique to characterize and inspect surfaces prior to bonding. Two popular methods for surface energy measurement are contact angles (CA) and Inverse Gas Chromatography (IGC). Contact angles are measured from a side view of the drop using a video goniometer. Inverse Gas Chromatography, while well-known for measuring the surface energies of powders, is a relatively new method for characterization of the surface energy of composite materials. With the development of a clamp shell attachment to accommodate cured composite samples, this dynamic technique gathers data on the composite's dispersive and specific (acid-base) surface energies to give the total surface energy. As various adsorptive molecules are passed along the prepared release ply, peel-ply, plasma treated, or orbital

sanded surface, the IGC records the retention time. These values are later used to calculate several physico-chemical properties of the composite material (absorbent). Surface energy measurements taken via IGC are compared with data collected through well-known contact angle goniometric methods for various surface preparation characterization.

5. Richard Lee (Advisor: Mehmet Sarikaya)

Making sense of miRNAs: Highly-Sensitive Early Detection of Pancreatic Cancer

Co-authors: Starkebaum, D; Yucesoy, D; Gresswell, C; Materials Science and Engineering, University of Washington

Pancreatic cancer is one of the most dangerous cancers in existence; it is the only cancer with 5-year survival rates of less than 10% and is projected to rank second in cancer-related deaths as early as 2020. An estimated 53,070 new cases will be diagnosed in the US this year, along with an estimated 41,780 deaths. Early detection remains a current challenge owing to the absence of symptoms that do not manifest until advanced stages—leading to late-stage detection and very poor prognosis. Very high medical costs reveal the heavy financial burden posed to the health system as well as the patients by this disease.

To address this long-standing malignancy, we have designed a nanobiosensor for detecting early-stage cancer biomarkers. The device works by sensing miRNAs expressed at various disease stages, which are released into the bloodstream and also excreted in urine. The biosensor exploits the evolving abnormal miRNA expression profile, thereby achieving immediate cancer detection, as well as identification of the type and stage of cancer. By using chimeric heterofunctional constructs composed of solid-binding peptides (GEPI, Genetically Engineered Peptides for Inorganic materials) and peptide nucleic acids (PNAs), and employing organic and graphene field-effect transistor (OFET/gFET) strategies, the biosensors can achieve high sensitivity and selectivity, specifically detecting circulating miRNAs by enhancing the detector signal upon miRNA biorecognition.

6. Yun Li (Advisor: Jihui Yang)

In-situ electrodeposition of MnO₂ cathode for rechargeable zinc batteries

Rechargeable aqueous Zn-ion batteries (ZIB), with the advantages of abundant and environmentally benign constituents, high theoretical energy density, and excellent safety, are regarded as a promising alternative to lithium ion batteries in large scale energy storage applications. Their application, however, is limited by the low cyclability of current cathode materials, predominately being the polymorphs of MnO₂. In this work, we established an in-situ forming Zn/MnO₂ cell where MnO₂ cathode is directly electrodeposited from MnSO₄-ZnSO₄ electrolyte. It delivers a high stable specific capacity of ~200 mAh g⁻¹ at 0.5 mA cm⁻² and shows good cycling performance, with no capacity fading after more than 100 cycles. The electrochemical reaction mechanism in the in-situ

forming cell involves a Mn^{2+} deposition to form porous and nanostructured MnO_2 on surface of the conductive carbon black film in the first charge process, and reversible shuttling of Zn^{2+} and H^+ in the afterwards discharge-charge processes. At a relatively low current density (0.05 mA cm^{-2}), H^+ conversion reaction with phase transition between MnO_2 and Mn_3O_4 and formation of new phase $ZnSO_4 \cdot 3Zn(OH)_2 \cdot nH_2O$ predominantly contributes to the high discharge/charge capacity, while Zn^{2+} intercalation reaction is mainly responsible for the good capacity retention at a relatively high current density (0.5 mA cm^{-2}) due to small phase change and suppressed inactive by-product formation. This novel active-material-free design will largely decrease the fabrication cost of ZIB and thus largely promote their development and practical applications.

7. Robert Masse (Advisor: Guozhong Cao)

Cloud Instruments: Recharging Battery Research

Co-authors: Shea, Dan; Revia, Richard; Homola, Wyatt; Materials Science and Engineering, University of Washington

Batteries have already played a key role in the wireless revolution, and energy storage is poised to enable grid-scale renewable energy, smart grid technologies, and all-electric vehicles. However, energy storage R&D is conducted with legacy software on equipment that either highly expensive or unreliable. These factors limit productivity and contribute to the slow pace of battery progress.

Cloud Instruments is a hardware/software platform that address both sides of this bottleneck. First, we deliver battery testing stations assembled from low-cost electronics (e.g. Arduino) and provide them at nominal upfront costs. Second, we provide a sophisticated API for data handling, storage, and analytics using a “platform as a service” model. In this way, the Cloud Instruments platform accelerates the pace of battery discoveries by deploying more channels with more functionality to more researchers.

8. Jonathan Onorato (Advisor: Christine Luscombe)

Improved Durability of Semiconducting Polymers by Self-Healing Chemistry

The sun provides a nearly limitless supply of renewable, clean energy, making solar an attractive option for green energy generation. Organic photovoltaic (OPV) materials are solution-processable, allowing for production at large scales through relatively cheap processes; unfortunately, these materials are often weak and brittle, despite their apparent flexibility, which can lead to damaging microcracking, and reduced device performance. My research will improve the durability of the active layer materials through the utilization of self-healing chemistry, allowing the material to fix any microcracking in the active layer. Specifically, I have incorporated a well-studied self-healing reaction, the thiol-disulfide exchange system, into a poly(3-hexylthiophene) (P3HT) active layer material via end-group modification. Thiol-disulfide exchange is particularly well tailored for solar cell materials, as the self-healing mechanism can be activated by either UV light or heat. Successful modification of the P3HT end-groups has

been achieved, as proven by MALDI analysis. Initial DSC studies indicate the presence of an additional thermal transition in the material at 60C, indicating the onset temperature of self-healing. AFM studies indicate no difference in morphology between unmodified P3HT and the thiol-disulfide exchange system. Ultimately, the ideal system would show no difference between itself and the unmodified P3HT in terms of initial solar cell performance. Future research will compare the modified and unmodified materials using both thermal stress and mechanical stress to degrade the polymer while monitoring electrical performance, with the goal of demonstrating the improved lifetime of the self-healing system.

9. Alex Peek (Advisor: Bruce Hinds)

Growth-Front Monolayer Plating of Precious Metals Through Insulating Mesoporous Membranes

Co-author: Linck, Nicholas; Department of Chemical and Materials Engineering, University of Kentucky

Monolayers of precious metals are deposited within the pores of insulating mesoporous membranes via a novel electrochemical underpotential deposition growth front mechanism. A gold electrode is evaporation deposited onto one membrane face and a monolayer of copper is underpotentially deposited through the membrane and to the top surface, followed by spontaneous galvanic replacement of copper by platinum or iridium. Detection of precious metal on the opposite membrane face via XPS surface analysis and quantification of areal density by ICP-IES demonstrates a novel copper monolayer growth front plating mechanism through the pores. Catalytic water splitting for hydrogen generation is demonstrated for applications including polymer electrolyte membrane fuel cells, hydrogen generation, flow battery energy storage, and electrocatalytic conversions.

10. Adharsh Rajagopal (Advisor: Alex Jen)

Functional Role of Tin Substitution in Perovskite Solar Cells

Co-author: Yang, Zhibin; Materials Science and Engineering, University of Washington

Here, we explored the functional role Sn substitution to modulate the band gap and phase stability of methylammonium lead halide (MAPbX₃) perovskites and thus realized high efficiency sub-cells required for tandem applications. The key challenge to realize low band gap MAPb_{1-x}Sn_xI₃ perovskites is achieving good film morphology due to the rapid reaction between SnI₂ and MAI. By employing a combination of compositional, process, and interfacial engineering, we successfully developed a low E_g (1.33 eV) MA_{0.5}FA_{0.5}Pb_{0.75}Sn_{0.25}I₃ perovskite which is highly crystalline along with dense morphology and improved intrinsic stability. This greatly reduced the propensity for oxidation of Sn²⁺ and resulted in perovskite solar cells with a high PCE of 14.19%. Subsequently, the device lifetime greatly improved, with 80% and 94% of initial PCE being maintained after being stored for 12 and 30 days in ambient (30-40% RH) and in inert atmospheres, respectively. On the other hand, the key issue with regard to wide bandgap

MAPb(1-yBry)₃ perovskites is its instability under illumination due to phase segregation when $y > 0.2$. By partially replacing Pb²⁺ with smaller Sn²⁺ ions, the resultant MAPb_{0.75}Sn_{0.25}(1-yBry)₃ based perovskite solar cells showed stable photovoltaic performance under illumination. Among these cells, MAPb_{0.75}Sn_{0.25}(I_{0.4}Br_{0.6})₃ perovskite with a bandgap of 1.73 eV exhibited a stable efficiency of 12.59% with enhanced phase stability under 1 sun illumination and thermal stability at 85 deg C in inert atmosphere. This study thus demonstrates composition engineering of metal site as a promising strategy to tune band gap and alter the phase stability in hybrid perovskites. Accordingly, the above developed small band gap (1.33 eV) and large band gap (1.73 eV) perovskite solar cells have great potential for realizing high efficiency tandem solar cells.

11. Daniel Shea (Advisor: Bruce Hinds)

Dynamic Electrochemical Membranes for Cyclic Protein Transport

Co-author: Akkineni, Susrut; Materials Science & Engineering, University of Washington

Recently, a mesoporous anodized alumina oxide membrane has been integrated with electrochemically functionalized nanoscale electrodes for selective and continuous protein separations [1]. This electrochemically functional membrane selectively binds genetically-modified, hexahistidine-tagged proteins using chemistry borrowed from immobilized metal ion affinity chromatography and subsequently pumps the protein across the membrane with alternating, sequential voltage pulses. The electrodes are templated across the mesoporous membrane surface and approximately 20 nm into the pore entrances, providing a convenient geometry for specific target capture while blocking transmembrane transport of non-specific proteins during the binding cycle. During the release cycle, imidazole is electrophoretically pumped towards the bound protein to facilitate release of the protein. Imidazole concentration is carefully controlled to keep the top surface of the membrane pores blocked while facilitating protein release at the bottom edge of the electrode inside the membrane pores. This strategy balanced protein release efficiency to improve selectivity, resulting in a separation factor for GFP:BSA of 16:1 (mass/mass). The existing, unoptimized platform demonstrates throughput of the 0.75 cm² area membrane has comparable throughput as 1 mL of commercially available chromatography columns. Our current work reported here focuses on improving selectivity and throughput to improve platform viability by measuring the kinetics of NTA-mediated protein binding and imidazole-based protein release on the modified electrode surface.

[1] "Dynamic Electrochemical Membranes for Continuous affinity protein separation", Z. Chen, T. Chen, X. Sun and B.J. Hinds. *Advanced Functional Materials* 2014 24(27) 4317-23

12. Alex Stark (Advisor: Dwayne Arola)

Reliability of Solid Oxide Fuel Cell Materials

Solid oxide fuel cells (SOFCs) have the potential to provide clean energy at very high levels of operating efficiency (> 60%). One of the primary concerns of these systems is their reliability, which includes the stability of the power generation and the structural integrity of the components. While most efforts have focused on the development of materials with better power stability, limited research has addressed the mechanical aspects of performance and their structural reliability. The latter aspect of their performance is perhaps the Achilles heel of SOFCs. Flaws introduced during the manufacturing of fuel cells can contribute to their reliability. In addition, these systems are operated at extremely high temperatures (500 – 1000°C) and under a range of oxygen and hydrogen rich environments. As such, it is necessary to understand the influence of intrinsic flaws and operating conditions to the strength distribution and structural reliability. To address these concerns, an experimental evaluation is being performed on commercial solid oxide cells, which includes a determination of the strength distribution under a range of environmental conditions related to standard fuel cell operation. In addition, a fractographic analysis is being performed to identify the origins of failure and to compliment quantitative results describing the reliability. Specifically, flexure strength distributions are presented for dense magnesia magnesium aluminate (MMA) candidate materials and the results of fractographic evaluations are used to illustrate the effects of flaws and their distribution to the performance under different evaluation conditions. A comparison of the performance for specimens prepared from candidate fuel cell components suggest that the flaw distribution is not homogeneous and that there are spatial variations in the component reliability. These findings are of substantial importance to finite element models for the structural reliability of the fuel cell stacks. Additional results for slow crack growth behavior will also be discussed.

13. Wes Tatum (Advisor: Christine Luscombe)

Solvent Effects on π -Conjugated Polymer Selectivity in Organic Nanowire Self-Assembly

In semiconducting polymers, charge carriers and excitons freely move through the system of conjugated π -orbitals. Defects in the polymer chains, such as lower regioregularity, disrupt this motion. It is classically predicted that in bulk films crystalline domains form that exclude these defects, pushing them into amorphous domains to retain perfect crystallinity. One of the main difficulties in studying the crystallization and its treatment of defects is separating the crystalline and the amorphous domains. By supersaturating solutions of poly(3-hexylthiophene) (P3HT), the participating π -orbitals attract and align with other π -orbitals either in other polymer chains or within its own chain, causing self-assembly and precipitation of micron-long wires with widths on the order of exciton diffusion lengths. Investigating these nanowires elucidates how defects within the polymer chains are incorporated into crystalline regions of bulk P3HT films because there are no predicted amorphous regions of P3HT in the isolated nanowires. Conventional understanding of crystallization predicts that any defects within the nanowires alter both the physical dimensions and the electronic properties. Contrary to these predictions, our results show that defects are incorporated into the nanowires but not alter the physical dimensions of the nanowires. As the solution ages, polymer chains with more defects and

lower degree of polymerization (DP), or both, are then incorporated into these nanoscopic, crystalline domains. Further, by altering the ratio of good/poor solvent that the P3HT nanowires assemble in, polymer chains with fewer defects and a higher DP can be more preferentially incorporated into the nanowires first.

14. Carolina Vinado (Advisor: Jihui Yang)

The use of $Li_{10}SnP_2S_{12}$ Electrolyte in All Solid State Batteries

Co-authors: Wang, Shanyu; Li, Yun; Material Science and Engineering Department, University of Washington
Salvador, James; Xiao Xingcheng; Chemical Sciences and Materials Systems Lab, General Motors R&D Center

All-solid-state batteries with $Li_{10}SnP_2S_{12}$ electrolytes and coated, as well as uncoated, $LiCoO_2$ as the active material were fabricated and their electrochemical performance was examined. Electrodes were prepared by hand grinding with an agate mortar and pestle, followed by cold press. The charge–discharge properties of the cells were investigated under various current densities and their impedance analyzed before and after cycling.

15. Shanyu Wang (Advisor: Jihui Yang)

Thermal conductivity and lattice-ion coupling in superionic $Li_7La_3Zr_2O_{12}$

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Understanding the lattice and ionic dynamics in superionic conductors is not only an important scientific topic but also critical for many technological applications, such as batteries, solid oxide fuel cells, and thermoelectrics, etc. In this study, focusing on Li-stuffed garnet $Li_7La_3Zr_2O_{12}$ (LLZO) which shows good ionic conductivity and chemical compatibility with metallic lithium, we systematically investigated thermal and ionic conductivities, and lattice and ionic dynamics of both ordered tetragonal (t-LLZO) and disordered cubic (c-LLZO) polymorphs. Superionic c-LLZO, stabilized by aluminum-doping, shows a glass-like κ with much lower values and distinct temperature dependence, as compared with those of crystalline t-LLZO, e.g., 1.7 vs. 4.3 W/m-K at 70 K and 1.4 vs. 2.4 W/m-K at 300 K. The ‘phonon-glass’ feature in c-LLZO is further revealed to be a consequence of intensive ‘resonant’ phonon scattering arising from the low energy phonon modes pertaining to the superionic Li^+ . By carefully examining the lattice and ionic dynamics via *ab initio* molecular dynamics (MD) simulations, we found a highly frequent hopping mechanism for Li^+ migration in c-LLZO, distinct from the liquid-like

diffusion mechanism for most of the reported superionic conductors. In c-LLZO, Li⁺ ions oscillate intensely about their equilibrium positions before the instantaneous hopping to adjacent lattice sites, and the corresponding collective soft-mode vibrations strongly damp acoustic phonons to lower the thermal transport. Meanwhile, the Li⁺-lattice coupling also causes the instability of Li⁺ ions and promotes their hopping which is responsible for the high ionic conductivity of $\sim 4 \times 10^{-4}$ S/cm. The strong correlation between ionic and thermal conductivities was further experimentally observed in a series of Al-doped samples with different degrees of disorder, further validating the strong lattice-ion coupling and its influence on ion and phonon transport. In addition, the elucidated lattice-ion coupling and its effects on ion and phonon transport in c-LLZO could be relevant for other superionic conductors, which can serve as a new paradigm to design high-performance superionic conductors for multiple applications.

16. Cheng Xu (Advisor: Minoru Taya)

Fabrication of Fe₇₀Pd₃₀ ferromagnetic shape memory alloy (FSMA) nano-actuator

Shape memory alloys (SMAs) are a class of materials that “memorize” their original shapes when subjected to thermal mechanical or magnetic treatment. FePd binary alloy exhibits shape memory effect and superelasticity when the chemical composition is close to Fe₇₀Pd₃₀. The key element that lies behind these unique properties of Fe₇₀Pd₃₀ is the reversible phase transformation of high temperature face-centered cubic (FCC) austenite phase to low temperature face-centered tetragonal (FCT) martensite phase. We designed an innovative nano-actuator that composed of a ferromagnetic nanoparticle as “head” and a Fe₇₀Pd₃₀ FSMA nano-spring as “tail”. To fabricate such nano-actuator with accurate Fe₇₀Pd₃₀ stoichiometry, first we synthesized helical void template based on the confined assembly of silica/block-copolymer composite within cylindrical nanopores of Anodic Aluminum Oxide (AAO). Then we used potentiostatic-galvanostatic mixed pulse deposition technique to fill the helical void that connects to the cylindrical pore of AAO. With such method, Fe₇₀Pd₃₀ nano-actuator composed of cylindrical nano-rod with diameter of 70 nm as “head” and nano-spring with wire diameter of 10 nm, mean diameter of 43 nm and pitch of 12 nm as “tail” is successfully obtained. Moreover, we experimentally verified the reversible FCC to FCT phase transformation of Fe₇₀Pd₃₀ nano-rods synthesized by electrodeposition followed by annealing at 800 °C for 1min in 5% H₂ balanced Ar environment and quenching.

By leveraging our fabrication method together with reversible phase transformations, the proposed Fe₇₀Pd₃₀ FSMA nano-actuator has great potential to be utilized as novel cancer therapy that combines imaging, targeting and treatment by mechanical vibration.

17. Yi Hsun Yang (Advisor: Fumio Ohuchi)

Polymer-derived ceramics for ultra high temperature electrode applications in direct energy extraction

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We are investigating a novel class of SiC-based ceramic composite materials through a polymer-precursor-derived route with tailored compositions for high temperature channel electrode applications in magnetohydrodynamic (MHD) power generators. MHD power generation utilize ultra high temperature combustion and is capable to boost thermal to electric power conversion efficiency from ~40% to ~60%. Electrode in MHD channel faces ultra high temperature propulsion with corrosive alkaline metal. Specific properties of the materials, such as stable structural integrity, high electrical conductivity, and high thermionic emission capability at elevated temperatures, and resistance to corrosion are required for this application. Important parameters to be investigated are the domain size, the type and distribution of carbon, and the sizes and volume fractions of crystalline SiC and the constituent of minor constituent X in Si-C-X.

We found that the nanodomain structure, resultant stoichiometry, nature of the carbon phase (e.g., graphene sheets, carbon nanoparticles), and the resulting thermo-mechanical properties at elevated temperatures, are strongly influenced by the effect of precursor chemistry (specifically C/Si) and processing conditions (e.g., temperature). A minor constituent X incorporated at the precursor stage during material synthesis has a strong effect on the electrical properties, including electrical conductivity, thermionic emissions and arcing property for use in the MHD generators.

By developing SiC-based materials with nanostructured features and tailoring their compositions, the high-temperature resistance, electrical properties, and plasma resistance of SiC will improve relative to that for SiC produced by conventional powder processing approaches, such as solid state synthesis. A successful outcome of this research will result in the emergence of reliable and affordable designed materials for MHD applications.

18. Ting Zhao (Advisor: Alex Jen)

Enhancing Hybrid Perovskites Solar Cell Performance through Post Deposition Treatments

Organic-inorganic hybrid perovskites (OHPs) have undergone a rapid development as promising photovoltaic (PV) materials with demonstrated power conversion efficiencies (PCEs) of over 22% within just few years' development. However, growth of a high quality thin film remains a challenge. Pin-hole formation, low crystallinity, and phase inhomogeneity are common in a solution processed OHP thin film. The polycrystalline feature of OHP thin film and perovskite's ionic nature inevitably incur substantial crystallographic defects, especially at the film surface and the grain boundaries (GBs), which deteriorate carrier transport and device performance. To improve film quality and passivate the defects of CH₃NH₃PbI₃ (MAPbI₃) thin film, we developed two facile post-treatment methods. Through utilizing the coordination between methylamine (MAO) vapor and MAPbI₃, we discovered a fast (<1 s) and simple post deposition chemical treatment in which crystal reconstruction induced by MAO vapor greatly improves

MAPbI₃ thin film coverage, crystallinity, and enhances PCE by around 9%. In addition to improving bulk property, a simple post treatment was introduced to passivate surface and GB defects of MAPbI₃ thin film with a rationally selected diammonium iodide. NH₃I(CH₂)₈NH₃I (C8) successfully passivates perovskite surface and GBs without forming 2D perovskite because of the elevated activation energy arising from its unique anti-gauche isomerization. Defect passivation of MAPbI₃ was clearly confirmed by scanning Kelvin probe microscopy (SKPM) and time-resolved photoluminescence (TRPL) studies, which results in the reduced recombination loss in derived devices. Consequently, the perovskite solar cell with C8 passivation showed a much improved PCE of 17.60% compared to the control device PCE of 14.64%.

19. Xuezhe Zhou (Advisor: Peter Pauzauskie)

Laser refrigeration of ytterbium doped fluoride nanocrystals in aqueous media

Modern cryogenic engineering enables the development of cryotherapy, Bose-Einstein condensates, and superconductivity. To achieve solid-state cryo-cooler which has advantages of compact, high reliability, no vibration, and no need for cryogenic fluid, laser cooling of solids have been intensively studied. Although laser cooling of bulk crystals have been shown to cool down to cryogenic temperatures (~90 K), to date the laser cooling of nanocrystals in aqueous media has not been reported. Here we show the first time laser refrigeration of Yb-doped nanocrystals in aqueous media with a single-beam near-infrared (NIR) laser trapping system. The local refrigeration of the individual nanocrystal in aqueous media is quantified through the analysis of its cold Brownian motion. An individual nanocrystal is optically trapped by a NIR continuous wave laser source. Then the individual nanocrystal shows local cooling by 9 °C with heat being extracted out of the lattice through anti-Stokes photoluminescence of Yb excited state-mediated optical phonon absorption. The ability to optically generate local refrigeration fields around individual nanocrystal promises to enable precise optical temperature control within integrated electronic/photonic/microfluidic circuits, and also thermal modulation of basic biomolecular processes, including the dynamics of motor proteins.

20. Jialin Zuo (Advisor: Devin Mackenzie)

All-printed, scalable and flexible sensor for combustion gases

Co-authors: Pavinatto, F.; Department of Materials Science and Engineering

Detection of combustion products using large-area sensor arrays at room temperature is still very hard nowadays. High-performance sensing units are currently available, and most of them make use of inorganic semiconducting nanoparticles as active elements to detect combustion sub-products, like carbon monoxide (CO) and other gases. However, the processing of such compounds and of associated charge-transport materials using plastic- and R2R-compatible fabrication methods is still elusive. Here, we have used inkjet-printing and coating methods to fabricate flexible devices containing nanomaterials as an active layer. Firstly, reduced graphene oxide (rGO) sheets were decorated with tin dioxide (SnO₂) nanoparticles through a solvothermal aerogel syntheses procedure. The product

of the syntheses had its chemical composition and nanostructured architecture confirmed by X-ray Diffraction (XRD) measurements, and both scanning and tunnelling electron microscopy (SEM-EDS or TEM), respectively. Secondly, silver (Ag) interdigitated electrodes were inkjet-printed on plastic substrates (PET and Kapton) with resolution under 100 μm and thickness of around 300 nm. Finally, drop-cast, slot dye coating or inkjet-printing were used to coat the Ag electrodes with the SnO₂-graphene nanocomposite, which was formulated into an ink in NMP for that aim. The flexible devices were tested against carbon monoxide (CO) and showed a variation of 7% of the initial resistance for a concentration of 50 ppm of the gas, showing that the use of graphene as a charge transport material, in fact, reduced the sensor working range at ordinary room temperatures. Currently, the same devices are being tested for different concentrations of CO and for mixtures of possible interfering gases. Overall, the proposed architecture and the combination of nanomaterials with solution-processing techniques have proven successful for attaining flexible sensors for combustion gases at room temperature. Specifically, the use of printing techniques led to a fabrication protocol of great technological viability and adaptable to scalable production.

21. MRS@UW

The Materials Research Society at University of Washington

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MRS@UW is the university chapter of the Materials Research Society at the University of Washington. The purpose of the chapter is to promote interdepartmental research, provide professional networking events, and organize an annual lecture series focused on materials research. Chapter activities are multifaceted and provide many opportunities for professional development (on-campus research presentations to fellow members), increasing technical knowledge (hands-on demonstrations and training sessions), educating and empowering youth (community outreach), identifying university resources (facility and laboratory tours), and building camaraderie amongst members (social events). The chapter invites all students, postdoctoral researchers, faculty and staff to join, explore and participate.

