IPF on Mesoscale Science and Technology of Materials and Metamaterials
Room: 210F - Session IPF+MS-MoM

Materials for Energy Generation and Storage (8:20-10:20) & Mesoscale Phenomena in the Biosciences I (10:40-12:00)
Moderator: Alain Diebold, SUNY College of Nanoscale Science and Engineering, Carolyn Larabell, University of California, San Francisco

8:20am **IPF+MS-MoM1 Synthesis and Behavior of Nanostructures in Mesoscale Architectures**, ***SangBok Lee***, *G.W. Rubloff, E. Gillette, C. Liu*, University of Maryland, College Park, *X. Chen*, Lam Research Corporation, *J. Hu, S. Wittenberg, L. Graham*, University of Maryland, College Park, *P. Banerjee*, Washington University, St. Louis **INVITED**

As advanced nanostructured electrodes continue to push boundaries for both high power and high energy, it will become increasingly important to understand how structure on the mesoscale impacts charge transport and electrochemical reactions. Understanding the influence of structure on ionic and electronic transport behavior, as well as its influence on degradation is highly essential to design and control improved electrodes. Here, we describe the fabrication of two types of electrodes; one with electrodes constructed in the most simple cylindrical nanopores - "all-in-one nanopore battery" - and the other with electrodes in controllable 3D interconnecting pore network to propose a strategy for bridging the gap between precision, self-aligned nanostructure electrodes and disordered, high density electrodes. These architectures highlight some of the challenges of characterizing tortuosity and porosity in nanostructures, but also provides an opportunity to work with a systematically variable mesoscale electrode structure.

9:00am **IPF+MS-MoM3 Ultralight Microlattices: Defining the Limits of Lightweight Materials**, ***William Carter***, HRL Laboratories, LLC **INVITED**

Design of "materials architecture" is emerging as a new and complimentary approach to classical materials selection in engineering design. By adjusting the geometric arrangement of solid phases and voids within a material, it is possible to extend the achievable property space for lightweight materials and functional coatings. Optimal microlattice materials that can be formed in a wide range of architectures and base materials, with properties spanning from unprecedented low density and surprisingly high mechanical recovery to structural alternatives to honeycomb and foams. The starting polymer microlattice templates are created using an array of interpenetrating self-forming photopolymer waveguides from a single exposure mask. Free-standing hollow micro-lattice materials can be formed based on a wide range of high performance thin films (metals, ceramics and polymers) by coating a micro-lattice template followed by subsequent removal of the template. The process enables precise and independent control over micro-lattice architecture at all levels of structural hierarchy (~100nm up to ~10cm). This technique is also inherently scalable to low-cost high-throughput manufacturing (~10-60 second exposure), highly scalable to large sizes (m2), enabling practical design and fabrication of a wide range of lattice materials including metals, polymers and ceramics.

9:40am **IPF+MS-MoM5 "Can Opto-Electronics Provide the Motive Power for Future Vehicles?"**, ***Eli Yablonovitch***, University of California, Berkeley **INVITED**

A new scientific principle[1] has produced record-breaking solar cells. The 28.8% single-junction solar efficiency record, by Alta Devices [2], was achieved by recognizing the importance of extracting luminescent emission. This is exemplified by the mantra: "A great solar cell also needs to be a great LED". It was essential to remove the original semiconductor substrate, which absorbed luminescence, and to replace it with a high reflectivity mirror. The solar efficiency record crept up as the rear reflectivity behind the photovoltaic film was increased, 96% reflectivity -- 97% -- 98% luminescent reflectivity;-- each produced a new world efficiency record.

In thermo-photovoltaics, high energy photons from a thermal source are converted to electricity. The question is what to do about the majority of low energy infrared photons? It was recognized that the semiconductor band-edge itself can provide excellent spectral filtering for thermophotovoltaics, efficiently reflecting the unused infrared radiation back to the heat source. Exactly those low energy photons that fail to produce an electron-hole pair, are the photons that need to be recycled.

Thus the effort to reflect band-edge luminescence in solar cells has serendipitously created the technology to reflect all infrared wavelengths, which can revolutionize thermo-photovoltaics. We have never before had such high rear reflectivity for sub-bandgap radiation, permitting step-function spectral control of the unused infrared photons for the first time. This enables conversion from heat[3] to electricity with >50% efficiency. Such a lightweight "engine" can provide power to electric cars, aerial vehicles, spacecraft, homes, and stationary power plants.

1. O. D. Miller, Eli Yablonovitch, and S. R. Kurtz, "Strong Internal and External Luminescence as Solar Cells Approach the Shockley–Queisser Limit", IEEE J. Photovoltaics, vol. 2, pp. 303-311 (2012). DOI: 10.1109/JPHOTOV.2012.2198434

2. Kayes, B.M.; Hui Nie; Twist, R.; Spruytte, S.G.; Reinhardt, F.; Kizilyalli, I.C.; Higashi, G.S. "27.6% Conversion Efficiency, A New Record For Single-Junction Solar Cells Under 1 Sun Illumination" Proceedings of 37th IEEE Photovoltaic Specialists Conference (PVSC 2011)Pages: 4-8, DOI: 10.1109/PVSC.2011.6185831

3. The heat source can be combustion, radio-activity, or solar thermal.

10:40am **IPF+MS-MoM8 The Convergence of Synthetic Biology and Biofabrication: Guiding Biological Function at the Mesoscale**, ***William Bentley***, Fischell Department of Bioengineering, University of Maryland **INVITED**

Synthetic biology provides a means for articulating concepts into new products and products. Its toolbox is extensive, including the ability to create synthetic genomes and tailor their regulation. Early successes augmented the cell's biosynthetic capacity and rewired its regulation, transforming our ability to produce products ranging from small molecules to fully functional therapeutic proteins at high yield. Also, the theoretical formalisms of metabolic engineering provided a basis for optimally routing its biochemical flux. With pathway analysis and optimization, cells are now engineered to produce large quantities of economically important molecules. Indeed, many "green" routes to chemical synthesis have appeared and many more are emerging. There exists great enthusiasm and investment to revolutionize several industries. Importantly, these activities have focused largely on the cell's intracellular biochemical network and relied less on molecular cues from the immediate surroundings. Largely untapped within synthetic biology are the signaling motifs that guide cell processes and interactions among communicating populations. That is, signal molecules guide many cellular processes and these can be exploited to endow cells with "executive" function, where decision events are programmed and cells carry out tasks in addition to making products. That is, the cells themselves can be the primary "products" of synthetic biology – putting them to work in complex "noisy" environments will require tailoring their exposure to chemical cues. For example, we may eventually use engineered bacteria to fight cancer, cure diabetes, or "tune" the microbiome in our GI tracts. Biofabrication, the use of biological components and biological processes for assembly, can provide a means for tailoring hierarchical order in biological systems. We exploit the principles of biofabrication to create 3D "test tracks" where chemical cues can be spatiotemporally controlled and task-accomplishing bacteria can be appropriately designed. We will discuss the link between synthetic biology and biofabrication and highlight the potential for new discovery as well as process and product innovation.

11:20am **IPF+MS-MoM10 Using Mesoscale Modeling to Design Materials that Compute: Coupling Self-Oscillating Gels and Piezoelectric Films**, *V.V. Yashin, S.P. Levitan*, ***Anna C. Balazs***, University of Pittsburgh **INVITED**

Lightweight, deformable materials that can sense and respond to human touch and motion can be the basis of future wearable computers, where the material itself will be capable of performing computations. To facilitate the creation of "materials that compute", we draw from two emerging modalities for computation: chemical computing, which relies on reaction-diffusion mechanisms to perform operations, and oscillatory computing, which performs pattern recognition through synchronization of coupled oscillators. Chemical computing systems, however, suffer from the fact that the reacting species are coupled only locally; the coupling is limited by diffusion as the chemical waves propagate throughout the system. Additionally, oscillatory computing systems have not utilized a potentially wearable material. To address both these limitations, we develop the first model for coupling self-oscillating polymer gels to a piezoelectric (PZ) micro-electro-mechanical system (MEMS). The resulting transduction between chemo-mechanical and electrical energy creates signals that can be propagated quickly over long distances and thus, permits remote, non-diffusively coupled oscillators to communicate and synchronize. Moreover, the oscillators can be organized into arbitrary topologies because the electrical connections lift the limitations of diffusive coupling. Using our model, we predict the synchronization behavior that can be used for computational tasks, ultimately enabling "materials that compute."

Monday Afternoon, October 19, 2015

IPF on Mesoscale Science and Technology of Materials and Metamaterials
Room: 210F - Session IPF+MS-MoA

Mesoscale Phenomena in the Biosciences II (2:20-3:40) & Metamaterials (3:40-5:40)
Moderator: Carolyn Larabell, University of California, San Francisco, Mark Brongersma, Stanford University

2:20pm **IPF+MS-MoA1 Mesoscale Imaging in Cell Biology**, ***Gerry McDermott***, *M. Do, J.-H. Chen, A. Walter, M.A. Le Gros, C.A. Larabell*, University of California, San Francisco **INVITED**

Soft X-ray tomography (SXT) is ideally suited to imaging the sub-cellular architecture of biological cells. In SXT, specimens are illuminated with 'water window' photons. X-rays within this energy range (284 – 543eV) are absorbed an order of magnitude more strongly by carbon- and nitrogen-containing organic materials than by water. Consequently, the variation in biomolecule composition and concentration within the specimen gives rise to quantitative, high-contrast images of intact, fully hydrated cells, without the need to use contrast-enhancing agents. The utility of SXT has recently been enhanced by the development of high numerical aperture cryogenic fluorescence tomography (CFT) for correlated imaging studies. This multi-modal approach allows labelled molecules to be localized in the context of a high-resolution 3-D tomographic reconstruction of the cell. This talk will describe correlated CFT-SXT and the application of this technique to long-standing questions in cell biology.

3:00pm **IPF+MS-MoA3 Biomimetic Material Approaches to Tissue Engineering, Regenerative Medicine, and Wound Healing**, ***Elizabeth Loboa***, UNC-Chapel Hill & NC State University **INVITED**

There is growing clinical need in wound healing, tissue engineering, and regenerative medicine for controlled release systems that encapsulate therapeutic compounds and provide sustained release in a site-specific manner. Biocompatible, biodegradable nanofibrous scaffolds with their morphological similarities to the natural extracellular matrix (ECM) in vivo, high surface area to volume ratio, and small interfibrous pore sizes hold great potential for this application. Loading dopants within an electrospun polymeric matrix allows for consistent entrapment throughout the nanofibers. Further, the high surface area to volume ratio of these matrices maximizes the interaction of the carrier with a surrounding medium. A critical parameter for achieving success in controlled release is controlled diffusion of molecules out of the electrospun scaffolds. The drug release characteristics of nanofibrous scaffolds rely on how well the drug is encapsulated inside the nanofibers. These characteristics are critically affected by fiber morphology.

In this presentation, Dr. Loboa will discuss approaches in her lab to elucidate and optimize biomimetic fibrous systems for wound healing, tissue engineering, and regenerative medicine applications. Focus will be placed on regeneration of skin and musculoskeletal tissues and approaches to wound care and tissue regeneration while combating multi-drug resistant bacteria.

3:40pm **IPF+MS-MoA5 Structured Light and Structured Surface Waves from Metasurfaces**, ***Federico Capasso***, Harvard University **INVITED**

Patterning surfaces with subwavelength spaced metallo-dielectric features (metasurfaces) allows one to locally control the amplitude, phase and polarization of the scattered light, allowing one to generate complex wavefronts such as optical vortices of different topological charge and dislocated wavefronts. 1,2 Recent results on achromatic metasurfaces will be presented including lenses and collimators. Metasurfaces have also become a powerful tool to shape surface plasmon polaritons (SPPs) and more generally surface waves. I will present new experiments on imaging SPP that have revealed the formation of Cherenkov SPP wakes and demonstrated polarization sensitive light couplers that control the directionality of SPP and lenses which demultiplex focused SPP beams depending on their wavelength and polarization.

1. N. Yu and F. Capasso Nature Materials 13, 139 (2014)

2. P. Genevet and F. Capasso Reports on Progress in Physics 78, 24401 (2015)

4:20pm **IPF+MS-MoA7 Quest for Extreme Photonics**, ***Nader Engheta***, University of Pennsylvania **INVITED**

Waves can be tailored, manipulated and sculpted by materials. Recent development in condensed matter physics, nanoscience, and materials science and technology has made it possible to construct materials and structures with unusual "extreme" characteristics. These "extreme" scenarios in light-matter interaction may come in several forms: It may be due to extreme in dimensionality such as metasurfaces and one-atom-thick materials, extreme near field such as subwavelength nonreciprocal vortexes in near zones of plasmonic structures, extreme anisotropy in design of superlattices with anisotropic effective mass of charged carriers, giant nonlinearity in phase-change dynamics, extreme information processing as in optical metatronics and "informatic" metastructures, and extreme material parameters such as epsilon- and/or mu-near-zero (ENZ, MNZ, and EMNZ) features leading to phenomena of "static optics". Such "extreme photonics" may provide us with exciting functionalities in both wave physics and quantum optics and engineering. In this talk, some of our ongoing work in these areas will be discussed along with some of the opportunities and challenges in this area.

5:00pm **IPF+MS-MoA9 2D Materials: Graphene and Beyond**, ***Tony Heinz***, Stanford University **INVITED**

The past few years have witnessed a surge of activity in the study of graphene and, more recently, in other atomically thin two-dimensional materials. We will describe some the reasons for the intense interest in these new material systems, highlighting their unusual electronic properties. We will show how we can use light to probe the distinctive properties electrons in model 2-D materials such as graphene and transition metal dichalcogenides. We will discuss the basics of light-matter interactions in these 2-D materials, as well as signatures of electron-electron and electron-phonon interactions, describing both the fascinating physics of these material systems and emerging applications in photonics.

IPF on Mesoscale Science and Technology of Materials and Metamaterials
Room: 210F - Session IPF+MS-TuM

Degradation Science (8:00-10:00) & Electrochemistry from Nano to Meso Scale (11:00-12:20)
Moderator: Gary Rubloff, University of Maryland, College Park, Stacey Bent, Stanford University

8:00am **IPF+MS-TuM1 Mesoscale Evolution & Temporal Analytics of Photovoltaic Energy Materials: A Degradation Science Approach**, ***Roger French***, Case Western Reserve University **INVITED**

Degradation science1 combines physical and statistical approaches to examine degradation mechanisms and pathways of a material or system in order to improve materials and reduce system failures by incorporating modeling, monitoring, and prediction of lifetime performance. Degradation of PV modules evolves over long time-frames and length scales, which is a characteristic of mesoscale science. Degradation arises due to the distinct, complex, and interactive phenomena which lead to failure. Real-world studies under diverse environmental conditions must be combined and cross-correlated with accelerated in-lab studies, using data science and analytics methodologies, so as to span the time and length scales that control the system's behavior over lifetime. Semi-supervised generalized structural equation (semi-gSEM) modeling can be used to relate physical mechanistic submodels with data-driven statistical submodels as networks of mechanisms and modes with statistically significant pathway relationships. The relationships and coupling strengths (βij) amongst variables can be rank-ordered in their contributions to the system's degradation. Temporal evolution, damage accumulation and change points among mechanisms/modes (variables) are accounted for in the semi-gSEM models. Towards these goals, a statistical methodology has been developed and applied to investigate the response of full sized PV modules to accelerated stress conditions. The results of this initial study indicate that a correlation exists between system level power loss and the buildup of acetic acid resulting from the hydrolytic degradation of EVA polymer encapsulant. To further explore this proposed mechanistic pathway, studies are underway to characterize the degradation of minimodule samples under a broader range of similar multifactor accelerated stress conditions. Sample types feature frontside silver gridlines of two different widths and exposure conditions vary in irradiance level and temperature. Samples are measured non-destructively at many points along their lifespan, using confocal Raman microscopy to capture chemical signals and various techniques to gather electrical performance information, with the goal of observing the co-evolution of EVA degradation and gridline corrosion. This represents an important first step towards exploring the often misunderstood role of EVA degradation in PV module performance loss, and building a more integrated picture of PV module degradation as a whole. Initial data analytics of six months' real-world performance data of 60 c-Si PV modules on the SDLE SunFarm shows deviation of performance ratio among modules at the same geometric location. Grouping of samples with similar performance patterns was performed with hierarchical clustering, K-means clustering was used to confirm the optimum number of clusters. A brand dependent module performance model was developed based on a subgroup of 21 modules from 7 manufactures. Over 1.5 million I-V curves measured every 5 minutes for 500 days on 10 modules with/without mirror on dual-axis trackers were analyzed use an automated analytic functions we developed. Maximum power point, open circuit voltage, short circuit current, slope of the curve near open circuit voltage, and slope of the curve near short circuit current are either directly extracted or estimated from measured I-V curves. An algorithm based on moving local regression model was developed to detect the change points on I-V curves, which caused by bypass diode turning on when I-V curve was measured under non-uniform irradiance. These examples of the use of degradation science, with its physical and statistical foundation and data analytics approach, will hopefully enable the community to address the long-term reliability uncertainty of photovoltaics as they become a major component in the world's energy systems.

1. French, Roger H., Rudolf Podgornik, Timothy J. Peshek, Laura S. Bruckman, Yifan Xu, Nicholas R. Wheeler, Abdulkerim Gok, et al., 2015, "Degradation Science: Mesoscopic Evolution and Temporal Analytics of Photovoltaic Energy Materials," Current Opinion in Solid State and Materials Science, Doi: 10.1016/j.cossms.2014.12.008

8:40am **IPF+MS-TuM3 Why Structural Failure is Mesoscale: From Dislocations to Fatigue Cracks**, ***Anthony Rollett***, Carnegie Mellon University **INVITED**

Structural failure of materials is a mesoscale problem because, for example, we lack the tools to predict when and where fatigue cracks will appear in relation to materials microstructure. Dislocations are well understood as line defects but we do not how to compute the behavior of large numbers of dislocations in relation to microstructure. Enormous strides have been made in quantifying the growth of fatigue cracks over the years and improving predictions of component lifetime but all at the microstructural scale and above. Nevertheless, it is clear that the behavior of short cracks is less well quantified, where short is relative to the length scale(s) found in materials microstructure, e.g. grain size. Short fatigue cracks in nickel-based superalloys have been characterized using conventional SEM and orientation mapping. High Energy Diffraction Microscopy (HEDM) and computed tomography (CT) was used to map out the crack positions in 3D. The main finding is that cracks develop most readily along long twin boundaries with high resolved shear stress on the slip systems parallel to the twin plane. Also, both halves of a different superalloy, fully fractured sample have been fully characterized in 3D using the same tools. The HEDM and CT were performed with high energy x-rays on beamline 1ID at the Advanced Photon Source (APS). This talk will review current dislocation modeling, empirical understanding of fatigue cracks in engineering materials and what the experimental and theoretical roadmap might be to address the problem set.

9:20am **IPF+MS-TuM5 Engineered 3D Mesoscale Battery Electrodes: Opportunities and Issues**, ***Paul Braun***, University of Illinois at Urbana-Champaign **INVITED**

Over the past decade, three-dimensional structures have been widely proposed as a path for enhanced lithium-ion batteries. While the sophistication of self and directed-assembly approaches for functional structures has increased dramatically, application of these structures has remained elusive, in part because real structures almost always contain finite defect densities, cannot be produced from materials with the appropriate electrochemical properties, and cannot be produced in sufficient volume for application. We have now made considerable strides in integration of electrically conducting and energy storage material into lithium-ion battery electrodes. We accomplish this by applying template-based and post-synthetic materials transformations, and have focused on ultra-large volume processing strategies. As the technology has approached commercialization, understanding the mechanistics of capacity fade and other electrochemical degradation pathways has become increasingly important.

11:00am **IPF+MS-TuM10 A Materials Genome Approach to Design of Novel Materials and Liquids for Energy Conversion and Storage**, ***Kristin A. Persson***, Lawrence Berkeley National Laboratory **INVITED**

The Materials Genome Initiative (MGI) aims to develop an infrastructure to discover, develop, manufacture, and deploy advanced materials at least twice as fast as possible today, at a fraction of the cost. In this talk I will highlight the advances and development of the Materials Project (www.materialsproject.org), which is an MGI-funded effort to compute the properties of all known inorganic materials and beyond, design novel materials and offer data to the community together with online analysis and design algorithms.1 The current release contains data derived from density functional theory (DFT) calculations for over 60,000 materials, each with searchable associated properties such as relaxed structure, electronic state, energy storage capability, aqueous and solid stability, and more. The software infrastructure enables thousands of calculations per week – enabling screening and predictions - for both novel solid as well as molecular species with target properties. Current application areas include photocatalysis, thermoelectrics, beyond-Li energy storage, and alloy design.

To exemplify the approach of first-principles high-throughput materials design, we will make a deep dive into future energy storage technologies, showcasing the rapid iteration between ideas, computations, and insight as enabled by the Materials Project infrastructure and computing resources. To understand and design novel electrodes for multivalent energy storage requires efficient and robust evaluation of stability, voltage, capacity, volume change, and most importantly, active ion mobility, which is the foremost bottleneck in these systems. Understanding of the structural and chemical features – extracted from calculations and benchmarked against available experimental data - which correlate with facile, selective ion diffusion will be presented and discussed. We are also devoting a large effort to understanding, screening and designing organic liquid electrolyte systems for novel energy storage systems for which the bulk solvation structure and its impact on electrolyte performance is largely uncharted. As an example, we find that contact ion-pair interaction is prevalent in multi-valent electrolytes, even at modest concentrations which influences charge transfer, conductivity and even the stability of the electrolyte.

11:40am **IPF+MS-TuM12 Electrical Double Layer Effects on Ion Transport in Thin-Layer Solid-State Electrolytes**, ***Henry White***, *J. Xiong*, *M. Edwards*, University of Utah **INVITED**

We present finite-element modeling of Li^+ transport in solid-state electrolytes, including the role of the double layer electric fields. We developed a 1-D model that describes the mass transport and electric potential, assuming that Li^+ is the predominant charge carrier. Mass transport is described by the Nernst-Planck equation and the electric potential is described by Poisson's equation. These equations were solved in a fully coupled manner, i.e., the electric field affects the mass transport through the electromigration term in the Nernst-Planck equation, while the excess charge due to unequal ion concentrations affects the electric field as the space charge term in Poisson's equation.

We present calculated potential and concentrations distributions, as well as the contributions of migration and diffusion to the flux of each species. We present investigations of the effect of the solid-state electrolyte thickness on mass transport, varying the thickness from 10 nm to 2000 nm. The current normalized to electrolyte thickness is shown to decreases as the thickness decreases.

IPF on Mesoscale Science and Technology of Materials and Metamaterials
Room: 210F - Session IPF+MS-TuA

Frontiers in Physics
Moderator: Jim Hollenhorst, Agilent, Cathy O'Riordan, AIP

2:20pm **IPF+MS-TuA1 Giving New Life to Materials for Energy, the Environment and Medicine**, ***Angela Belcher***, MIT Koch Institute for Integrative Cancer Research **INVITED**

Organisms have been making exquisite inorganic materials for over 500 million years. Although these materials have many desired physical properties such as strength, regularity, and environmental benign processing, the types of materials that organisms have evolved to work with are limited. However, there are many properties of living systems that could be potentially harnessed by researchers to make advanced technologies that are smarter, more adaptable, and that are synthesized to be compatible with the environment. One approach to designing future technologies which have some of the properties that living organisms use so well, is to evolve organisms to work with a more diverse set of building blocks. The goal is to have a DNA sequence that codes for the synthesis and assembly of any inorganic material or device. We have been successful in using evolutionarily selected peptides to control physical properties of nanocrystals and subsequently use molecular recognition and self-assembly to design biological hybrid multidimensional materials. These materials could be designed to address many scientific and technological problems in electronics, military, medicine, and energy applications. Currently we are using this technology to design new methods for building batteries, fuel cells, solar cells, carbon sequestration and storage, enhanced oil recovery, catalysis, and medical diagnostics and imaging. This talk will address conditions under which organisms first evolved to make materials and scientific approaches to move beyond naturally evolved materials to genetically imprint advanced technologies with examples in lithium ion batteries, lithium-air batteries, dye-sensitized solar cells, and ovarian cancer imaging.

3:00pm **IPF+MS-TuA3 XFEL Movies of Molecular Machines at Work**, ***John Spence***, Arizona State University **INVITED**

With about 1E12 coherent hard X-ray photons per shot of 10 fs duration at 120 Hz, the invention of the X-ray laser (XFEL) has provided many new research opportunities for stuctural biology, which I will review. Our first discovery, that these pulse are so brief that they outrun radiation damage, so that damage-free diffraction patterns at atomic resolution and femtosecond time resolution can be recorded to make movies of protein function, has proved immensely fruitful. Other advances in solution scattering, analysis of protein nano crystals, and imaging of single particles which cannot easily be crystallized, such as viruses, wll be also be reviewed. This work forms part of the activity of the NSF's BioXFEL STC, a consortium of seven US campuses devoted to the use of XFELs for Biology. (http://www.bioxfel.org).

4:20pm **IPF+MS-TuA7 Frontiers of Ocean Sensing**, ***Susan K. Avery***, Woods Hole Oceanographic Institution **INVITED**

The ocean accounts for more than two-thirds of Earth's surface and is our planet's largest biome, yet remains largely unexplored. Because seawater is opaque to most wavelengths of electromagnetic radiation, all but a few centimeters of the upper ocean are invisible to satellites. As a result, only about 5 to 15 percent of the seafloor is mapped in any detail and much of the water column has not been explored. Many of the transient phenomena that occur on, in, or above the ocean—and across a wide range of spatial and temporal scales—have been extremely difficult to capture, and even more difficult to monitor over long periods. New technologies and new adaptations of existing technologies, however, are opening the ocean in all its complexity to researchers at sea and on shore. Our challenge now is to take advantage of these innovations in sensing and observing, not only to fully grasp the role that the ocean plays in making Earth habitable, but also how it fits into planetary and societal changes that are taking place before our very eyes.

5:00pm **IPF+MS-TuA9 New States of Electronic Matter and their Potential for Science and Computation**, ***Joel Moore***, University California, Berkeley **INVITED**

A major development in solid-state physics over the past decade is the discovery of several new classes of electronic materials that combine features of metals and semiconductors in novel and potentially useful ways. "Topological insulators" are materials that insulate in bulk but have atomically thin conducting layers at their surfaces as a subtle consequence of spin-orbit coupling. "Weyl" and "Dirac" semimetals are three-dimensional materials that realize two different 3D generalizations of the massless electronic structure of graphene, a single layer of carbon atoms, whose discovery was recognized by the 2010 Nobel Prize. We explain the origin of these materials and how they might enable dissipationless electrical conduction and superconducting states with fractional "Majorana" particles.

5:40pm **IPF+MS-TuA11 The Universe in Motion: Listening to Gravitational Waves with LIGO**, ***Michael Zucker***, Massachusetts Institute of Technology **INVITED**

Almost 100 years ago, Einstein showed that traces of matter and energy's gyrations are continuously broadcast throughout the universe, in the form of *gravitational waves:* ripples in the underlying geometry of space. Fresh from a major upgrade, the Laser Interferometer Gravitational-wave Observatory (LIGO) is now poised to detect and decode these broadcasts, opening a new era of physics and astronomy. I will talk about why LIGO is so different from other observatories, and describe some of the daunting technological challenges we've overcome to help us realize Einstein's vision.

Authors Index

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