Nanoscale Science and Technology Division
Room On Demand - Session NS-Invited On Demand

Nanoscale Science and Technology Invited On Demand Session

NS-Invited On Demand-1 Engineering Quantum Forces and Torques*, Jeremy Munday,* University of California, Davis **INVITED**

The quantum vacuum gives rise to many effects that would not occur classically. One example is that the confinement of quantum electromagnetic fluctuations between two, isotropic macroscopic objects results in a force, i.e. the Casimir force. This force depends on both the geometry and the optical properties of the materials involved. An additional effect has been predicted for optically anisotropic materials, which can cause a rotation, i.e. a Casimir torque. Here we present our recent measurements of both of these phenomena. First, I will describe our results pertaining to the Casimir force between two spheres – a geometry that has previously eluded measurement due to experimental difficulties. Second, I will discuss additional geometries including pillars and holes that are now possible with this measurement technique and why they are interesting. Finally, I will conclude with a discussion of our recent measurement of the Casimir torque.

NS-Invited On Demand-13 Visualizing Inside of 3D Self-Organizing Systems by 3D-AFM*, Takeshi Fukuma,* Kanazawa University, Japan **INVITED**

Recently, three-dimensional atomic force microscopy (3D-AFM) has been proven to be a powerful tool for investigating various structures and phenomena at solid-liquid interfaces. In the method, a tip is scanned in the *XY* and *Z* directions in a 3D interfacial space. During the tip scan, the variations in the force applied to the tip is recorded to produce a 3D force image. At a solid-liquid interface, the tip interacts with surrounding solvent molecules during the tip scan. Thus, the obtained 3D image represents the distribution of solvent molecules. So far, the method has been used for visualizing 3D hydration structures on minerals, organic thin films, and biological systems with subnanometer-scale resolution. This emerging technology has attracted attention due to its potential applications in the research on interfacial control technologies for anti-fouling, lubrication, anti-freezing, colloidal dispersion, cosmetics and cleaning.

In the meanwhile, here I would like to draw attention to another important implication of the success of the 3D hydration measurements. In the AFM community, it has been a common sense that we should fix atoms or molecules to a solid surface to visualize them with atomic or molecular resolution. However, 3D-AFM allows us to visualize subnanometer-scale distribution of mobile water molecules that are not fixed on a solid surface. This is a big surprise and may lead to the breakthrough for the aforementioned limitation of AFM. Then, the next question would be what is the requirements to be visualized by 3D-AFM. We believe that the answer is capability of self-organization. For example, in the case of 3D hydration measurements, the hydration structure is significantly disturbed during the vertical tip scan yet it is quickly recovered before starting the next vertical scan. Such a self-organization capability is essential for visualizing inside of 3D structures. One may think this is too severe condition yet we can find large number of important 3D self-organizing systems in both natural and artificial environments. Examples include interfacial phenomena and devices (hydration, lubrication, electric double layer devices and liquid crystal devices) to biological systems (cells, nucleus, chromosomes and proteins). 3D-AFM may allow us to directly visualize inside of these various 3D self-organizing systems.

Based on this idea, we have recently started to explore inside of various 3D self-organizing systems: polymer-water interfaces, ionic liquid - electrode interfaces, and inside of chromosomes and live cells. With these examples, here I would like to propose to apply 3D-AFM not only for visualizing hydration structures but also for imaging inside of various 3D self-organizing systems.

NS-Invited On Demand-19 Tackling Instabilities in Hybrid Perovskites from the Macro- to the Nanoscale*, Marina Leite,* University of California at Davis **INVITED**

Halide perovskites for optoelectronics are often composed by micro- and nano-scale inhomogeneous constructs. Therefore, high spatial resolution characterization methods are required for mapping and quantifying their electrical behavior. In this talk I will present our latest developments on atomic force microscopy (AFM) methods to assess the dynamic physical and chemical processes that take once perovskite materials and photovoltaic devices are exposed to light. Briefly, we realize a 4D imaging method that enables mapping open-circuit voltage (Voc) changes with in real-time (16 seconds per scan), and at the nanoscale (< 50 nm in spatial resolution) based on illuminated Kelvin probe force microscopy (KPFM). Using this paradigm, we have demonstrated ion motion within a single nanoscale grain in $MAPbI_3$ solar cells upon 1-sun illumination, which results in a residual Voc that lasts for several minutes even under dark conditions. For multi-cation structures, we found that Cs-based perovskites deliver fully reversible and stable nanoscale voltage response, in excellent agreement with macroscopic measurements. We correlate the Voc nanoscale maps with chemical imaging through nano-IR and discover that the local variations in voltage are related to the power conversion efficiency enhancement in KI-treated perovskite. The heterogeneity revealed in both the local electrical and chemical responses reveals that the KI additive migrates our of the perovskite films, yet surprisingly; does not affect device performance. Our functional imaging platform can be extended to other perovskite materials, including Pb-free options. At the macroscopic scale, we provide a detailed comparison between $MAPbBr_3$ and $MAPbI_3$ through time-dependent voltage measurements. They reveal that, upon illumination, high-energy photons leads to a > 10x slower voltage decline toward equilibrium than low-energy photons in $MAPbBr_3$. Yet, $MAPbI_3$ shows wavelength-independent decay rate, resulting from ion migration. Through in situ photoluminescence (PL) under environmentally controlled conditions, we resolve a humidity-induced PL hysteresis. Further, we apply a machine learning algorithm to predict the luminescence response for > 12 hs. Concerning the unique behavior of multi-cation perovskites, a correlative microscopy approach is realized, combined with environmental-controlled PL measurements.

NS-Invited On Demand-31 Programming Assembly of 3D Nanoscale Systems*, Oleg Gang,* Columbia University **INVITED**

The ability to organize nano-components into the desired architectures with targeted properties can enable a broad range of nanotechnological applications, from energy materials to information processing. However, we are currently lacking an adaptable and broadly applicable methodology for the bottom-up fabrication of desired nanoscale structures. I will discuss our efforts on establishing a versatile assembly platform based on the molecular programming for guiding the formation of targeted architectures from nano-components of different types. The recent advances on assembly of targeted 2D and 3D periodic organizations, hierarchical structures, and arbitrary designed architectures from DNA-encoded abiotic and biological nano-components will be presented. Finally, I will discuss how these assembly approaches can be used for fabrication of nanomaterials with novel optical, mechanical, and catalytic functions.

NS-Invited On Demand-37 Nanoelectronic Devices and Architectures for Energy-Efficient Computing*, An Chen,* IBM Almaden Research Center **INVITED**

As the CMOS scaling driven by the Moore's Law approaching some fundamental limits, high power consumption and heat dissipation on chip have been recognized as the most critical challenges. The semiconductor industry has explored numerous nanoelectronic devices with the potential to achieve significantly lower power based on unconventional mechanisms, materials, and structures, including steep-slop transistors, phase-transition switches, spintronics, van der Waals devices, etc. For example, the Nanoelectronics Research Initiative (NRI) was funded by the Semiconductor Research Corporation (SRC) for over a decade to pursue the "next switch" beyond CMOS. Despite abundant scientific breakthroughs achieved in these device researches, no beyond-CMOS device has been demonstrated to significantly outperform CMOS for Boolean logic and von Neumann architectures. On the other hand, many nanoelectronic devices have shown unique characteristics, e.g., device-level reconfigurability, built-in memory-in-logic capability, tunable analog behaviors, programmable randomness, etc. They can be utilized in novel architectures and computing paradigms, including reconfigurable logic, analog and neuromorphic computing, compute-in-memory, nonvolatile logic, stochastic computing, etc.

To effectively utilize these unique characteristics in novel architectures, it is essential to cooptimize devices and architectures in order to achieve improved functionalities and efficiency. Both bottom-up (optimizing devices to meet architectural requirements) and top-down (designing circuit blocks and architectures to exploit device properties) approaches are needed. Sustainable and scalable technology advancement is often driven by material and device innovations; therefore, it is important to explore emerging materials and devices capable of native implementations of some novel computing paradigms. At the same time, CMOS technology has also been adopted in many novel computing paradigms, which presents not only a mature baseline for comparison but also a formidable competitor. Nanoelectronic devices and architectures need to provide convincing advantages in performance and efficiency over CMOS to justify significant research investment, which should be addressed by comprehensive benchmarking. A holistic approach from material exploration to device engineering and further up to architecture co-design has been emphasized in several research programs, including E2CDA (Energy-Efficient Computing from Devices to Architectures) at NSF, nCORE (nanoelectronic Computing Research) at SRC, etc. This presentation will discuss the opportunities and challenges of nanoelectronic devices and architectures for energy-efficient computing in the context of these recent research programs.

Author Index

Bold page numbers indicate presenter