Nanomaterials
Room Naupaka Salon 5 - Session NM-TuE
Magnetic Properties and Nanocomposites

Moderator: H. Henry Lamb, North Carolina State University

5:40pm **NM-TuE1 Voltage-Assisted Magnetic Switching in MgO/CoFeB-Based Magnetic Tunnel Junctions by Way of Interface Reconstruction**, *J. Ko, **Jongill Hong**,* Yonsei University, Republic of Korea **INVITED**

Engineering of interfacial structures has become important to find new scientific observations and to create novel applications more than ever before. In this presentation, we show that the interface reconstructed by sub-monolayer-thick Mg insertion improved the magneto-electrical properties of perpendicular magnetic tunnel junctions essential for modern spintronic applications. The 0.2−0.4 nm-thick Mg inserted between MgO tunnel barrier and CoFeB ferromagnet restructured the interface in such ways as to protect the CoFeB from over-oxidation, to strengthen the texture, to make the interfacial roughness smooth, and to relax the mechanical stress. Observed were great increases in the perpendicular magnetic moment and perpendicular magnetic anisotropy of the CoFeB by 2.1 and 1.8 times, respectively, which can be ascribed to the optimum interfacial condition because of the least possible chemical damage. Furthermore, strong enhancement of (010) in-plane and (001) out-of-plane texture and of interfacial roughness led to a significant increase in the tunnel magnetoresistance by 4.4 times from 13.2 to 57.6% by the insertion. Most importantly, the electric field-controlled magnetic anisotropy coefficients became *symmetrically bipolar* to the electric field, which is essential for device applications, and they were increased over 100 fJ/V·m, which is 6 times larger than one found before the Mg insertion owing to optimum chemical and physical structures at the interface. As a result, we could successfully demonstrate the voltage-induced magnetization switching for the perpendicular magnetic tunnel junctions with the help of an external magnetic field. We strongly believe that our findings will ignite further study on the new way of electrical control over magnetic switching and provide an essential ingredient to realize electric field-driven energy-effective magneto-electronic devices.

6:20pm **NM-TuE3 A Theoretical Outlook on the Exotic Properties of Spin Ice and Other Magnetic Pyrochlore Thin Films**, ***Michel Gingras,*** University of Waterloo, Canada

Frustrated magnetic materials and strongly correlated electron systems are a forefront of research in modern condensed matter physics and materials science. Despite almost three decades of investigations, the theoretical understanding of these fascinating systems remains incomplete. The most prominent theoretical frameworks used to tackle these systems take the form of an *emergent gauge theory* akin to the gauge theory that describes conventional electromagnetism.

Spin ice is an unusual substance in which the magnetic moments of individual atoms behave very similarly to the protons in conventional water ice — hence the name spin ice — failing to align even at very low temperatures and displaying the same residual entropy that Linus Pauling calculated for water ice and which is measured experimentally. Spin ices, which belong to the broad class of compounds called magnetic pyrochlores, actually have something in common with electromagnetic fields; both can be described by a gauge theory. Many aspects of conventional electromagnetism are sensitive to constraints from enclosure boundaries, such as total internal reflection used in communication with optical fibers. It is then reasonable to wonder if spin ices have similar sensitivities to boundary effects and confinement. Motivated by the recent experimental realizations of spin ice and other magnetic pyrochlore thin films, I will explore in this talk some of the exotic physical phenomena that arise when considering spin ice thin films such as, for example, a novel magnetic charge crystallization on the film surface while the bulk remains thermally disordered **[1]**. From a broader context, magnetic pyrochlore thin films offer a natural platform to study the confinement of emergent gauge fields describing strongly correlated systems and the evolution of nontrivial magnetic correlations as one moves from three to two dimensional spin textures **[2]**.

[1] L. D. C. Jaubert, T. Lin, T. S. Opel, P. C. W. Holdsworth, and M. J. P. Gingras, Phys. Rev. Lett. **118**, 207206 (2017).

[2] Étienne Lantagne-Hurtubise, Jeffrey G. Rau, and Michel J. P. Gingras; Phys. Rev. X **8**, 021053 (2018).

6:40pm **NM-TuE4 Extending Compound Semiconductor Nanowire Functions by the Introduction of Additional Elements**, ***Fumitaro Ishikawa,*** Ehime University, Japan **INVITED**

Semiconductor nanowires are promising as building blocks in nanoelectronics and nanophotonics. The introduction of III–V compound semiconductor heterostructures into NWs provides dynamic control for the electronic band structure of these systems. On the other hand, oxides displaying advantageous dielectric, thermal, and resistive properties, which cannot be achieved in semiconductors, make their combination with semiconductors appealing. GaAs and related heterostructure have realized various optical and electronic devices with high speed and efficiency, e. g., transistors, lasers, and solar cells. To extend the functions of the materials system, diluted nitride and bismide has been paid attention over the past decade. They can largely decrease the band gap of the alloys, providing the greater tunability of band gap and strain status, eventually suppressing the non-radiative Surface and/or Auger recombinations. Selective wet oxidation for Al-rich AlGaAs is a vital technique for vertical surface emitting lasers. That enables the introduction of precisely controlled oxides in the system, enabling the optical and electrical confinement, heat transfer, and mechanical robustness.

We introduce the above materials into GaAs nanowires.[1] GaAs/GaAsN core-shell nanowires showed clear redshift of the emitting wavelength toward infrared regime. Further, the N introduction passivates non-radiative surface recombination, demonstrating laser emission from the single nanowire.[2,3] GaAs/GaAsBi core-shell structure was also obtained, showing a characteristic modification of the nanowire morphology.[4] Selective and whole oxidations of GaAs/AlGaAs core-shell nanowires produce semiconductor/oxide composite GaAs/AlGaOx. Possibly sourced from molecular species, the oxide shell shows white luminescence. [5,6]

[1] Ed. F. Ishikawa and I. A. Buyanova, *Novel Compound Semiconductor Nanowires: Materials, Devices and Applications*, Pan Stanford Publishing, 2017. [2] M. Yukimune, R. Fujiwara, H. Ikeda, K. Yano, K. Takada, M. Jansson, W. M. Chen, I. A. Buyanova, F. Ishikawa, Appl. Phys. Lett. 113, 011901, 2018 [3] S. Chen, M. Jansson, J. E. Stehr, Y. Huang, F. Ishikawa, W. M. Chen, I. A. Buyanova, Nano Lett. 17, 1775. [4] F. Ishikawa, Y. Akamatsu, K. Watanabe, F. Uesugi, S. Asahina, U. Jahn, and S. Shimomura, Nano Lett. 15, 7265, 2015. [5] H. Hibi, M. Yamaguchi, N. Yamamoto, and F. Ishikawa, Nano Lett. 14, 7024, 2014. [6] F. Ishikawa, P. Corfdir, U. Jahn, O. Brandt, Adv. Opt. Mater., 4, 2017, 2016.

7:40pm **NM-TuE7 Single-molecule Study on Nanocarbon Materials**, ***Shintaro Fujii,*** Tokyo Institute of Technology, Japan **INVITED**

Understanding charge transport through nanocarbon materials across the metal–molecule interface is a fundamental issue in organic devices. In recent years, single-molecule scale studies on charge transport through the metal–molecule interface have been made possible by break junction techniques. Here, we present our recent single-molecule transport studies on nanocarbon meterials using scanning tunneling microcopy (STM) and break junction techniques in combination with current-voltage measurements and fist principle simulations [1-4].

Bowl-shaped π-conjugated nanocarbons, or buckybowls, are a novel class of sp^2-hybridized nanocarbon materials. In contrast to tubular carbon nanotubes and ball-shaped fullerenes, the buckybowls feature structural flexibility. Bowl-to-bowl structural inversion is one of the unique properties of the buckybowls in solutions. Bowl inversion on a surface modifies the metal–molecule interactions through bistable switching between bowl-up and bowl-down states on the electrode surface, which makes surface-adsorbed buckybowls a relevant model system for elucidation of the mechano-electronic properties of nanocarbon materials. We demonstrate that the bowl inversion can be induced by approaching the STM tip toward the molecule. By tuning the local metal–molecule interaction using the STM tip, the sumanene buckybowl exhibits structural bistability with a switching rate that is two orders of magnitude faster than that of the stochastic inversion process.

Aromaticity of nanocarbons is a fundamental concept in chemistry. Antiaromatic nanocarbons are predicted to exhibit remarkable transport properties and high redox activities. However, it has only been possible to measure compounds with reduced aromaticity but not antiaromatic nanocarbons due to their energetic instability. We addressed these issues by investigating the single-molecule charge transport properties of a genuinely antiaromatic nanocarbon, showing that antiaromaticity results in an order of magnitude increase in conductance compared with the aromatic counterpart. Single-molecule *I-V* measurements and first principle transport calculations reveal that this results from a reduced energy gap and a frontier molecular resonance closer to the electrode potential in the antiaromatic species. The conductance of the antiaromatic complex is further modulated electrochemically, demonstrating its potential as a high-conductance transistor.

References

[1] Y. Komoto et al., Sci. Rep. 6, 26606 (2016). [2] Y. Isshiki et al., J. Am. Chem. Soc., 140, 3760 (2018). [3] S. Fujii et al., J. Am. Chem. Soc., 38, 12142 (2016). [4] S. Fujii et al., Nat. Commun., 8, 15984 (2017).

8:20pm **NM-TuE9 Interfacial Defect Vibrations Enhance Thermal Transport in Amorphous Multilayers with Ultrahigh Thermal Boundary Conductance***, **Ashutosh Giri**, J. Braun, J. Gaskins,* University of Virginia*; S. King,* Intel Corporation*; A. Henry,* Massachusetts Institute of Technology*; W. Lanford,* University at Albany*; P. Hopkins,* University of Virginia

The role of interfacial nonidealities and disorder on thermal transport across interfaces is traditionally assumed to add resistance to heat transfer, decreasing the thermal boundary conductance (TBC). However, recent computational works have suggested that interfacial defects can enhance this thermal boundary conductance through the emergence of unique vibrational modes intrinsic to the material interface and defect atoms, a finding that contradicts traditional theory and conventional understanding. By manipulating the local heat flux of atomic vibrations that comprise these interfacial modes, in principle, the TBC can be increased. In this work, we provide experimental evidence that interfacial defects can enhance the TBC across interfaces through the emergence of unique high frequency vibrational modes that arise from atomic mass defects at the interface with relatively small masses. We demonstrate ultrahigh TBC at amorphous SiOC:H/SiC:H interfaces, approaching 1 GW m^{-2} K^{-1} and are further increased through the introduction of nitrogen defects. The fact that disordered interfaces can exhibit such high conductances, which can be further increased with additional defects, offers a unique direction to manipulate heat transfer across materials with high densities of interfaces by controlling and enhancing interfacial thermal transport.

8:40pm **NM-TuE10 Icephobic and Hydrophobic Behaviour of Laser Patterned Polyurethane Nanocomposite Coatings***, **Bartlomiej Przybyszewski**,* Warsaw University of Technology, Poland*; R.K. Kozera,* Technology Partners Foundation, Poland*; A. Boczkowska,* Warsaw University of Technology, Poland*; A.G. Gonzalez-Elipe, A.B. Borras,* Instituto de Ciencia de Materiales de Sevilla, Spain

Laser Patterning (LP) is a versatile tool for the fabrication of micro and sub-micropatterns on different materials. Inspired by typical plant surfaces with super-hydrophobic character such as lotus leaves and rose petals, structured hydrophobic surfaces have been prepared to discuss the wettability properties. In this work, LP was used to produce periodic surface structures on modified polyurethane (PU) coatings with periods ranging from 10 to 30 µm. The influence of the different modifications of PU as well as topographical characteristics of the produced micropatterns on coatings' wettability and icephobicity was investigated. The morphologies of structured samples include linear, square and rhombic protuberances. 2024 Al alloy and commercially available polyurethane topcoat, an extensively used materials in aircrafts and marine vessels, were employed as the substrates. To characterize the surface topography of the produced structures Scanning Electron Microscopy and Laser Profilometry were utilized. Static contact angle (SCA) and contact angle hysteresis (CAH) have been determined using standard wettability tests. Ice accretion, ice adhesion and freezing delay time tests have been carried out to assess icephobic properties of investigated coatings. It was found that prepared structured surfaces showed hydrophobic property with a WCA as high as 170° and CAH lower than 10°. Measurements of the contact angle of water on the treated surfaces allowed to identify an wetting behavior depending mainly on the laser period, surface roughness and chemical composition of investigated surfaces.

Author Index

Bold page numbers indicate presenter