## Two Dimensional Materials

*Ripples, Strains and Quantum Transport in Few Layer Graphene Membranes*, **CHUN NING (JEANIE) LAU** (Department of Physics and Astronomy, University of California, Riverside, CA 92521; lau@physics.ucr.edu)

Graphene, a two - dimensional single atomic layer of carbon, has the double identity as nature thinnest membrane as well as an extraordinary conductor with unique electrical properties. Here I will present our results on suspended high mobility single- and few-layer graphene devices. We demonstrate ripple formation, strain manipulation and the presence of an intrinsic gapped state in bilayer and trilayer graphene at the charge neutrality point, evidence for quantum phase tranisition, stacking-order dependent transport in trilayer graphene, and if time permits, quantum Hall transitions in these systems. Our results underscore the fascinating many-body physics in these 2D membranes, and have implications for band gap engineering for graphene electronics and optoelectronic applications.

*Optoelectronic and Thermal Transport Properties of Two-Dimensional Materials and Heterostructures*, **CHUN CHUNG CHEN[1], ZHEN LI[1], SHUN-WEN CHANG[2], and STEPHEN B. CRONIN[1,2]*** ([1]Department of Electrical Engineering, [2]Department of Physics, University of Southern California, Los Angeles, CA 90089, USA; scronin@usc.edu).

I will report our latest results studying the optoelectronic properties and thermal transport characteristics of nanoscale materials and devices. We have measured thermal transport across a graphene/hexagonal boron nitride (*h*-BN) interface by electrically heating the graphene and measuring the temperature difference between the graphene and BN using Raman spectroscopy (*Applied Physics Letters*, 104, 081908 (2014)). Because the temperature of the graphene and BN are measured optically, this approach enables nanometer resolution in the cross-plane direction. A temperature drop of 60K can be achieved across this junction at high electrical powers (14mW). Based on the temperature difference and the applied power data, we determine the thermal interface conductance of this junction to be $7.4 \times 10^6$ $Wm^{-2}K^{-1}$, which is substantially below the $10^7$-$10^8$ $W/m^2{\times}K$ values previously reported for graphene/$SiO_2$ interface.

We also report the first photocurrent spectra measured from single layer $MoS_2$. Here, substantial improvements and modulation in the photocurrent (PC) and photoluminescence (PL) spectra of monolayer $MoS_2$ are observed under electrostatic and ionic liquid gating conditions. The magnitude of the photoluminescence can be increased 300% by ionic liquid gating due to the passivation of surface states and trapped charges that act as recombination centers. The photocurrent also doubles when passivated by the ionic liquid. Interestingly, a significant shift of the PL peak position are observed under electrostatic (14meV) and ionic liquid (30meV) gating, as a result of passivation.

*Indirect Excitons in van der Waals Heterostructures*, **M.M. FOLGER, L.V. BUTOV, and K.S. NOVOSELOV** (Department of Physics, University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0319; mfogler@ucsd.edu).

All known superfluid and superconducting states of condensed matter are enabled by composite bosons (atoms, molecules, Cooper pairs) made of an even number of fermions. Temperatures where such macroscopic quantum phenomena occur are limited by the lesser of the binding energy and the degeneracy temperature of the bosons. High critical temperature cuprate superconductors set the present record of ~100 K. Here we propose a design for artificially structured materials to rival this record. The main elements of the structure are two monolayers of a transition metal dichalcogenide (TMD) and an atomically thin hexagonal boron nitride (hBN) spacer. Electrons and holes generated in the system would accumulate in the separate TMD layers and form bosonic bound states --- the indirect excitons. The resultant degenerate Bose gas of excitons would exhibit macroscopic occupation of a quantum state, vanishing viscosity, and superconductivity at high temperatures.

*Manipulating Correlated Phases in Graphene*, **ALESSANDRA LANZARA** (Department of Physics, University of California, Berkeley, 321 Birge Hall, Berkeley, CA 94720-7300; alanzara@lbl.gov).

The peculiar electronic structure of graphene, where quasiparticles have zero effective mass and follow the relativistic Dirac equations, is at the basis of a variety of novel exciting properties of this two dimensional material. In this talk I will discuss how strongly correlated electron phases can be realized in monolayer graphene and how the underlying band structure can be engineered by a variety of different tuning parameters. Comparisons to other Dirac-like two dimensional materials such as the topological insulators will be discussed.

*Electron-Hole Excitations in Two-Dimensional Atomic Layer Materials*, **NATHANIEL M. GABOR** (Department of Physics and Astronomy, University of California Riverside, 900 University Avenue, Riverside, CA 92521; nathaniel.gabor@ucr.edu).

Electron-hole pair excitations, or excitons, have been explored in a wide variety of materials, ranging from individual molecules to nanoscale semiconductor crystals, and in numerous fields from chemical biology to solid-state physics. This diverse interest stems from the fact that electron-hole pairs are discrete, neutral excitations that are highly sensitive to both a material's electronic properties and the dielectric environment. Recently, considerable progress has been made in probing excitons and their dynamics, uncovering numerous phenomena such as multi-exciton generation and indirect exciton Bose-Einstein condensation. While electron-hole pairs have been explored in conventional materials, progress is no more evident than in quantum-confined materials, in which one, two, or three of the spatial dimensions of the system approaches the effective Bohr radius of the bound electron-hole pair.

While quantum electronic measurements probe charge transport of carriers at low energy, photoexcitation may drive electron-hole systems into a regime dominated by high-energy interactions. Near the charge neutrality point (CNP) in graphene and in atomic layer semiconductors, neutral electron-hole excitations are expected to dominate energy transport. In this talk, I will discuss photoresponse measurements of graphene and molybdenum ditelluride quantum systems that explore the emergence of novel mechanisms for energy transport through electron-hole excitations. By combining quantum transport with precision optical techniques, these measurements provide a glimpse into the strong interactions of electron-hole pairs, and establish the first steps in the search for correlated electron behavior in the regime of strong light-matter interactions.

*2D Transition Metal Dichalcogenide Films: Facile Single-Layer Film Growth on $SiO_2$ and Bandgap Engineering through Alloying*, **LUDWIG BARTELS** (Department of Chemistry, University of California, Riverside, CA 92521; bartels@ucr.edu).

Transition metal dichalcogenides (TMD) present exciting materials systems that provide tunable and direct –bandgap semiconducting properties at the single-layer limit. Single layer films of $MoS_2$, $MoSe_2$, $WS_2$, etc. can be grown in CVD-like processes on $SiO_2$ and similar materials at process temperatures of ≤700°C. They extend in a continuous fashion across cm-scale substrates and are composed of micron-scale rotational domains. This provides for exciting opportunities in integration of direct bandgap materials and materials with photonic potential into silicon-based devices. By means of alloying, their bandgaps can be tuned in a continuous fashion between 1.9 and 1.6 eV. Their growth can be seeded by pre-patterning of the substrate.

*Engineering a Fault-tolerant Quantum Computer*, **JASON ALICEA** (Department of Physics, and Institute for Quantum Information and Matter, California Institute of Technology, Pasadena CA 91125; aliceaj@caltech.edu).

During the past few decades studies of two-dimensional materials have catalyzed the development of numerous new physics paradigms. The quantum Hall effect—which can be seen in systems ranging from GaAs quantum wells to graphene and beyond—provides a spectacular example. Quantum Hall systems have indeed given birth to revolutionary concepts such as topological order, fractionalization, and the emergence of particles known as 'anyons' that exhibit richer exchange statistics than that of ordinary bosons and fermions. In this talk I will describe how one can modify well-understood quantum Hall phases that are routinely observed in the lab to stabilize different classes of so-called non-Abelian anyons. These particles not only promise to further push the boundary of our understanding of quantum mechanics, but may also ultimately allow for the fabrication of an intrinsically decoherence-free quantum computer.

*Magnetic Topological Insulator Hetero-Structures*, **KANG L. WANG** (Device Research Laboratory, Department of Electrical Engineering, WIN Institute of Neurotronics Systems, KACST-UCLA Center on Green Nano Electronics, University of California, Los Angeles, Los Angeles, CA 90095-1594; wang@ee.ucla.edu).

Magnetic topological insulator comprised of two-dimensional (2-D) materials has a potential of providing many interest physics and applications by manipulating the surfaces states, e.g., yielding quantum anomalous Hall effect giving rise to dissipation-less chiral edge current, giving axion electromagnetism and others. In the first part of this talk, we show the generation of robust magnetism by doping magnetic ions (Cr) into the host 2-D $(Bi_xSb_{1-x})_2Te_3$ materials. With gate-controlled magneto-transport measurements, we demonstrate the presence of both the hole-mediated RKKY coupling and carrier-independent van Vleck magnetism. By adjusting the Cr doping concentration and Bi/Sb ratio, an experimentally demonstration in the QAHE region was obtained. The second part of this talk will discuss the manipulation of surface-related magnetism in the modulation-doped TI/Cr-doped TI heterostructures. We investigate the role of massive surface Dirac fermions in the bulk RKKY mediation process. Both our theoretical models and experimental results reveal that the topological surface-related magnetic order can be either enhanced or suppressed, depending on the magnetic interaction range between the surface states and Cr ions. With this magnetic insulator, we also observe quantum anomalous Hall effect at 80 mK. In addition, using such TI heterostructures, we also demonstrate the magnetization switching via giant (a 3- orders-of-magnitude increase) spin-orbit torque and induced effective field induced by an in-plane current.

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*Topological Insulators and Beyond*, **DAVID HSIEH**, (Institute for Quantum Information and Matter, California Institute of Technology, Pasadena CA 91125; dhsieh@caltech.edu).

Over the past several years, topological insulators have become an intensively researched topic in condensed matter physics. Interest in these materials stems not only from their being a fundamentally new phase of quantum matter, but also because they hold promise for novel technological applications ranging from low power spin-based electronics to fault-tolerant quantum computers. In this talk, I will describe the early theoretical and experimental works that established the existence of topological insulators. In particular, I will focus on the role that spin- and angle-resolved photoemission spectroscopy played in the discovery of topological insulators in three-dimensional bulk crystals. Finally I will discuss some of the exciting new varieties of topological matter that have more recently been proposed and describe experiments underway to search for them.