Electronic Materials and Photonics Division
Room 14 - Session EM+2D+MI+MN-WeA

Materials and Devices for Quantum Information Processing

Moderators: Rachael Myers-Ward, U.S. Naval Research Laboratory, Steven Vitale, MIT Lincoln Laboratory

2:20pm **EM+2D+MI+MN-WeA-1 Controlling the Valley Degree of Freedom in 2D Transition Metal Dichalcogenides*, Tony Heinz,*** Stanford University / SLAC National Accelerator Laboratory **INVITED**

Monolayer transition metal dichalcogenide crystals in the MX_2 family with M = Mo, W and X = S, Se have been shown to provide attractive possibilities for access to the valley degree of freedom both optically and through the valley Hall effect. In this paper we will summarize recent advances in the electrical and optical control of the valley degree of freedom in this class of materials.

The optical selection rules in the transition metal dichalocogenide monolayers permit selective creation of excitons in either the K or K' valley through the use of circularly polarized light. Excitons consisting of coherent superpositions of both valleys can also be produced through excitation with linearly polarized light. While these results have already been demonstrated experimentally, to date there has been no report of an approach to *manipulate* the valley exciton pseudospin after its creation. In this paper we present our recent use of the optical Stark effect to dynamically modify the valley pseudospin. The approach is based on selectively altering the energy of one valley vis-a-vis the other through application of a sub-gap optical pulse with circular polarization. This perturbation leads to a rapid rotation of the exciton valley pseudospin, as revealed by a change in the polarization state of the exciton emission.

In a second line of investigation, we have applied to spin-valley Hall effect in transition metal dichalocogenide monolayers to produce spatially separated regions with enhanced valley (and spin) populations. This is achieved by running a current through a hole-doped monolayer and relying on the anomalous velocity terms to separate the holes spatially. The resulting spin-valley spatial profile has been directly imaged on the micron scale and characterized using measurements based on the optical Kerr effect. The magnitude of this spin-valley imbalance and its dependence on doping and bias fields have been investigated and compared with theoretical predictions.

3:00pm **EM+2D+MI+MN-WeA-3 VOI-based Valleytronics in Graphene*, Yu-Shu Wu,*** National Tsing-Hua University, Taiwan, Republic of China **INVITED**

Electrons in gapped graphene carry a unique binary degree of freedom called valley pseudospin, in association with the two-fold valley degeneracy at the Dirac points (K and K') of Brillouin zone. Such pseudospin carries an intrinsic angular momentum and responds to external electromagnetic fields in ways similar to those of an ordinary electron spin [1,2]. We examine the response and address the important issue of valleytronics - the electrical manipulation of valley pseudospin. A unified methodology called VOI based valleytronics will be presented, which exploits the valley-orbit interaction (VOI) between an in-plane electric field and a valley pseudospin for the implementation of valleytronics. Based on the VOI mechanism, a family of fundamental structures have been proposed with important device functions, such as valley qubits, valley filters, and valley FETs [3]. We will report recent theoretical developments in these structures.

[1] Rycerz et al., Nat. Phys. **3** (2007),172.

[2] Xiao et al., Phys. Rev. Lett. **99**, (2007), 236809.

[3] Wu et al., Phys. Rev. B **84**, (2011), 195463; *ibid* B **86** (2012), 165411; *ibid* B **88** (2013), 125422; *ibid* B **94** (2016), 075407.

4:20pm **EM+2D+MI+MN-WeA-7 Creating Quantum Technologies with Spins in Semiconductors***, B Zhou, **David Awschalom,*** University of Chicago **INVITED**

There is a growing interest in exploiting the quantum properties of electronic and nuclear spins for the manipulation and storage of information in the solid state. Such schemes offer fundamentally new scientific and technological opportunities by leveraging elements of traditional electronics to precisely control coherent interactions between electrons, nuclei, and electromagnetic fields. Although conventional electronics avoid disorder, recent efforts embrace materials with incorporated defects whose special electronic and nuclear spin states allow the processing of information in a fundamentally different manner because of their explicitly quantum nature [1]. These defects possess desirable qualities – their spin states can be controlled at and above room temperature, they can reside in a material host amenable to microfabrication, and they can have an optical interface near the telecom bands. Here we focus on recent developments that exploit precise quantum control techniques to explore coherent spin dynamics and interactions. In particular, we manipulate a single spin in diamond using all-optical adiabatic passage techniques [2], and investigate the robustness of the acquired geometric (Berry) phase to noise as well as novel strategies to overcome traditional speed limits to quantum gating. Separately, we find that defect-based electronic states in silicon carbide can be isolated at the single spin level [3] with surprisingly long spin coherence times and high fidelity, can achieve near-unity nuclear polarization [4] and be robustly entangled at room temperature [5]. Finally, we identify and characterize a new class of optically controllable defect spin based on chromium impurities in the wide-bandgap semiconductors silicon carbide and gallium nitride [6].

[1] D.D. Awschalom, L.C. Bassett, A.S. Dzurak, E.L. Hu and J.R. Petta, Science 339, 1174 (2013).

[2] C. G. Yale, F. J. Heremans, B. B. Zhou, et al., Nature Photonics 10, 184 (2016); B. B. Zhou et al., Nature Physics 13, 330 (2017).

[3] D. J. Christle, A. L. Falk, P. Andrich, P. V. Klimov, et al., Nature Materials 14, 160 (2015); D. J. Christle et al., arXiv:1702.07330 (2017).

[4] A. L. Falk, P. V. Klimov, et al., Physical Review Letters 114, 247603 (2015).

[5] P. V. Klimov, A. L. Falk, D. J. Christle, V. V. Dobrovitski, and D. D. Awschalom, Science Advances 1, e1501015 (2015).

[6] W. F. Koehl et al., Editors Suggestion, Phys. Rev. B 95, 035207 (2017).

5:00pm **EM+2D+MI+MN-WeA-9 Diamond as an Electronic Material: Opportunities and Challenges*, Steven Vitale,*** *J Varghese, M Marchant, T Wade, M Geis, T Fedynyshyn, D Lennon, M Hollis,* MIT Lincoln Laboratory

Diamond possesses extraordinary semiconductor properties including carrier mobility, saturation velocity, and thermal conductivity which far exceed those of silicon and essentially all other semiconductor materials. In spite of these incredible qualities diamond has not yet become a mainstream transistor material, for two primary reasons. First, existing small single-crystal substrates have not been able to take advantage of commercial microelectronics processing equipment and growth of wafer-scale single-crystal diamond has not been vigorously pursued. Second, deep donor and acceptor levels in diamond imply that the impurity ionization fraction is quite low at room temperature which results in low carrier density in conventional FET architectures.

However the situation has changed dramatically in the past few years. Plasma-enhanced CVD promises to create large-wafer single-crystal diamond through mosaic or novel catalytic growth.[1] Additionally, the discovery of the diamond surface FET has addressed the problem of low carrier density.[2] Together, these advancements may allow development of practical diamond transistors with unparalleled performance for high-power, high-frequency applications. Many unit process and process integration challenges remain to develop diamond surface FETs into commercial technology. This paper will report on the state of the art in diamond surface FET technology and will examine current unmet needs.

We have developed diamond surface FETs with current densities in excess of 100 mA/mm. This is enabled by a novel surface activation process using a high concentration of NO_2 in air to react with a hydrogen-plasma-treated diamond surface. The electron accepting nature of the modified surface abstracts an electron from the diamond, resulting in a 2D hole gas (2DHG) in the diamond. We measure a hole mobility of 30-130 $cm^2/V\text{-}s$ and a repeatable surface resistance of ~ 1.5 $k\Omega\ sq^{-1}$ using this technique. 2DHG formation has been demonstrated using other surface moieties as well, including photoacid radical generators and trinitrotoluene. Pros and cons of these different surface adsorbates will be discussed. The performance of Au, Mo, Pt, Al, Pd, Ti, Cr contacts, as well as combinations of these metals will be presented, with a record-low diamond contact resistance of 0.6 ohm-mm and good ohmic behavior.

[1] M. Schreck, et al, Sci. Rep. 7, 44462 (2017).

[2] M. Kasu, Japanese Journal of Applied Physics 56, 01AA01 (2017).

5:20pm **EM+2D+MI+MN-WeA-10 Studies on Influence of Processing on Optical Characteristics of Electron Irradiated 4H-SiC Nanostructures***, **Shojan Pavunny**,* ASEE Research Fellow at U.S. Naval Research Laboratory*; H Banks,* NRC Research Fellow at U.S. Naval Research Laboratory*; P Klein,* U.S. Naval Research Laboratory*; K Daniels,* NRC Research Fellow at U.S. Naval Research Laboratory*; M DeJarld,* ASEE Research Fellow at U.S. Naval Research Laboratory*; E Glaser, S Carter, R Myers-Ward, D Gaskill,* U.S. Naval Research Laboratory

Spin-coherent single silicon defect centers (V_{Si}) in wide bandgap silicon carbide polytypes have recently drawn great research interest for future applications in information technologies such as scalable quantum computing, sensing and metrology. Identification of these deep defects, gaining a thorough knowledge of their characteristics, active control of their concentrations, isolation of single spin defects and understanding the effects of semiconductor processing on their properties are crucial challenges for the realization of SiC based quantum electronic and integrated photonic devices. These color centers coupled to photonic crystal cavities (PCC) have the capability of high efficiency emission of zero phonon lines which can significantly improve the performance of on-chip photonic networks and long-distance quantum communication systems, as compared to conventional solid-state emitters. Here we investigate the impact of fabrication process on the photoluminescence properties of PCCs realized using three techniques: hydrogen implantation to form thin SiC layers on an oxide layer that can be easily etched away to form an air gap under the PCC, wafer bonding and mechanical thinning of the SiC, also on an oxide layer, and selective electrochemical anodization of an n-p epitaxial SiC structure to form an air gap. We also comment upon the impact of electron irradiation for these three fabrication techniques.

5:40pm **EM+2D+MI+MN-WeA-11 Ab Initio Simulations of Point Defects in Solids Acting as Quantum Bits***, **Adam Gali**,* Wigner Research Centre for Physics, Hungarian Academy of Sciences, Hungary **INVITED**

Luminescent and paramagnetic point defects in insulators and semiconductors may realize quantum bits that could be the source of next generation computers and nanoscale sensors. Detailed understanding of the optical and magnetic properties of these defects is needed in order to optimize them for these purposes.

In this talk I show our recent methodology developments in the field to calculate the ground and excited state of point defects and to determine their Auger-rates, hyperfine tensors and electron spin – electron spin couplings, and intersystem crossing rates. We show recent results on the nitrogen-vacancy center in diamond as well as divacancy and other defects in silicon carbide that we have found a very promising alternative to the well-established nitrogen-vacancy center for integration of traditional semiconductor and quantum technologies into a single platform.

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