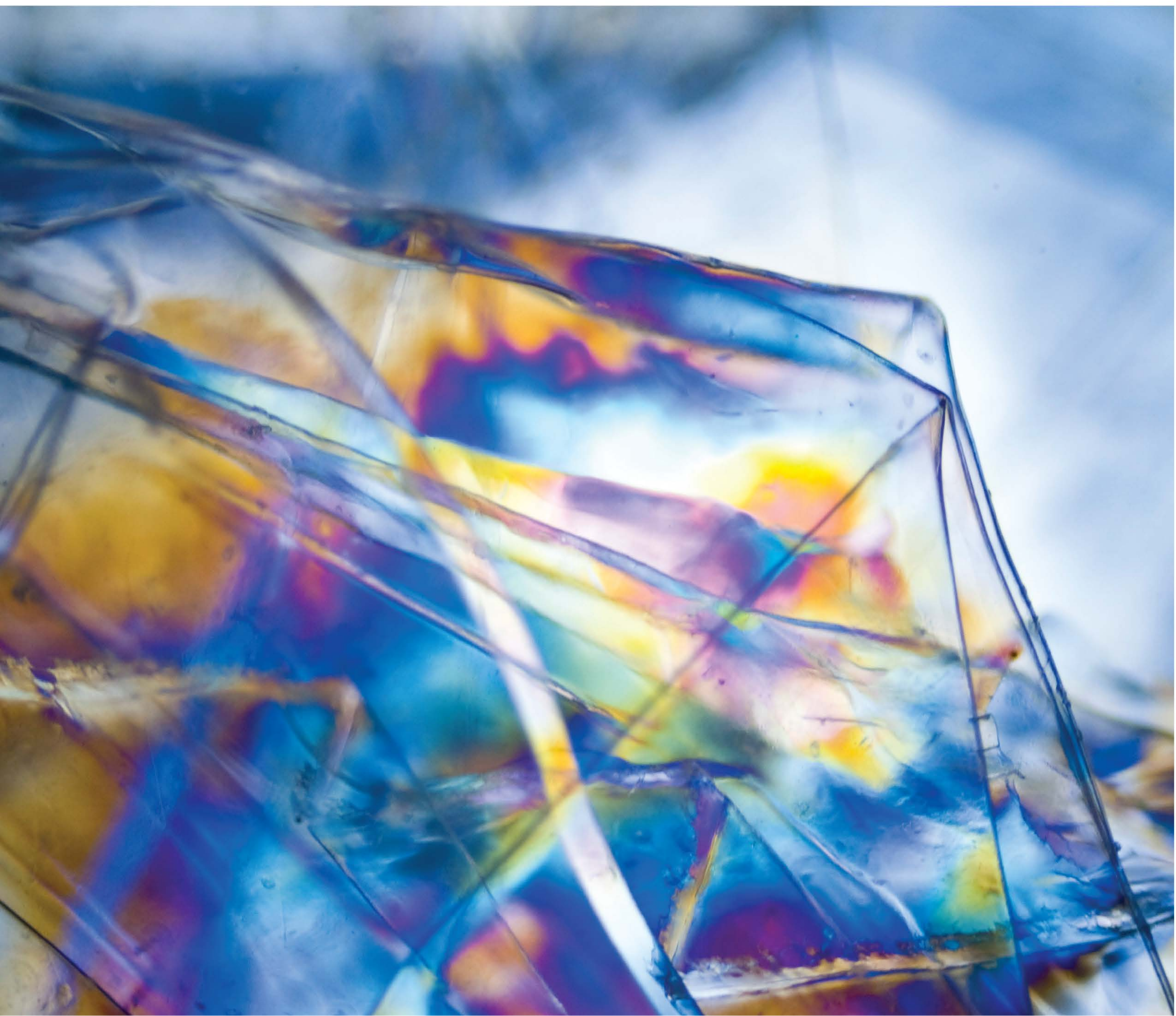
Materials Day

Quantum Materials



Materials Resources:

Materials Processing Center provides an environment where students and professionals from industry, government and academia collaborate to identify and address pivotal multidisciplinary issues in materials processing and manufacturing at MIT.
http://mpc-www.mit.edu

Microphotonics Center @ MIT builds interdisciplinary teams, focused on collaborative research for the advancement of basic science and emerging technology pertaining to integrated photonic systems.
http://mphotonics.mit.edu

The Communications Technology Roadmap (CTR) is a project under the Microphotonics Industry Consortium, which in turn is part of the MIT Microphotonics Center. The purpose of this Roadmap is to understand the interaction between technology, industry, and policy dynamics and from there, formulate a vision for the future of the microphotonics industry.
http://mph-roadmap.mit.edu/

The Crystal Physics and Electroceramics Laboratory is devoted to the modeling, processing, characterization and optimization of energy related devices (sensors, batteries, fuel cells, solar/photolysis cells) and the integration of sensor, actuator and photonic materials into microelectromechanical (MEMS) systems.
http://electroceramics.scripts.mit.edu/

The Skoltech Center for Electrochemical Energy Storage (CEES) is an inter-university/interdepartmental center with three major goals; development of advanced lithium ion and multivalent ion batteries, the development of rechargeable metal-air batteries, and the development of reversible low and elevated temperature fuel cells.
http://cees-www.mit.edu/

Center for Materials Science & Engineering is devoted to the design, creation, and fundamental understanding of materials that are capable of enhancing the human experience.
http://mit.edu/cmse

Department of Materials Science & Engineering is known as the world-wide leader in its field, pioneering advances in engineering sciences and technologies.
http://dmse.mit.edu

Dates for future Materials Day events:

Tuesday, October 18, 2016

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MATERIALS PROCESSING CENTER

Materials Day at MIT

Quantum Materials

October 14, 2015

Hosted annually by the MIT Materials Processing Center, Materials Day features emerging research and applications in materials engineering and science for products and processes across the industrial spectrum. The theme for this year's symposium is "Quantum Materials". This year's speakers will include leading researchers from the Science & Technology Center for Integrated Quantum Materials, an NSF-sponsored research center based at Harvard University with co-investigators at MIT, Howard University and the Museum of Science. Quantum materials include atomic layers, such as graphene, topological insulators, and nitrogen vacancy diamond. Topics will cover the synthesis of these novel materials, their characterization, and their use in quantum devices. Materials Day activities include conference speakers from within and outside the Institute and a student poster session showcasing results from the diverse materials research communities in MIT's Schools of Science and Engineering.

Materials Processing Center
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 24-517
Cambridge, MA 02139
http://mpc-www.mit.edu
email: mpc@mit.edu

Materials Day Agenda

8:00 am	**Registration** (Kresge Auditorium)
8:45 am	**Welcome and Overview** Dr. Carl V. Thompson Director, Materials Processing Center Professor of Materials Science & Engineering Department of Materials Science & Engineering MIT
Session I:	
9:00 am	**Shining Light on Topological Insulators** Professor Nuh Gedik Professor of Physics Department of Physics MIT
9:40 am	**Novel Materials and Condensed Matter Phenomena for Cognitive Information Processing** Dr. George Bourianoff Senior Principal Engineer Components Research Intel
10:20 am	**Break**
Session II:	
10:40 am	**Quantum Transport and Optoelectronics with van der Waals Heterostructures** Professor Pablo Jarillo-Herrero Professor of Physics Department of Physics MIT
11:20 am	**System-Level Applications of Two-Dimensional Materials: Challenges and Opportunities** Professor Tomas Palacios Department of Electrical Engineering & Computer Science MIT

12:00 - 1:00 pm **Lunch**
Student Center, 3rd floor, Twenty Chimneys/Mezzanine Lounge (Bldg. W20)

Session III:

1:10 pm **The Battle to Control Diamond**
Dr. Daniel Twitchen
Chief Technology Officer
Element Six

1:50 pm **Exploring Condensed Matter Physics Using Nitrogen Vacancy Center Based Nano-Scale Magnetometry**
Dr. Amir Yacoby
Professor of Physics
Harvard University

2:30 pm **Diamond, A Quantum Material: You Have Come A Long Way Baby, BUT!**
Dr. Gary L. Harris, P.E.
Associate Provost for Research and Graduate Studies
Dean of the Graduate School and
Professor of Electrical and Computer Engineering
Howard University

3:10 pm **Wrap-up and Discussion**

Materials Research Review Poster Session

3:30 pm **Poster Session and Social**
La Sala De Puerto Rico
2nd Floor Stratton Student Center
(Bldg. W20)

5:30 pm **Poster Awards**

5:45 pm **Adjourn**

Professor Carl V. Thompson

Director
Materials Processing Center
Stavros Salapatas Professor of Materials Science and Engineering
Department of Materials Science and Engineering
Massachusetts Institute of Technology

Biography

Professor Thompson received his S.B. in Materials Science and Engineering from MIT, and his S.M. and Ph.D. in Applied Physics from Harvard University, the latter in 1981. He was an IBM postdoctoral Fellow in the Research Laboratory of Electronics at MIT in 1982, and joined the faculty of MIT in 1983. Professor Thompson spent the 1990-91 academic year in the Department of Metallurgy and Materials Science at Cambridge University and the 1997-98 academic year at the Max Planck Institut fur Metallforschung in Stuttgart Germany, and 2012 at the Karlsruhe Institute of Technology. He has also been very active in MIT's programs with Singapore, including a twelve years leading the program for Advanced Materials for Micro- and Nano-Systems of the Singapore Alliance. He served as the President of the Materials Research Society in 1996 and served on the MRS council from 1991 to 1997. He is currently the Director of MIT's Materials Processing Center and Co-Director of the Skoltech Center for Electrochemical Energy Storage. Professor Thompson has been a consultant with over thirty companies, including Intel, IBM, DEC, and a number of start-ups involved in development of microelectromechanical devices and systems. He has also collaborated in research with Intel, IBM, DEC, AMD, Motorola, TI, Chartered Semiconductor, and other companies.

Professor Thompson's research interests include structure evolution during formation and processing of thin films and nanostructures; the mechanical and electrical properties of nanostructures; and the incorporation of thin films and nanostructures in electronic, electromechanical, and electrochemical devices and systems.

Professor Nuh Gedik
Professor of Physics
Department of Physics
Massachusetts Institute of Technology

Shining Light on Topological Insulators

Abstract

Topological insulators are novel materials that do not conduct electricity in their bulk but possess exceptional conducting electronic states on their surface. These surface electrons have a number of highly unusual characteristics: (i) they behave like massless relativistic particles similar to photons, (ii) their spin is locked perpendicular to their momentum and (iii) this state is robust against moderate disorder. Understanding and characterizing unique properties of these materials can lead to novel applications such as current induced magnetization or extremely robust quantum memory bits. In this talk, I will first give a brief introduction to these materials and then describe our recent experiments in which we used ultrashort laser pulses to probe and control properties of the topological surface states. Utilizing the short duration of these pulses, we succeeded in capturing femtosecond movies of the electronic energy bands in a three dimensional manner. These movies reveal an exotic hybrid state between electrons and light, which was predicted theoretically but has never been observed in solids before.

Biography

Nuh Gedik is the Lawrence C. (1944) and Sarah W. Biedenharn Career Development Associate Professor of Physics. Gedik uses advanced optical techniques for investigating and manipulating the properties of quantum materials, such as topological insulators and high-temperature superconductors. Using ultrafast laser pulses, he studies processes in solids that take place within femtoseconds (billionth of a millionth of a second). Gedik employs these techniques to search for answers to important problems in condensed matter physics, with a primary focus on understanding the mechanisms behind the unique properties of strongly correlated electron systems. Gedik received his BS in Physics in 1998 from Bogazici University, Istanbul, Turkey and his PhD in Physics in 2004 from the University of California, Berkeley. Following a postdoctoral appointment at Caltech, he joined the joined the faculty of the Department of Physics in 2008. Gedik has received several awards and honors, including the Moore Experimental Investigator Award in Quantum Materials (2014), an Alfred P. Sloan Fellowship (2012), an NSF CAREER Award (2009), DOE Early Career Award (2011), DARPA Young Faculty Award (2013).

Dr. George Bourianoff
Senior Principal Engineer, Components Research
Intel

Novel Materials and Condensed Matter Phenomena for Cognitive Information Processing

Abstract

The Internet of things (IoT) is growing at a super exponential rate and creating a voracious demand for new energy efficient computing resources in general and cognitive computing resources in particular. To obtain the required efficiencies, new cognitive computing systems will need to operate directly on images and patterns rather than bits and bit streams similar to the way the brain processes information. Future information processing systems will require novel materials material systems with novel functionalities such as topologically protected states and multiferroic ordering. In order to develop the existing potential, it will be necessary to co-develop the material systems, devices, architectures and applications. In the past, development has always occurred sequentially usually driven by new materials. The novel materials, processes and paradigms can be thought of as forming the axes of an orthogonal 3 dimensional space which is sparsely populated with solutions at discrete points in this space.

Some of the new material systems to consider, include Perovskites, Van der Wall materials, strongly correlated electron oxides, layered manganites, topologically protected materials, Spin Hall materials and carbon based materials such as graphene and graphene bilayers. These materials can be bulk, thin films, nanowires or quantum dots. The new solid state phenomena include 2DEGs, topological Insulators, Bose Einstein condensates, mutiferroic ordering, magnetoelectric phase formation in strongly correlated electrons, interface dynamics, spin wave synchronization and interference. New computational paradigms include direct synchronization, magnetic holography, association, neuromorphic and reservoir computing. This presentation will focus on two specific examples. They are synchronization of coupled oscillator arrays for association and reservoir computing with arrays of quantum dots or magnetic skyrmions.

Biography

Dr. Bourianoff is an internationally recognized authority on advanced, computational technologies including novel devices beyond CMOS, novel architectures beyond Boolean architectures, novel data representations beyond binary bit streams, and most importantly, the intersection of these highly interdependent domains that can lead to viable technologies for emerging and future applications. His current research interests include nano-device fabrics such as arrays of coupled oscillators and novel spin devices for potentially low energy information processing tasks. Dr. Bourianoff's research in these areas was utilized in the development of preliminary concepts for the current DARPA/MTO Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE) and DARPA Semiconductor Technology Advanced Research Network (STARnet) Programs.

Professor Pablo Jarillo-Herrero
Professor of Physics
Department of Physics
Massachusetts Institute of Technology

Quantum Transport and Optoelectronics with van der Waals Heterostructures

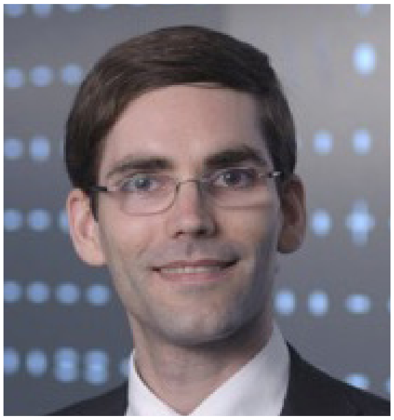
Abstract

Over the past decade, a revolution in materials science has taken place with the advent of atomically-thin layered materials. These materials exhibit unique physical properties, different from their bulk counterparts, as exemplified by graphene's ultra-relativistic electronic properties. Moreover, the possibility to stack different layered materials arbitrarily on top of each other to form what are known as van der Waals heterostructures, has paved the way for an even richer variety of electronic, optical, chemical and mechanical behaviors, which the physics, chemistry and engineering communities are just beginning to explore. In this talk I will describe my group's efforts in the area of quantum electronic transport and optoelectronics with van der Waals heterostructures, with examples ranging from the opening of a band gap in graphene to the thinnest photodetectors, solar cells, and LEDs based on transition metal dichalcogenides.

Biography

Pablo Jarillo-Herrero is an associate professor in the MIT physics department. Jarillo-Herrero's group explores quantum transport and optoelectronics in novel condensed matter systems such as graphene, transition metal dichalcogenides, and topological insulators. In recent work, he has demonstrated the presence of a bandgap in graphene-based van der Waals heterostructures, novel quantum spin Hall and photothermoelectric effects in graphene, as well as light-emitting diodes, photodetectors, and solar cells in the atomically thin tungsten diselenide system. He has also made advances in characterizing and manipulating the properties of other ultrathin materials, such as ultra-thin graphite and molybdenum disulphide, which lack graphene's ultrarelativistic properties, but possess other unusual electronic and electronic properties. Jarillo-Herrero has co-authored over 60 journal publications and directed 4 PhD thesis.

After earning an M.Sc. at the University of Valencia, Spain in 1999 and another at the University of California, San Diego in 2001, Jarillo-Herrero earned his PhD at the Delft University of Technology in 2005. He remained at Delft for a year as a postdoctoral researcher and then worked as a NanoResearch Initiative Fellow at Columbia University until he joined the MIT faculty in 2008. Jarillo-Herrero's awards include an NSF Career Award (2008), an Alfred P. Sloan Fellowship (2009), the IUPAP Young Scientist Prize in Semiconductor Physics (2010), a DOE Early Career Award (2011), a Presidential Early Career Award for Scientists and Engineers (PECASE, 2012), an ONR Young Investigator Award (2013), and a Moore Foundation Investigator Award (2014).



Professor Tomas Palacios

Professor of Electrical Engineering and Computer Science
Department of Electrical Engineering & Computer Science
Massachusetts Institute of Technology

System-Level Applications of Two-Dimensional Materials: Challenges and Opportunities

Abstract

This talk will discuss some of the many applications of two dimensional materials in future electronic systems. These materials have tremendously diverse and unique properties. For example, graphene is a semimetal with extremely high electron and hole mobilities, hexagonal boron nitride forms an almost ideal insulator, while MoS2 and other dichalcogenides push the limits on large area semiconductors. At the same time, the extreme thinness (3 or less atoms thick) of all these novel materials gives them great flexibility, optical transparency and an unsurpassed surface-to-volume ratio.

The growth of these materials over large areas has allowed their use in numerous system-level applications. For example, the zero bandgap of graphene and its ambipolar conduction enables many new rf and mixed devices, including transistors with very high frequency performance, frequency multipliers, mixers, oscillators and digital modulators. At the same time, graphene has excellent properties for mid-infrared detectors, which can be easily integrated with conventional silicon chips to enhance their functionality in a beyond-Moore future.

In spite of the outstanding performance of graphene in many applications, digital electronics typically requires a semiconductor with a significant bandgap. Recently, the wide bandgap of MoS2 in combination with advanced fabrication technology has enabled its use in memory cells, analog to digital converters and ring oscillators with orders of magnitude better performance than other materials being considered for large area applications. These and other examples will be reviewed to highlight the numerous new opportunities of 2D materials.

Biography

Tomas Palacios is an Associate Professor in the Department of Electrical Engineering and Computer Science at MIT. He received his PhD from the University of California - Santa Barbara in 2006 and his current research focuses on demonstrating new electronic devices and applications for materials such as graphene and gallium nitride. His work has been recognized with multiple awards including the Presidential Early Career Award for Scientists and Engineers, the IEEE George Smith Award, and the NSF, ONR, and DARPA Young Faculty Awards, among others. Prof. Palacios has authored numerous contributions in international journals and conferences, 10 of which have received a best-paper award, as well as 5 book chapters and more than 20 patents. Prof. Palacios is the founder and director of the MIT MTL Center for Graphene Devices and 2D Systems.

Dr. Daniel Twitchen
Chief Technology Officer
Element Six

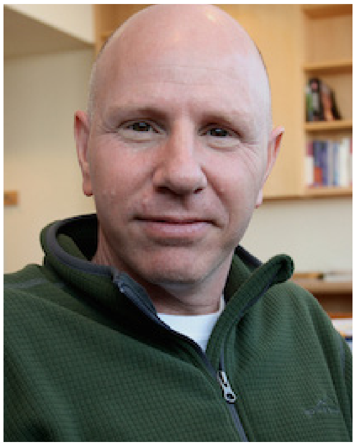
The Battle to Control Diamond

Abstract

Diamond possesses remarkable physical and chemical properties, and in many ways is the ultimate optical engineering material, but its use until relatively recently has been limited by the lack of scalable techniques for manufacture, processing and integration. This presentation will review and summarize key progress in fabrication techniques utilizing chemical vapour deposition (CVD), processing using mechanical and chemical methods and solutions for integration. It will present several case studies that include polycrystalline and single crystal diamond for high power optics for applications that range from IR imaging to integrated photonics. Manipulation of optical signals at single-photon level in single crystal CVD diamond using nano-cavities and waveguides will also be discussed for applications that include quantum optics and magnetic sensing.

Biography

Daniel Twitchen based in Santa Clara, CA, is the Head of Product Application Engineering and Strategic Development at Element Six. He received M.A. and PhD degrees in physics from Oxford winning the Mordan and Harmsworth Senior Scholarships at Merton College. After his doctorate, he held junior fellowship positions at Oxford with a sabbatical in Novosobirsk (Siberian Academy of Sciences). His academic research interests focused on using magnetic resonance and some optical techniques to study defects in wide bandgap semiconductors (including diamond). After being awarded a UK Academic Fast Track EPSRC Advanced Fellowship, he joined Element Six where his research interests focus on developing technology for growing synthetic CVD diamond with tailored properties for applications that range from electronics to optics. This work has led to more than 150 papers, >50 patents and several commercial ventures as well as contributing the first commercialization of single crystal CVD for thermal and optical applications.



Dr. Amir Yacoby
Professor of Physics
Harvard University

Exploring Condensed Matter Physics Using Nitrogen Vacancy Center Based Nano-Scale Magnetometry

Abstract

Correlated-electron systems support a wealth of exotic magnetic properties, ranging from conventional spin waves to fractional spin excitations in low-dimensional spin systems as well as topological spin textures in geometrically-frustrated materials. Probing such properties on nanometer length scales is essential for unravelling the underlying physics and developing new spintronic logic and memory nano-devices. However, no established technique provides quantitative real space, few-nanometre-scale probing of magnetic properties under ambient conditions. Magnetometry based on single nitrogen-vacancy (NV) centers in diamond has recently been shown to provide both high sensitivity and spatial resolution under ambient conditions. In this talk I will describe the use NV magnetometry for exploring such local magnetic properties. As a first example we focus on spin-wave excitations in a ferromagnetic microdisc, and demonstrate local, quantitative, and phase-sensitive detection of the spin-wave magnetic field at ⍰ 50 nm from the disc. In addition, we characterize the spin-noise spectrum by NV-spin relaxometry, finding excellent agreement with a general analytical description of the stray fields produced by spin-spin correlations in a 2D magnetic system. Finally we will demonstrate direct imaging of skyrmionic spin textures in magnetic thin films which are of great interest for memory devices.

Biography

Amir Yacoby is a Professor of Physics at Harvard University. He is also a Professor of Applied Physics at the School of Engineering and Applied Sciences at Harvard University and a visiting Professor at the University of Waterloo. He currently holds the Lazaridis Chair in Physics.

Following a bachelor's degree in Aeronautical Engineering and a master's degree in theoretical physics, Professor Yacoby turned to experimental condensed matter physics. He received his PhD in 1994 from the Weizmann Institute of Science in Israel. His work focused on understanding coherence in quantum mesoscopic systems. During his postdoc at Bell labs Professor Yacoby developed new techniques to explore electrical conduction in quantum wires and was the first to observe spin-charge separation, a hallmark of Luttinger Liquids. In 1998 Professor Yacoby joined the faculty of the Weizmann Institute where he developed new techniques for imaging electrical charge in mesoscopic systems.

Professor Yacoby joined the Harvard faculty in 2006. His current interests are in understanding the behavior of correlated electrons in low-dimensional systems and their applications to quantum information technology and metrology. His research topics include: spin based quantum computing and metrology using semiconducting quantum dots and color centers in diamond; topological quantum computing using two dimensional topological insulators; and interacting electrons in graphene multilayers and transition metal dichalcogenides.

Dr. Gary L. Harris, P.E.

Associate Provost for Research and Graduate Studies
Dean of the Graduate School and
Professor of Electrical and Computer Engineering
Howard University

Diamond, A Quantum Material: You Have Come A Long Way Baby, BUT!

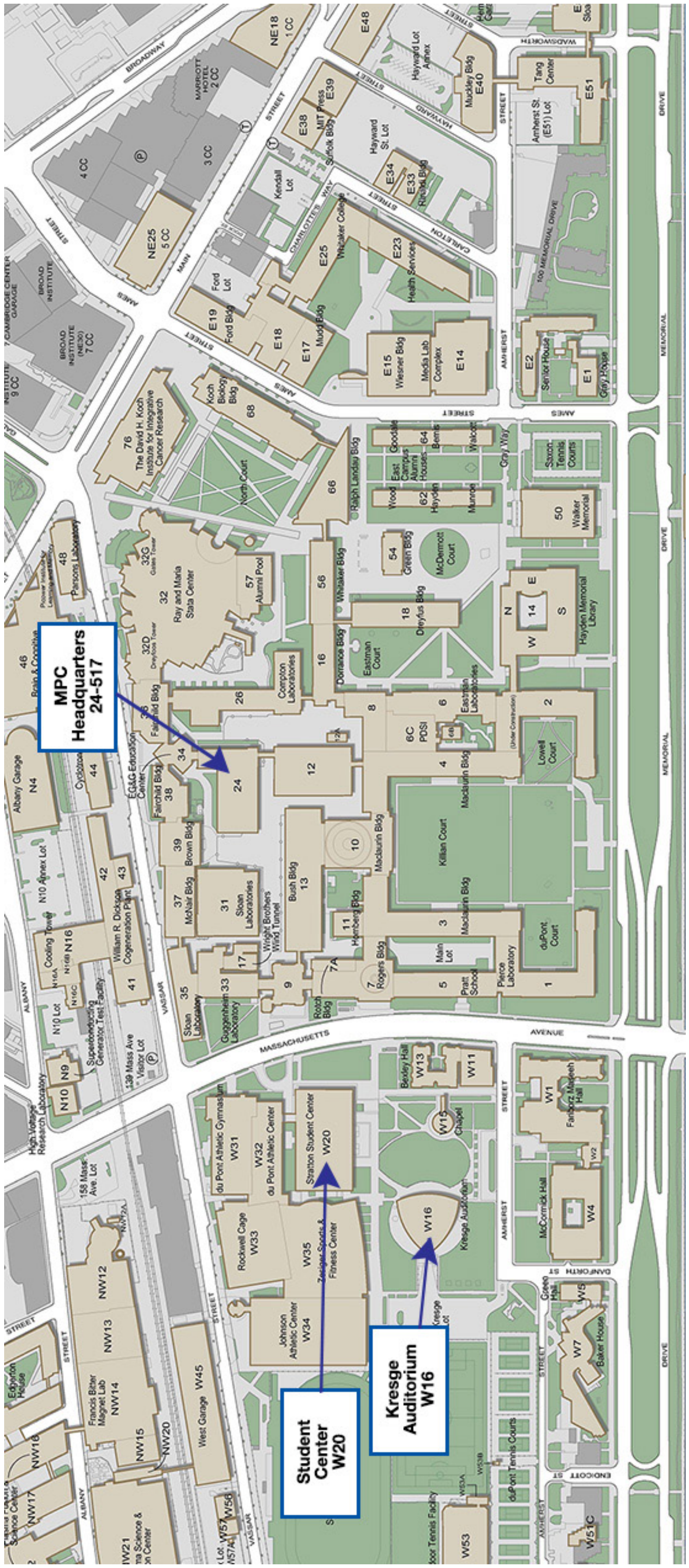
Abstract

Materials with extremely high bulk modulus, high electron mobilities, and high hardness are marked with short bond lengths, high coordinate numbers, and low iconicity. Diamond is such a material and it is an excellent wide-band gap semiconductor. The first successful synthesis of diamond was achieved using a high pressure and high temperature (HPHT) method developed by General Electric in the 1960s. Diamond synthesized by the HPHT process is in the form of small particles, ranging in size from nanometers to a few millimeters, which is too small for large-scale production of diamond quantum devices. In this presentation, we will update you on the latest development of diamond as a quantum and electronic material. For instance, we have demonstrated how silicon carbide (SiC) can be used as a substrate for high quality epitaxial growth of diamond on SiC by using nanodiamond seeding. We will discuss the conditions that affect diamond growth on primarily the C face of 6H-SiC, as well as discuss growth on other polytypes of SiC and on silicon. The system employed uses a hot-filament chemical vapor deposition reactor in which the distance from the source can be varied. Its basic system configuration allows for excellent and repeatable uniform growth processes for diamond. We discuss some novel ways in which we are developing for quantum applications of diamond using nitrogen, silicon, and germanium as quantum dopants. The diamond epic-layers were characterized by a variety of methods including scanning electron microscopy (SEM), energy dispersive x–ray spectroscopy (EDS) and Raman spectroscopy. The mobilities of the as grown layers were as high as 420 cm2/V-sec. This work was supported by the STC Center for Integrated Quantum Materials, NSF Grant No. DMR-1231319.

Biography

Dr. Gary L Harris, P.E., the Associate Provost for Research and Graduate Studies and Dean of the Graduate School at Howard University. He received his doctorate, masters and BSEE degrees from Cornell University in Electrical Engineering-Electro-Physics in 1980, 1976 and 1975 respectively. Currently, he is a Professor of Electrical and Computer Engineering and the Director of the Howard Nanoscale Science and Engineering Facility in the College of Engineering, Architecture and Computer Science at Howard University. Dr. Harris also serves as co-PI for the Center for Integrated Quantum Materials (CIQM) an NSF STC between Harvard, Howard, and MIT. His primary research interests are the growth and characterization of electronic and optical materials, the fabrication of semiconductor devices with special attention on wide band gap and compound semiconductor materials, and applications to nanotechnology. These materials include GaAs, SiC, graphene, diamond, and other III-V and IV-IV compounds. He has also grown and characterized GaN, GaInN, InN, etc. nanowires and tubes for photonic and high-speed applications. While at Howard, Dr. Harris has published well over 100 peer reviewed scientific articles; edited five books and presented over 200 papers at scientific conferences. In addition, he was conference chairman of the International Conference on Silicon Carbide and Related Materials, chairman of the Institute of Electrical and Electronics Engineers (IEEE) - Washington Section Electron Devices Group 1984-85 and a participant and lecturer in the International School of Solid-State Device Research in Erice, Trapani in Sicily. Dr. Harris has received numerous awards that include the 1987 Electrical Engineering Outstanding Teaching Award and the National Society of Black Engineers 1985-86 Scientist of the Year Award.

Notes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