Talk Abstracts

Manipulation of Two Individual Electron Spins and Dephasing Problem in Double Quantum Dots Integrated with a Micro-Magnet

Seigo Tarucha
University of Tokyo

Since the early proposal of spin-based quantum computing by Loss and DiVincenzo, much effort has been devoted to implement the relevant technologies for manipulating and detecting spin degrees of freedom in quantum dots (QDs). Universal sets of quantum gates are prepared by combination of spin qubit operation and SWAP1/2. Single spin qubits and SWAP have already been demonstrated using coupled two QDs in various ways. To further promote the QD technologies, it is crucial to develop spin qubits robust enough to be scaled up using multiple-QDs.

Electron spin resonance (ESR) is the fundamental concept of spin qubits, in which two Zeeman states are defined by a static magnetic field and superposed by an ac magnetic field. Note conventional ESR can only apply for a large ensemble of electrons. To manipulate individual electron spins in QDs in a scalable manner, both magnetic fields must be local to each QD. We have recently developed a technique of using a micro-magnet and ac electric field to meet this requirement. A micro-magnet placed on top of each QD is magnetized by application of external in-plane magnetic field to generate a field gradient out-of-plane and an excess in-plane field at the dot. Application of an ac electric field to the dot oscillates an electron inside to generate a local ac magnetic field only experienced by the electron. In addition, the ESR frequency or magnetic field depends on the external magnetic field as well as the micro-magnet induced in-plane field, which is local to the dot. We have initially applied such a micro-magnet technology for a double QD. In this talk I will show the experiments on cw ESR peaks and Rabi oscillations of two individual spins, Ramsey/spin echo, hyperfine coupling induced dephasing, and finally preliminary approach to extend the technique to triple quantum dots as the next step.

The Zamboni Force: Feedback between Nuclear Inhomogeneity and Electron States in a Double Dot

Michael Stopa
Harvard University

We identify a feedback mechanism between the electron states in a two-electron double quantum dot and the difference between the nuclear spin polarization in the two dots, which we term the "Zamboni force." The Overhauser interaction is known to cause angular momentum transfer, spin flip-flops, between electrons and nuclei in GaAs-AlGaAs heterostructures. In double quantum dots, transport and pumping experiments have been performed to study the evolution of nuclear spin polarization in response to certain electronic transitions. We show that, in flipping from singlet (S) to triplet (T+), "flopping" of the nuclear spin can occur in the left dot, the right dot or in the barrier depending on the composition of the singlet state. Assuming a composite nuclear spin for each the left dot, the right dot and the barrier, we numerically integrate the Schrödinger equation to study the gate voltage sweep through the S-T+ anti-crossing point. We show that the (nuclear) effective magnetic field gradient tends to produce spin flips in the dot with the weaker field and thereby constitutes a force toward nuclear spin equilibration.

Nuclear Spin Ordering in Nanostructures

Daniel Loss
University of Basel

The physics of itinerant or quantum-confined electrons interacting with localized magnetic moments is central for numerous fields in condensed matter such as decoherence of spin qubits [1], nuclear magnetism [2,3], heavy fermions, or ferromagnetic semiconductors. Nuclear spins embedded in metals or semiconductors offer an ideal platform to study the interplay between strong electron correlations and magnetism of localized moments in the RKKY regime. In two dimensions the magnetic properties of the localized moments [2] depend indeed crucially on electron-electron interactions. In one-dimensional (1D) systems such as single wall carbon nanotubes (SWNTs) or nanowires electron correlations are even more important, being described by Luttinger liquid physics. Recently, SWNTs made of 13C, forming a nuclear spin lattice, have become experimentally available (C. Marcus et al., 2009). Motivated by this we have studied nuclear magnetism in metallic 13C SWNTs and showed that even a weak hyperfine interaction can lead to a helical magnetic order of the nuclear spins coexisting with an electron density order that combines charge and spin degrees of freedom [3]. The ordered phases stabilize each other, and the critical temperature undergoes a dramatic renormalization up into the milli-Kelvin range due to electron-electron interactions. In this new phase the electron spin susceptibility becomes anisotropic and the conductance of the SWNT drops by a universal factor of two. Similar nuclear spin ordering effects occur in GaAs nanowires (A. Yacoby et al., 2008). Due to the much longer Fermi wave length the ordering temperature of the nuclear spins is lower in nanowires than in SWNT but still in the 10-100 milli-Kelvin regime.

Quantum Dots in Photonic Crystals: from Quantum Information Processing to Optical Switching at a Single Photon Level

Jelena Vuckovic
Stanford University

Quantum dots in photonic crystals are interesting both as a testbed for fundamental cavity quantum electrodynamics (QED)experiments, as well as a platform for quantum and classical information processing.

Quantum dot-photonic crystal cavity QED has been probed both in photoluminescence and coherently, by resonant light scattering from such a system [1]. In the latter case, both intensity and photon statistics of the reflected beam have been analyzed as a function of wavelength, leading to observation of effects such as photon blockade and photon induced
tunneling - for the first time in solid state [2]. The system has also been employed to achieve a controlled phase and amplitude modulation
between two modes of light at the single photon level [3] - nonlinearity observed so far only in atomic physics systems.

These demonstrations lie at the core of a number of proposals for quantum information processing, and could also be employed to build novel devices, such as optical switches controlled at a single photon level.

1. Dirk Englund, Andrei Faraon, Ilya Fushman, Nick Stoltz, Pierre Petroff, and Jelena Vuckovic, "Controlling cavity reflectivity with a single quantum dot," Nature, vol. 450, No. 7171, pp. 857-861, December 2007

2. Andrei Faraon, Ilya Fushman, Dirk Englund, Nick Stoltz, Pierre Petroff, and Jelena Vuckovic, "Coherent generation of nonclassical light on a chip via photon-induced tunneling and blockade," Nature Physics, Vol. 4, pp. 859 - 863 (2008)

3. Ilya Fushman, Dirk Englund, Andrei Faraon, Nick Stoltz, Pierre Petroff, and Jelena Vuckovic, "Controlled phase shift with a single quantum dot," Science, vol. 320, number 5877, pp. 769 -772 (2008)

Light-Matter Interaction in Quantum Dots with 2D/3D Photonic Crystal Nanocavity

Yasuhiko Arakawa

University of Tokyo

Following Esaki's pioneering work on super-lattices and quantum wells, the concept of quantum dots was proposed by Arakawa et al. in 1982 for application to semiconductor lasers together with the theoretical prediction of temperature-insensitive threshold current characteristics1. The three-dimensional confinement of electrons in the quantum dots has brought up unique features of artificial atoms, such as discrete energy states and quantum correlation due to spin/charging effects.

The confinement of photons in an extremely small volume is led to a strong interaction between light and matter. In particular, quantum dots embedded in photonic crystal nanocavity systems2 exhibit characteristic physics that can be described by cavity quantum electrodynamics, including vacuum Rabi splitting3,4 in the strong-coupling regime and highly efficient lasing in the weak-coupling regime.

In this paper, we discuss recent advances in exaction-photon interaction in single quantum dot with 2D photonic crystal nanocaviy, showing successful demonstration of single quantum dot laser operation (i. e., single artificial atom lasers)3. Moreover, we report on an experimental demonstration of coupling of quantum dots with a point-defect nanocavity in woodpile 3D photonic crystal with the highest Q factor among those for 3D photonic crystal cavities by micromachining technique4,5. The Q factor of more than 8,600 was so far achieved by stacking 25 layers by optimizing the size of the square-shaped defect cavity to tune the cavity mode to the midgap frequency of the complete photonic bandgap.

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Electric-Field Manipulation of Magnetization Direction

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Tohoku University

Using a ferromagnetic III-V semiconductor (Ga,Mn)As, we show that electrical control of magnetization direction can be done through electronically manipulating the magnetic anisotropy energy landscape [1]. The energy landscape that governs the magnetization direction can be modified by controlling the population of carriers on spin-split anisotropic valence bands. This opens up a new and unique opportunity for switching magnetization direction solely by electronic means, not resorting to magnetic-field, spin-current, mechanical stress, nor multiferroics. The conditions that one needs to meet in order to realize switching of the magnetization direction from one stable state to another will be discussed.

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The work was done with D. Chiba, F. Matsukura, M. Sawicki, Y. Nishitani, and Y. Nakatani and was supported in part by the "Research and Development for Next-Generation Information Technology" program from MEXT, Japan.

Micro/Nanomechanical Systems Based on Compound Semiconductor Heterostructures

Hiroshi Yamaguchi

NTT Basic Research Laboratories

The use of compound semiconductor heterostructures allows us to fabricate micro/nanoelectromechanical systems (MEME/NEMS) with new functionalities. In this talk, I present the experimental results that we have recently obtained from our investigations of electromechanical resonators fabricated from compound semiconductor heterostructures.
The mechanical resonance characteristics can be controlled by the photon-carrier interaction in a dynamical way. The generation of electron-hole pairs by laser light illumination can modify the internal friction in the mechanical systems. What is remarkable is that the quality factor can not only be decreased but also increased by appropriately choosing the wavelength and the cantilever orientation. When the photon energy is close to the band gap, the electron-hole pair is generated selectively depending on the cantilever deflection, leading to the control of resonance characteristics. We demonstrated vibration amplification, damping, and self-oscillations in micromechanical resonators by opto-mechanical coupling through carrier excitation [1].

Piezoelectricity has been playing an important role in micro- and nano-electromechanical devices, where it makes possible the highly efficient transduction of mechanical motion into electric signals. Compound semiconductors are piezoelectric materials and highly functional micro- and nano-electromechanical devices can therefore be integrated with electronic architectures. We have fabricated micro-electromechanical parametric resonators based on the piezoelectricity in GaAs/AlGaAs modulation-doped heterostructures. We demonstrate the possible applications of the parametric resonator for signal amplification [2], sensitive charge detection [3], and the logic data storage [4].

The Superconducting quantum interference devices (SQUIDs) are the most sensitive detectors of magnetic flux. Using InAs-based heterostructures, a novel class of devices that incorporate micromechanical resonators into SQUIDs was fabricated to achieve sensitive motion detection of the resonators. I also briefly show the results demonstrating the detection of a 2MHz flexural resonator. The resonator's thermal motion at millikelvin temperatures was measured, achieving an amplifier-limited displacement sensitivity of 10 fm Hz−1/2 and a position resolution that is 36 times the quantum limit [5].

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Measurements of Persistent Currents in Normal Metal Rings using a Micromechanical Magnetometer

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A striking manifestation of quantum mechanics is the existence of a dissipationless current in a resistive metal ring. This persistent current is a micron scale analog of the orbital angular momentum of electrons in atoms. Since its prediction over 20 years a handful of experiments have reported a persistent current, with many of the results in disagreement with theory and with each other. The small size of the current and the necessity of measuring it through its associated magnetic moment have left the controversy surrounding persistent currents unresolved.

I present measurements of persistent currents in normal metal rings using a cantilever based torsional magnetometer we developed, which is more sensitive and less invasive than the detectors used in the past, primarily SQUID's. Our results provide the clearest picture to date of the temperature, ring size, array size, and magnetic field dependence of the persistent current.

Cooling and Amplifying Micro-Mechanical Motion with Light

Kerry Vahala

California Institute of Technology

Optical forces have had a profound effect on atomic physics, enabling remarkable scientific discoveries and advances in metrology. Now, these same forces are giving life to a new field at the intersection of optical microcavities and micromechanics. Recent results have a striking parallel with early work on optical control of atoms and ions, while also giving new insights on manipulation of micro-mechanical dynamics by light. It seems clear that an exciting period is underway that will leverage these cavity optomechanical phenomena for new science and technology. There is a rich theoretical history that considers the implications of optical forces in resonators used for precision measurement, including gravity-wave detectors. Despite this, the dynamical manifestations of these forces have only recently become an experimental reality. We will review the physics of these forces in optical resonators, including demonstrations of both mechanical amplification and mechanical cooling using light pressure. After this introduction, recent, chip-based demonstrations of these effects will be described as well as efforts directed towards quantum-ground-state cooling of macroscale mechanical oscillators. Such quantum-limited motion with a "built-in" optical readout suggests new approaches to ultra-sensitive force detection will be possible. At the same time, the rapid evolution of microfabrication methods within this field can provide for powerful miniaturization and integration protocols. The prospects for future directions of research will also be considered.

Graphene Electronics and Optoelectronics

Phaedon Avouris

IBM, T.J. Watson

Graphene is a two-dimensional, zero-gap semiconductor with linear electron dispersion and rather unique electrical, optical and thermal properties. Despite the absence of a band-gap, the small electric field tuning of its conductance made possible by is its linear density-of-states and the exceptionally fast carrier transport make graphene very promising for high-frequency electronic and optical devices. I will first discuss the fabrication and operation of field-effect devices in the GHz range, along with corresponding device physics issues, such as transport mechanisms, role of the metal contacts, chemical doping and energy dissipation. Both extended graphene and nanoribbon devices will be discussed. I will then focus on the use of the photoconductivity of graphene, ultra-wide spectral response, and fast carrier transport in optoelectronic applications in the 100GHz range. Comparisons between the merits of graphene and nanotube devices will be made.

Graphene Bilayer Pseudospin Field Effect Transistor (BiSFET): a Proposed Ultra-low Power Logic Switch

Sanjay Banerjee

University of Texas, Austin

Power dissipation in Si CMOS will reach crisis proportions if one simply follows Moore's law. We will discuss novel transistors that could potentially consume much less power. Specifically we will discuss the Bilayer pseudoSpin Field Effect Transistor (BiSFET). This is based on a concept called "pseudospin" that is analogous to the spin of a electron. The BiSFET is a new type of graphene-based transistor intended to allow lower voltage, lower power operation than possible with Complementary Metal Oxide Semiconductor Field-Effect Transistors. Increased energy efficiency is not only important for its own sake, but is also necessary to allow continued device scaling and the resulting increase in computational power in CMOS-like logic circuits. We will describe the basic device structure and physics and predicted current-voltage characteristics. Advantages over CMOS in terms of lower voltage and power will be analyzed. Other electron wavefunction engineering and tunneling based transistors will also be briefly discussed.

Nanoscale Electronic Contacts: from Single Atom Junctions to Graphene Doping

Klaus Kern

Max Planck Institute for Solid State Research

Electron transport through metal-molecule contacts greatly affects the operation and performance of electronic devices based on organic semiconductors and is at the heart of molecular electronics exploiting single molecule junctions. Much of our understanding of the charge injection and extraction processes in these systems relays on our knowledge of the potential barrier at the contact. Despite significant experimental and theoretical advances in our understanding of electron transport in atomic and molecular junctions, a clear rationale of the contact barrier at the single atom/molecule level is missing.

We exploit scanning tunneling microscopy to probe directly the nanocontact between single atoms and molecules and a metal electrode. For single cobalt atom contacts we find a dependence of the Kondo scattering on the local atomic geometry, which can be related to the delicate interplay between the structural relaxations and the electronic properties in the near-contact regime. For metal-molecule nanocontacts, contrary to the common assumption of a uniform barrier, our experiments reveal a dramatic variation on the sub-molecular scale. This behaviour is ascribed to the interaction between specific molecular groups and the metal electrode. Guided by this result we introduce a novel scheme to locally manipulate the potential barrier of molecular nanocontacts.

Metal contacts are also crucial for the operation of graphene based devices. Scanning photocurrent microscopy reveals that these contacts lead to potential steps that act as transport barriers. In this technique, the short-circuit photocurrent detected at zero drain-source bias is a measure of the local-electric-potential gradient. Evaluation of the gate-dependent short-circuit photocurrent at the contacts shows that gold as a high-work-function metal leads to local p-type doping of the sheet, whereas the low-work-function metal titanium imparts local n-type doping. Photoemission and transport experiments further reveal that the gold contacts not only provide an efficient route for hole doping of graphene but also effect the localization properties of the Dirac-like states by spin-orbit coupling.

Power Tool at Atomic Scales: Nanosculpting Metals and Graphene with Highly-Focussed Electrons in a Transmission Electron Microscope

Marija Drndic

University of Pennsylvania

Manipulation of matter on the scale of atoms and molecules is an essential part of realizing the potential that nanotechnology has to offer. In this talk I will describe the fabrication of nanostructures and fully integrated devices by nanosculpting matter with electron beams. Electron irradiation in a standard high-resolution transmission electron microscope (TEM) is used to controllably displace or ablate regions of the material, such as thin metal films and graphene sheets, with nearly atomic resolution. In situ TEM imaging of the ablation action with atomic resolution allows for real-time feedback control during fabrication. Nanostructures including nanorings, nanowires and multi-terminal nanogaps with islands or pores between the terminals are fabricated at precise locations on a chip and seamlessly integrated into large-scale circuitry. The combination of high resolution, geometrical control and yield make TEMs unique power tools for nanofabrication. The impact of this work in nanoelectronics studies, including electronic DNA sequencing and graphene electronics, will be discussed.

Observation and Control of Single Magnetic Ions in Semiconductors

David Awschalom
University of California, Santa Barbara

As the density of magnetic information storage scales upwards, the number of magnetic moments in each bit decreases. This pathway ends with the desire to manipulate a single spin, a requirement that is also important for nascent information processing schemes including quantum computation. Current demonstrations of coherent single spin control include electron spins in semiconductor quantum dots and nitrogen-vacancy centers in diamond [1]. Single magnetic ions in semiconductors have also emerged as an intriguing spin system due to their surprising ability to be manipulated in zero-field. Manganese (Mn) ions in gallium arsenide (GaAs) are strongly exchange coupled to the charge carriers and can be rapidly controlled either optically or electrically in bandgap-engineered heterostructures. Recently we demonstrated optical control and readout of a small ensemble of Mn ion spins in a GaAs quantum well without magnetic materials or applied magnetic fields [2]. In the limit of low doping, their spin lifetimes increase with decreasing concentration as the ions become isolated. Here we describe the spatially-resolved observation and manipulation of isolated Mn spins integrated within photonic microcavities. A single magnetically-doped GaAs quantum well is fabricated within both microdisk and vertical Fabry-Perot cavities in which their respective cavity modes are coupled to the neutral Mn acceptor emission. Scanning micro-photoluminescence measurements reveal cavity-coupled emission and a dramatic increase in the measured signal to noise ratio, thereby allowing direct imaging of narrow linewidth luminescence from the Mn moments. These Mn ion spins are optically polarized at zero-field, exhibit long spin lifetimes, and may be manipulated through a variety of techniques for coherent storage and communication.

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Semiconductor Nanowires for Applications in Nanoelectronics and Photonics

Lars Samuelson
Lund University

The nanowires (NWs) that I will talk about are single-crystalline semiconductors which form via guided self-assembly, replicating the crystalline structure of the substrate and with location and dimensions controlled by top-down lithography. One advantage of our approach is that high-performance III-V devices structures can be grown using silicon wafers as templates. I will initially dwell on our present understanding of the way nanowires grow, including recently explored manipulation and control of the growth of cubic and hexagonal NWs. After an overview of the physical properties of homogeneous as well as hetero-structured NWs I will concentrate on recent device studies, such as the realization of state-of-the-art wrap-gate controlled NW field-effect transistors, and on the potential for single-QD emitters, NW-light emitting diodes and NW-based solar-cells.

Controlling Si and Ge Nanowire Structures through Real-Time Growth Studies

Frances M. Ross
IBM, T.J. Watson

The controlled fabrication of heterostructure nanowires composed of segments of different materials is key to exciting electronic applications involving quantum dots and barriers. Abrupt interfaces, in which the nanowire composition changes over only one or two atomic planes, have been demonstrated in group III-V nanowires grown using Au catalysts, and have led the way to a host of applications. Yet it has proved difficult to produce abrupt interfaces in Si/Ge nanowires. The reason for this is thought to be a “reservoir effect” arising from the nature of the catalyst itself: for Si and Ge nanowires, the catalyst is a liquid eutectic droplet, AuSi or AuGe respectively, and it takes time to change the droplet composition when switching between Si and Ge segments. Solid catalysts should have lower solubility for the growth species so may mitigate this effect. By starting with AuAl alloys rather than pure Au, we find that Si and Ge nanowires can indeed be grown with solid catalysts. We grow these nanowires in situ in an ultra high vacuum transmission electron microscope, allowing us to determine the structure of the catalyst directly during growth and compare with growth using conventional liquid catalysts. Movies show the fascinating dynamic nature of the solid catalyst during growth and heterostructure formation. We demonstrate compositionally abrupt Si/Ge and Si/SiGe interfaces grown using these novel catalysts, compare with the growth of group IV / group III-V nanowire interfaces, and discuss the implications of interface control for improved Si nanowire-based electronic devices.

Carbon Nanotube Quantum Dots and Nanostructures

Koji Ishibashi
RIKEN

Single-wall carbon nanotube quantum dots (SWCNT-QDs) have been fabricated simply by depositing metallic contacts on top of an individual SWCNT. It has been shown that the SWCNT-QD behaves as an artificial atom where electrons are confined in the one-dimensional confinement potential. Compared with well-known semiconductor quantum dots fabricated by advanced lithography techniques, there are some unique features in the SWCNT-QD. First, the energy scales associated with the QDs are one or two orders larger than those of the semiconductor QDs, ranging from submillimeter to THz frequencies. Second, the shell structures are experimentally observable even though there are many electrons in the QD. This is because the level degeneracy is always four in the SWCNT QD, independent on the quantum number, and the confinement level spacing (ΔE) is of the order of the charging energy of the single electron (Ec). Besides, the electron-electron interaction energies are much smaller than ΔE. These facts have made the simple shell filling possible. Third, the chemical modification of the SWCNT surface is possible, so that by combining with the possible SWCNT-molecule heterojunction, molecular scale nanostructures can be fabricated. These unique features have made SWCNTs promising building blocks of the quantum nanodevices.

In this presentation, we begin with a brief review of the SWCNT artificial atom that includes shell structures and energy spectrum. To demonstrate the energy scales that exist in the THz range, the THz photon assisted tunneling (THz PAT) in a single SWCNT QD is shown, and a route to the single THz photon detection scheme is given. Finally, the nanostructure fabrication by using the chemical modification and SWCNT-molecule heterojunctions is demonstrated. The nanostructures are characterized by the scanning tunneling microscope (STM) and optical methods.

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Nanowire Growth

Gary L. Harris
Howard University

Over the last decade our laboratory has grown a variety of nanowires including GaN, InN, SiC, InAs, ZnO and Si using both catalytic and non-catalytic methods. Nanowire growth occurs at significantly lower temperatures than thin film growth. The limiting step appears to be formation of small "seed" nanowires, from which longer nanowires grow rapidly replicating the structure of the "seed". In general, the width of the nanowires do not change. In the case of biphasic GaN nanowires, the complex structure of the wire is preserved along the entire length. Nanowire growth can be efficiently started by undulating the surface of the underlying substrate as well as depositing catalysts on the surface. Wire growth on the rough edges of substrates has also been observed. It is argued that the growth process is selecting those crystal faces for which the activation energy for precursor decomposition is lowest. Identification of these crystal faces by analysis of the nanowire crystal structure can provide important information for thin film growth in general.

Quantum Interfaces of Oxide Semiconductors

Masashi Kawasaki

Tohoku University

We present quantum Hall effect (QHE) in ZnO and superconductivity in $SrTiO_3$, both of which could be modulated by an electric field effect using organic gate structures.

ZnO is a promising material for ultraviolet light emitting diodes [2]. Through fine-tuning of film growth processes, we found that two dimensional electron gas (2DEG) with a sheet charge density of 10^{11}-10^{13} cm^{-2} emerges at the interfaces of ZnO and (MgZn)O due to the discontinuity in spontaneous polarizations of these piezoelectric materials [2]. With spin-coating of poly (3,4-ethylenedioxythiophene) poly (styrenesulfonate) (PEDOT:PSS) on ZnO, nearly ideal Schottky junctions could be formed [3]. From capacitance-voltage (*C*-*V*) relations, we could profile the carrier concentration along depth that clearly indicated the presence of 2DEG as designed. Metal-semiconductor field effect transistors (MES-FET) with a Hall-bar geometry clearly showed that the quantum transport such as Shubnikov-de Haas (SdH) oscillation and QHE were modulated by the tuning of the sheet charge density in the channel of the MES-FET.

Another example is inducing superconductivity in a pristine $SrTiO_3$ crystal with accumulating electrons at the surface by an electric double layer (EDL) gating with polymer electrolyte. Polyethylene-oxide electrolyte with $KClO_4$ as a supporting salt was applied on an atomically flat $SrTiO_3$ surface [4]. The key was to make very good Ohmic contacts by using self-assembled ion bombardment metallization for contact pads. By applying 2.5-3.5V at the Pt electrode in the electrolyte, electrons with a sheet charge density of 10^{13}-$10^{14}$$cm^{-2}$ could be induced. The system underwent to superconducting state with a T_C of about 0.4K [5]. Surprisingly, T_C was almost unchanged in a wide range of the sheet charge density spanning a decade. We present a possible relation with almost constant density of states at Fermi level due to large change in dielectric constant of quantum paraelectric $SrTiO_3$.

*This work was carried out under the collaboration with A. Tsukazaki, K. Ueno, A. Ohtomo, M. Nakano and the group of Prof. Y. Iwasa.

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(De)-Constructing Oxygen Vacancies in Thin Film Oxides and Superlattices

Shriram Ramanathan

Harvard University

A central problem in the field of oxide materials science is the role of point defects in determining functional properties. These may range from electronic reconstructions at hetero-interfaces to fast-ion conduction. I will discuss our investigations into controlling oxygen concentration in ultra-thin oxides, quantification of oxygen concentration and electrical/electrochemical measurements in low-dimensional oxides. Specific examples to be discussed include metal-insulator transitions in vanadium oxide, ionic conduction along interfaces in fluorite oxides and the use of photons and electric fields in controlling oxygen incorporation into oxides.

Contributions from group members will be acknowledged in the presentation.

Electric-Field Manipulation of Magnetization Direction

Christopher Palmstrom

University of California, Santa Barbara

Embedded nanoparticles can be produced by codeposition of metal and semiconductor species at metal concentrations above the solubility limit of the metal in the semiconductor. The ability of embedding a material with very different properties within a semiconductor while maintaining high crystalline perfection has enabled the growth of composite materials with novel electronic, optical and thermal properties. Embedded epitaxial semi-metallic rare-earth monopnictide nanoparticles can behave as dopants, fast carrier recombination centers and phonon scatterers. The property of the composite materials depends on the distribution, size and shape of the embedded nanostructures. The nanoparticles produced by molecular beam epitaxial codeposition of ErAs and GaAs are not necessarily randomly arranged, but can spontaneously form regular arrays of nanorods with diameters of approximately 3 nm. The rods show intense optical absorption in the spectral region below the GaAs bandgap. This presentation will discuss the growth and properties of semi-metal nanostructure/compound semiconductor composite materials.

Voltage Tunable THz Absorption and Optical Properties of a Novel Self Assembled Nanostructure.

Pierre Petroff

University of California, Santa Barbara

Semiconductor self-assembled quantum dots (QDs) provide 3D carrier confinement and have been used successfully for understanding the physics of confined carriers and in a variety of devices for studying charged excitons, spins, single photon emission and single electron transistors. However applications involving intra-subband transitions in the THz range have remained elusive since in the QDs the electrons (1s-2p) transition is in the 40-60meV range. We have developed a novel quantum dot based nanostructure grown by molecular beam epitaxy [1] called quantum posts (QPs). It allows reaching 1s-2s energy transitions with intra-subband energy level spacing in the 2-20 meV range. These structures whose height can be controlled with nanometer precision, form short nanowire-like structures (average composition In.43Ga.67As) aligned along the growth direction terminated at both ends by a quantum dot. Precise control of their conduction band ground to excited states state transitions is achieved simply by varying their height during growth. The QPs is imbedded in an In.1Ga.9As QW of the same height as the QPs. Up to now heights of 23 nm to 60 nm have been achieved, with predicted electron ground state transitions between 6 THz and 0.5 THz.

We first discuss the electronic properties of the QPs and use the delocalization of the electrons along the QPs axis to demonstrate an exciton memory and a source of single photon on demand.

We then present absorption measurements in which an MIS structure containing a layer of QPs is used for loading the QPs with electrons in the 1s ground state. The MIS structure consists of a single QP (QW) layer embedded in between an n-doped back-gate and a Schottky-contact, allowing us to load controllably the QPs with electrons. The electron loading of the QPs is followed by measuring the MIS capacitance changes as a function of a gate voltage. The absorption measurements were performed using an FTIR and were taken at T=4 K. Winston-cones were employed to efficiently couple into the cleaved facets and to couple to the transition of interest and the polarization was set parallel to the growth direction.

We will present absorption spectra of 2 different QPs layers with different height (30 and 35nm). The broad absorption spectrum of the 30nm QPs shows a maximum at 5.2 THz, which corresponds well to the computed theoretical value. Voltage tunability of the absorption is also observed and is due to the Quantum Confined Stark effect. We will discuss the potential advantages of the QPs which allow THz absorption under normal incidence illumination and a modest applied electric field.

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Quantum Optics with Nanowires and Quantum Dots

Val Zwiller
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Nanowires grown by epitaxial methods enable the fabrication of complex semiconducting heterostructures where composition, size, position and doping can be controlled with unprecedented freedom. We study the optical properties of single nanowires containing single quantum dots with the aim of interfacing the world of quantum transport and quantum optics. We have demonstrated the operation of a single nanowire light emitting diode and photocurrent measurements on gated quantum dots were performed to probe the energy levels of a single quantum dot in a nanowire. The polarization properties of nanowire heterostructures will also be discussed and photoluminescence measurements done in different orientations demonstrate that vertical nanowire devices enable the extraction of any polarization. We show that vertical nanowires enable the generation and readout of any exciton spin orientation and we demonstrate optical access to single spins in nanowire quantum dots. Because both zincblende and wurtzite crystal phases are stable in nanowires, a novel type of charge confinement where quantum dots composed of the same material than the surroundings is possible. We will present recent results obtained on InP quantum dots in InP nanowires.

Superconducting nanowire detectors are well established single photon detectors, we have demonstrated the direct detection of plasmons using superconducting detectors, paving the way towards integrated plasmonics where emission, waveguiding and detection is performed on a chip at the single plasmon level.

The possible coupling of quantum dots to atomic system will also be discussed. We have coupled the emission of a single quantum dot to a rubidium vapor, this enables slowing down single photons and tuning several quantum dots to one frequency.

Silicon Photonics: The Optical Spice Rack

Michal Lipson
Cornell University

Silicon is evolving as a versatile photonic platform with multiple functionalities that can be seamlessly integrated. The tool box is rich starting from the ability to guide and switch multiple wavelength sources at GHz bandwidths, to optomechanical MEMS and opto-fluidics devices. Some of the challenges in the field of silicon photonics are discussed, among them are the decrease of losses in silicon waveguides and the integration of silicon photonics with current CMOS microelectronics.

Microdisk Resonators in Polar and Non-Polar GaN

Evelyn Hu
Harvard University

The GaN family of materials (including In(Ga)N and Al(Ga)N) has already demonstrated their exceptional optical performance in a broad spectral range encompassing the UV to the visible. Microdisk and nanophotonic cavities provide ideal device geometries for these materials which have large exciton binding energies and evidence of long spin coherent lifetimes. The high cavity Q's and small modal volumes possible in these devices could lead to ultra-low threshold optical sources, evidence of strong coupling and possible new means of the control of spin states. We describe the fabrication and performance of InGaN quantum wells embedded within microdisks of either c-plane or m-plane GaN. Room temperature, low-threshold CW lasing was observed for the c-plane microdisks. The m-plane microdisks, of high optical quality and comparable geometry to the c-plane microdisks, showed very different modal structure, revealing the importance of the internal field structure and of re-absorption processes in the microdisk materials.

Nanophotonics Platform for Quantum Information Processing in Diamond

Marko Loncar

Harvard University

The advances in nanotechnology have enabled us with the opportunity to fabricate nanoscale optical devices and chip-scale systems that can generate, manipulate, and store optical signals at single-photon level. Photonic crystal platform, for example, allows realization of ultra-high quality factor (Q) optical cavities that are capable of storing photons to sub-wavelength volumes for long periods of time. Such a high confinement of light enables strong light-matter interaction what is crucial for realization of quantum networks.

In this talk I will describe our work on diamond photonics and in particular application of color centers in diamond for quantum information processing. Nitrogen-vacancy (NV) color centers in diamond have emerged as promising quantum emitters. They form a basis for very promising approach to a few-photon all-optical switches, since they combine the key advantages of isolated atomic systems with solid-state integration, and have following unique optical properties: (i) room temperature operation, (ii) little inhomogeneous broadening, (iii) deterministic positioning (using ion implantation). In order to further improve the efficiency of NV-based quantum-emitters, it is important to enhance the photon production rate as well as the collection efficiency of emitted photons. This can be achieved by embedding NCs within optical structures including cavities, waveguides and nanowires. A major challenge, however, is the fact that the zero phonon line (ZPL) optical transition is in the visible (637 nm), and structures must therefore be designed in a visibly transparent material.

I will present our work on novel single-photon sources based on NV color centers embedded within diamond nanowires fabricated in single-crystal synthetic diamond. This approach improves the collection efficiency from photons emitted within nanowire resulting in bright sources of single photons. In order to take advantage of Purcell effect and further increase the brightness of the single photon sources (due to enhanced photon production rate from NV centers), it is beneficial to embed NVs in optical cavities. I will describe nanophotonic platforms based on Si3N4 and TiO2 suitable for integration with diamond nanocrystals (DNCs). Moderately low refractive index of materials that are transparent in visible (Si3N4, TiO2) has often been considered an impediment to ultra-high-Q photonic crystal nanocavity designs, which thusfar have only been demonstrated in high index semiconductors such as silicon. Recently we demonstrated that Si3N4 photonic crystal nanocavities with a Q factor of 1.4 ×106 and a mode volume of ~ 0.78(λ /n)3 can be designed. We predicted that DNC-nanocavity system can enter so called “strong coupling regime” of light matter interaction, in which the coherent dynamics between the emitter and the cavity mode dominate the dissipative loss rates from the system. With an NV center positioned on the top surface of the cavity, we found the relevant rates for strong coupling dynamics to be (g,κ, γ) = (0.52, 0.23, 0.05) GHz, where g is the Rabi frequency, κ is the cavity loss rate of the highest Q cavity, and γ is the spontaneous emission rate of the NV center. As such, our system is a promising platform for integrated quantum optics with diamond NV centers.