Abstracts from Invited Speakers

Keiji Ono (RIKEN)

A High-temperature Silicon Qubit and its Quantum Interference

Spin qubits are attractive building blocks for quantum computers. Si is a promising host material for spin qubits since it could enable long coherence, high-density integration, and high compatibility with classical computers. Spin qubits have been implemented in Si using gate-defined quantum dots or shallow impurities. However, these qubits must be operated at temperatures <0.1 K, limiting the expansion of qubit technology. We used deep impurities in Si to achieve room-temperature single-electron tunnelling and spin qubit operation at 5–10 K [1]. We employed tunnel field-effect transistors (TFETs) instead of conventional metal–oxide–semiconductor field-effect transistors and achieved strong confinement of the single quantum dots embraced in TFETs up to 0.3 eV. Furthermore, double-quantum-dot devices were operated as spin qubits, and read-out was realized using a spin blockade. These results will enable broadening of the range of spin qubit applications such as sensing, security, and quantum computing.

We also study quantum interference effects of a qubit whose energy levels are continuously modulated [2]. The qubit energy levels are modulated via its gate-voltage-dependent g-factors, with either rectangular, sinusoidal, or ramp radio-frequency waves. The energy-modulated qubit is probed by the electron spin resonance. Our results demonstrate the potential of spin qubit interferometry that is implemented in a Si device and is operated at a relatively high temperature.

[1] K. Ono, T. Mori, S. Moriyama, High-Temperature Operation of Spin Qubits based on Silicon Tunnel Field-Effect Transistors, arXiv:1804.03364, Scientific reports, in print.
[2] K. Ono, S. N. Shevchenko, T. Mori, S. Moriyama, Franco Nori, Quantum interferometry with a high-temperature single-spin qubit, arXiv:1809.02326.

Sergei Studenikin (NRC)

Tunable Single-hole EDSR in a Lateral GaAs/AlGaAs Quantum Dot Device

Single holes are attractive for fundamental physics research and also for spin qubit applications due to their unique properties as compared to electrons, for example, a reduced hyperfine interaction to mitigate nuclear decoherence, a strong spin-orbit coupling for sub-nanosecond spin rotations using gates, and the absence of valleys to completely eliminate the harmful qubit valley degeneracy problem encountered in electron silicon qubits.

In my talk I will review our recent Electric Dipole Spin Resonance (EDSR) experiments on a single hole confined in a lateral GaAs/AlGaAs double quantum dot (DQD) device described in Ref. [1].

A single hole is confined in one of the dots with the Fermi level of the adjacent lead positioned in between the Zeeman split spin states so the current through the DQD is energetically blocked. A small microwave voltage is applied to a plunger gate to mediate hole EDSR to flip hole spin from the lower to the upper spin state above the Fermi level to allow the hole to exit to the lead. Spin resonance is detected as a small current increase when the EDSR resonant condition is fulfilled. The g-factor tunability is achieved by setting the DQD device in the very strong inter-dot coupling regime. The Zeeman-split levels of the second axillary dot are used to tune the g-factor of the first dot by gate detuning in the millivolt range. The axillary dot is never occupied and is employed as a vehicle to tune the effective g-factor in the first dot via strong spin-dependent inter-dot tunnel coupling.

[1] A. Bogan et al., Phys. Rev. Lett. **120**, 207701 (2018).

Mona Berciu (University of British Columbia)

Using Polaronic Effects to Engineer the Dispersion and Effective Interactions of Quasiparticles

The polaron which forms when a particle interacts with bosons from its environment is generically believed to be heavier than the original particle, and the boson-mediated effective interactions between polarons are generically expected to be attractive. In my talk, I will highlight a few examples where these expectations turn out to be wrong: polarons that are lighter than the bare particles can form in the strong coupling limit, and boson-mediated interactions can also be repulsive, or attractive but with very unusual form. This proves that the quasiparticles' dispersion and effective interactions can be suitably tailored by a careful engineering of their environment.

Ryuichi Ohta (NTT)

Mechanical Control of Localized Excitons: Strain-induced Coupling between Dark and Bright States and Mechanical Control of Exciton Lifetimes

Ryuichi Ohta[1], Hajime Okamoto[1], Takehiko Tawara[1,2], Hideki Gotoh[1], Hiroshi Yamaguchi[1]

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Mechanical strain has been employed to control the optical and electrical properties of solid-state two-level systems instead of electric and magnetic fields. For instance, the exciton energies of quantum dots [1] and the electron spins of nitrogen vacancy centers [2] have been controlled by the vibrational strains. In this talk, we demonstrate two alternative mechanical controls of exciton dynamics. One is strain-induced coupling between dark and bright states, which enables one to optically address the long-lived dark excitons [3]. The other is mechanical modulation of exciton lifetime [4]. We further investigate the back-action effect from excitons to the mechanical motion via this dissipative process. These results open the way to manipulate the various solid-state two-level systems with microelectromechanical systems and acoustic devices.

[1] M. Montinaro *et al.*, Nano Lett. **14**, 4454 (2014).
[2] A. Barfuss *et al.*, Nat. Phys. **11**, 820 (2015).
[3] R. Ohta *et al.*, Phys. Rev. Lett. **120**, 267401 (2018).
[4] R. Ohta *et al.*, Phys. Rev. B **99**, 115315 (2019).

Paul Barclay (University of Calgary)

Diamond Opto-mechanical Devices for Coupling Photons, Phonons and Spins

Cavity opto-mechanical devices couple light to mechanical resonator motion via radiation pressure. By fabricating cavity opto-mechanical devices with low mechanical and optical dissipation, combined with wavelength scale optical field confinement and resulting strong opto-mechanical coupling, it is possible to coherently transfer energy between photons and phonons in these systems. Diamond devices offer the additional benefit incorporating colour centre spins useful for quantum information processing. This talk will present our progress in using diamond opto-mechanical devices for optical information processing (memory and switching) and for spin-opto-mechanics.

Takao Aoki (Waseda University)

Coupled-Cavities Quantum Electrodynamics

In a cavity quantum electrodynamics (QED) system, where atoms coherently interact with photons in a cavity, the eigenstates of the system are the superposition states of atoms and cavity photons, the so-called dressed states of atoms. When two cavities are connected by an optical fiber with negligible loss, the coherent coupling between the cavities gives rise to photonic normal modes. Here we demonstrate the setting of coupled-cavities QED, where two nanofiber cavity-QED systems [1] are coherently connected by a meter-long low-loss channel in an all-fiber fashion. Specifically, we observe dressed states of distant atoms with delocalized photons of the ‘fiber-dark’ normal mode [2], as well as remote excitation and nonlocal saturation of atoms in the ‘cavity-dark’ normal mode [3].

[1] S. Kato and T. Aoki, Phys. Rev. Lett. **115**, 093603 (2015).
[2] S. Kato, N. Német, K. Senga, S. Mizukami, X. Huang, S. Parkins, and T. Aoki, Nature Communications **10**, 1038 (2019).
[3] D. White, S. Kato, N. Német, S. Parkins, and T. Aoki, submitted.

Francois Sfigakis (University of Waterloo)

To be confirmed

Akira Oiwa (Osaka University)

Photon-spin Quantum Interface Using Gate-defined Quantum Dots

Communications using qubits entangled each other provide quantum internet for quantum key distribution, secure access to remote quantum computers and other novel concepts of quantum technologies. We are investigating the quantum repeaters based on photon-electron spin quantum interface (Poincaré interface) consisting of gate-define quantum dots (QDs). The electron spins in the gate-defined GaAs QDs have a great potential for the quantum repeaters; coupling to polarization of photons at optical communication wavelength and long coherence time. The ingredient technologies are quantum state conversion from single photons to single electron spins and the entanglement conversion from photon pairs to electron spin pairs. In this talk, we present the recent experimental progresses on the quantum state conversion in a gate-defined QD and the coincidence measurement between single photo-electron detection in a QD and single photon detection using an entangled photon source. Moreover the recent progresses on the enhancement of the coupling between photons and electron spins in QDs and future prospects are discussed.

Satoshi Iwamoto (University of Tokyo)

Confinement of Light in Semiconductor Using Topological Concept

We will discuss topological localized states of light realized in semiconductor photonic crystal (PhC) platforms. We designed two topologically distinct PhC nano-beams and experimentally demonstrated lasing oscillation using a topological localized mode at the interface between them. A nano-cavity using a topological corner state in a 2D PhC slab will be also discussed.

Kin Fai Mak (Cornell University, USA)

Path Towards Exciton Condensation at High Temperatures

Excitons, composite Bosons made of Coulomb bound electron-hole pairs, are important objects underlying the operations of many optoelectronics devices in our daily life. As a result of the much smaller exciton mass compared to that of atoms, they also hold great promise in the realization of Bose-Einstein condensation at high temperatures. However, the small exciton binding energy in conventional semiconductors has so far limited the condensation temperature to below 1K. In the past few years, a new class of two-dimensional (2D) semiconductors with much larger exciton binding energy has emerged. In this talk, I will first discuss the measurement of the exciton binding energy in these materials by optical spectroscopy methods. I will then tell you the path we have taken in trying to realize exciton condensation in these materials. Signatures of exciton condensation above 100 K have been observed in a recent set of experiments. Prospects of condensate-based optoelectronics and exciton-mediated high-temperature superconductivity will also be discussed.

Ryota Negishi (Osaka University)

Anomalous Electrical Transport Properties of Multilayer Graphene with Turbo-stratic Stacking Fabricated by CVD on Graphene Templates

Ryota Negishi[1] and Yoshihiro Kobayashi[1]

[1]*Osaka University*

The multilayer graphene with a turbo-stratic stacking has weak interlayer coupling, resulting in preserving linear dispersion relation similar to monolayer graphene. This unique feature is completely different from the usual AB stacking graphene, and enables us to expect to emerge exotic quantum properties beyond graphene in addition to the excellent performance of monolayer graphene. Although theoretical researches have predicted anomalous electrical properties due to the pseudo-linear dispersion, the precise control of the layer numbers and the stacking structures have remained as critical issues for fabricating the turbo-stratic graphene. In this study, we successfully fabricated the turbo-stratic graphene using chemical vapor deposition (CVD) at high temperature. The highly crystalline graphene multilayer was grown on a monolayer graphene template. The turbo-stratic stacking was confirmed by a variety of structural analysis such as Raman spectroscopy, scanning transmission electron microscopy and reflection high energy positron diffraction. In the analysis of electrical transport, the turbo-stratic graphene exhibits higher conductivity and carrier mobility than the monolayer template graphene. These improved carrier transport properties are originated from the pseudo-linear dispersion and the screening effect for the charge impurities on the substrate. The quasi-monolayer characteristics clarified here lead us to investigate the quantum transports in the turbo-stratic graphene such as half-integer quantum Hall effect.

Mark Freeman (University of Alberta)

Hybrid Nanomagnetic-nanomechanical Systems

Nano-cavity opto-mechanics dramatically extends the capabilities of sensors based on nano-mechanical displacement detection. Our group and collaborators have been developing hybrid nano-magnetic-nano-mechanical systems as mechanical torque-based probes of magnetism. Particular features of the approach include Einstein - de Haas torque as a general purpose tool at radio frequencies, and mechanical detection of spin resonance. The present measurements are far from quantum-limited, suggesting the promise of further development of hybrid spin-mechanical systems.

Junko Ishi-Hayase (Keio University)

Quantum Protocols for AC Magnetic Field Sensing using Nitrogen-vacancy Centers in Diamond

Electric spin of negatively-charged nitrogen-vacancy (NV) centers in diamond are utilized for highly-sensitive nanoscale quantum sensor at room temperature [1]. In this study, we propose and demonstrate two quantum protocols for highly-sensitive AC magnetic field sensing using NV center ensemble in diamond.

One of the proposed protocol is effective to improve the sensitivity for vector magnetic field sensing by multi-frequency control of electric spins of NV centers. The key idea is that four types of NV centers with different axes are simultaneously controlled by multi-frequency microwave pulses [2, 3]. Another protocol enables us to detect high-frequency (MHz range) AC magnetic field with continuous application of microwave and laser. This method fully utilizes spin-1 properties of electron spins of NV centers [4].

This work was done in collaboration with Dr. Matsuzaki, Dr. Watanabe (AIST), Dr. Saito, Dr. Kakuyanagi (NTT BRL), Prof. Mizuochi (Kyoto Univ.), Prof. Itoh and Hayase Laboratory members (Keio Univ.). This work was supported by JSPS KAKENHI (Grant No. 15K17732) and MEXT KAKENHI (Grants No. 18H01502, 15H05868, 15H05870, 15H03996, 26220602, and 26249108), and Spin-NRJ.

Kazuhiko Hirakawa (University of Tokyo)

Terahertz Dynamics of Electron-vibron Coupling in Single Molecules with Tunable Electrostatic Potential

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Clarifying electronic and vibronic properties of individual molecules provides key insights to future tailor-made medicine, chemistry, nanoelectronics, and quantum information technologies. Terahertz (THz) spectroscopy has been developed as a powerful tool for clarifying vibrational dynamics of various kinds of molecules. Because of the long-wavelength nature of the THz radiation (typically, ~100 microns), however, spectral information was obtained only for ensemble average of a huge number of molecules. It has been a formidable challenge to overcome the diffraction limit and focus THz radiation on a single molecule. Furthermore, the number of mobile charges that can absorb THz radiation in a single molecule is very few, which makes THz absorption by a single molecule extremely small.

Here, we report on the THz spectroscopy of single molecules by using the single molecule transistor (SMT) geometry [1]. Using the source and drain electrodes separated by a sub-nm gap as a THz antenna [2], we focused the THz radiation onto a single fullerene molecule trapped in the nanogap electrodes and measured THz-induced photocurrent in the SMT. A great advantage of the present SMT geometry is that the electrostatic potential and the number of electrons on the molecule can be precisely controlled. We have observed low energy vibrational modes due to the center-of-mass nanomechanical motion of the fullerene molecule. Furthermore, we found that the observed peaks are finely split into two, reflecting the difference in the van der Waals potential profile experienced by the molecule on the metal surface when the number of electrons on the molecule fluctuates by one during the single electron tunneling process. Such an ultrahigh-sensitivity to the electronic/vibronic structures of a single molecule upon adding/removing a single electron has been achieved by using the THz spectroscopy in the SMT geometry. This SMT scheme provides a novel opportunity for investigating ultrafast THz dynamics of sub-nm scale systems.

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Amr Helmy (University of Toronto)

Integrated Photonic Paradigms which Enable Emerging Quantum Technologies

In this talk I plan to overview the capabilities of an intergraded photonics platform in the context of enhancing quantum photonics functionality and integration density on chip. A platform based on active and passive compound semiconductors, where battery operated source of photon pairs and the circuitry that prepared quantum states generated from these sources to benefit applications in quantum sensing will be reviewed.

Yuichiro Matsuzaki (AIST Tsukuba)

Quantum Remote Sensing with Asymmetric Information Gain

Quantum technology technologies enable high precision sensing. In the future, people might use the quantum sensor located at a distant place via internet. A client-server model describes such a circumstance. The client needs to measure target fields from a sample, but he/she does not have a sensitive field sensor. The client delegates the sensing task to a remote server with a high-precision sensor. The server honestly obeys every instruction from the client. The server measures the sample, sends the information to the client, and returns the sample to the client. However, if the server's sensor is stolen by eavesdroppers after the protocol, the information stored in the sensor can be leaked, because classical information is inerasable. To overcome the problem, we will introduce a novel quantum sensing scheme with a security in build. Interestingly, there is an asymmetric information gain where the amount of achievable information at the client side can be much larger than that of the server side. This guarantees the security even if the sensor of the server is stolen.

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[2] S. Kitazawa, *et al*., Phys. Rev. **A 96**, 042115 (2017).
[3] K. Yahata, *et al*., Appl. Phys. Lett. **114**, 022404 (2019).
[4] S. Saijo, *et al*., Appl. Phys. Lett. **113**, 082405 (2018).

Jack Sankey (McGill University)

Spin Transfer Controlled Magnetic Dynamics Probed with a Single Bulk NV Spin

The point-like nature and exquisite magnetic field sensitivity of bulk nitrogen vacancy (NV) centers can be used to gain new insights into the inner workings of spintronic and magnetic nano-circuits. We fabricate a spin transfer (ST) controlled magnetic nanowire upon a single crystal diamond substrate containing NVs embedded tens of nanometers below the surface. By probing the nanowire's stray field with a nearby NV spin, we observe unambiguous evidence of ST tuned, parametrically pumped, large-angle magnetic oscillations, and demonstrate how these oscillations can directly drive NV spin transitions. We also use the NV as a local noise thermometer, observing strong ST damping of the stray field noise, consistent with magnetic cooling from room temperature to ~150 K (a lower temperature than previously reported, likely due to the high power handling of the diamond substrate).

Shintaro Nomura (Tsukuba University)

Wide-field Imaging of Microwave with Nitrogen-vacancy Center Ensembles in Diamond

Microwave imaging has been performed either by using a scanning dipole antenna or a dipole array for imaging in the mm-scale resolution. There have been difficulties, however, in higher resolution imaging due to sensitivity and the mutual coupling that is present when an array is used. Wide field imaging of microwave using ensembles of nitrogen-vacancy (NV) center ensembles in diamond offers high resolution-imaging in the micro- and nano-scale, avoiding the mutual coupling. In this talk, we will present our results of quantitative imaging of microwave field distribution by driving the Rabi oscillations of the NV electronic spin. We measured microwave field distribution in the vicinity of micrometer-sized non-fed antenna structures. The obtained microwave images reveal that the microwave field amplitude (intensity) is enhanced by a factor of 21.5 (462) near a micrometer-sized antenna structure. Our method may contribute to local control of quantum spins, evaluation of microwave devices, and microwave bio-imaging.

Mikio Eto (Keio University)

Physics in Double Quantum Dot in Parallel

I will talk about two topics: (i) The Kondo effect is theoretically examined in one of the quantum dots when the other has a broad linewidth. This is a tractable model for the quantum dot interferometer, an Aharonov-Bohm ring with an embedded single quantum dot. We find an asymmetric Fano-Kondo resonance or conventional Kondo plateau, depending on the number of conduction channels in the leads. (ii) The photocurrent is examined through identical quantum dots in parallel, under the irradiation of the terahertz (THz) light. The THz light induces the excitation of an electron from an energy level below the Fermi level to that above the Fermi level, which results in the electric current in the presence of asymmetry of tunnel couplings for the associated energy levels. We propose a sensitive THz detector by the Dicke effect, a reverse process of "superradiance".

Moritz Cygorek (University of Ottawa)

Million-atom Simulations of InAs/InP Nanowire Quantum Dots and Quantum Dot Arrays

The growth of quantum dots in nanowires allows a precise control of their sizes and shapes. Moreover, multiple dots can be grown within the same nanowire, which enables studies of quantum dot molecules or arrays and might ultimately lead to solid state implementations of synthetic Haldane chains with symmetry protected topological ground states. We present recent advances in modelling InAs/InP nanowire quantum dots in the wurtzite phase using the tight-binding and configuration-interaction tool QNANO involving calculations of about a million atoms and we show how the geometry, the As concentration and the randomness of alloying influence the excitonic and multiexcitonic spectra.

Michihisa Yamamoto (RIKEN Center for Emergent Matter Science)

Measurement of the Kondo Cloud Length

Kondo effect arises due to the interaction between a localized magnetic moment and surrounding conducting electrons. In the Kondo ground state, the localized magnetic moment is screened by formation of a Kondo cloud, known as a spatially extended many-body singlet state between the localized magnetic moment and many conducting electrons. Since the Kondo cloud has a finite size ξ_K, universal scaling of the Kondo effect by the dimension of the system has been theoretically investigated. However, detection of the Kondo screening length as well as the corresponding universal scaling has been elusive. We perform experiments on detection of the Kondo screening length using a quantum dot containing a localized electron spin coupled to a one-dimensional Fabry-Perot interferometer. The Kondo temperature is modified by the density of states in the interferometer when the interferometer length L is smaller than ξ_K. We find both theoretically and experimentally that the modified Kondo temperature normalized by the Kondo temperature without the interferometer shows a universal scaling and depends only on L/ξ_K.

Eva Dupont-Ferrier (University of Sherbrooke)

Hybrid devices: Interfacing Spins in Silicon with Superconducting Resonators

Hybrid systems between superconducting circuits and spins acting as a quantum memory have been explored [1]. In this context spins of Bismuth appears as a very good candidate as they exhibit exceptionally long coherence times (up to 2.7 s) and a narrow spin linewidth of 270 kHz when placed in 28 Si [2] and when placed under magnetic field of 26 mT, at the so-called clock transition. Tuning the frequency of superconducting resonator to bring in and out of resonance with the spin is an important requirement. We report on magnetic field and SQUID tuning of the superconducting resonators made out of Nb, able to withstand magnetic field required to reach the Bi clock transition [3]. Tunability up to 100 MHz while maintaining quality factors of 10000 has been observed, opening the way for coherent transfer between the Bi spins and superconducting circuits.

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[2] Wolfowicz et al. Nature Nanotechnology **8**, 561 (2013).
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Marek Korkusinski (NRC)

Interaction of Nuclear and Electron Spins in a Hybrid Quantum System

M. Korkusinski[1] and Hawrylak[2]

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There is currently interest in hybrid quantum systems combining electrons and nuclear and/or localized impurity spins due to their long coherence times [1-4]. These localized spins could be utilized as a resource in quantum information provided that they can be manipulated with spins of electrons. The major problems with the hyperfine coupling to nuclear spins are a) the microscopic understanding of the coupling of valence electrons to nuclear spin, and b) matching the energy to flip the electron spin with the corresponding energy to flip the nuclear spin. Here we start with a theory of the interaction of a nuclear spin with the domain wall formed by the spins of electrons in a two-dimensional electron gas confined in an InSb quantum well and in a weak lateral parabolic confinement [5]. The formation of spin domains in this quantum Hall ferro-magnet [4] is made possible by the degeneracy of subsequent Landau levels with opposite spins, brought about by the large g factor of InSb. We map out the energy structure of the droplet from the spin singlet $\nu=2$ phase to the fully spin-polarized phase involving two Landau levels. We show that any state with an intermediate spin polarization contains a well-defined domain wall, separating the spin-polarized droplet in the center and spin-unpolarized outer region of the charge density. The electron spin-nuclear spin interaction is modeled by the hyperfine interaction and therefore depends strongly on the relative position of the impurity and the domain wall. We demonstrate that energy needed to flip one electron spin, i.e., to move the domain wall by one orbital, and the Zeeman splitting of the nuclear spin states are of the same order, enabling manipulation of the nuclear spin by electrical means.

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Abstracts from Poster Presenters

Yunhui Wu (Tokyo University)

Experimental Investigation of Size Effect on Surface Phonon Polaritons on SiN Submicron Membranes

Thermal conduction becomes less efficient as structures scale down into submicron sizes since phonon-boundary scattering becomes predominant and impede phonons more efficiently than Umklapp scattering. Recent studies indicated that the surface phonon polaritons (SPhPs), which are the evanescent electromagnetic waves generated by the hybridization of the optical phonons and the photons and propagating at the surface of a polar dielectric material surface, potentially serve as novel heat carriers to enhance the thermal performance in micro- and nanoscale devices. We study the condition of SPhPs existing in a dielectric submicron film with a broad frequency range. The calculation of SPhPs thermal conductivity based on Boltzmann transport equation (BTE) demonstrates that the heat flux carried by SPhPs exceeds the one carried by phonons. We also conduct a time-domain-thermal-reflectance (TDTR) measurement of SiN submicron films and demonstrate that the stronger the in-plane thermal conductivity enhancement exists at high temperatures by decreasing the film thickness, potentially due to the contribution of the SPhPs. The results presented here have future applications in the field of heat transfer, thermal management, near-field radiation and polaritonics.

Motoi Takahashi (NRC, Tohoku University)

EDSR of a Single Heavy Hole in a Lateral GaAs/AlGaAs Double Quantum Dot Device

Motoi Takahashi[1,2], Sergei Studenikin[1], Guy Austing[1], Alex Bogan[1], Louis Gaudreau[1], Marek Korkusinski[1], Piotr Zawadzki[1], Yoshiro Hirayama[2], and Andy Sachrajda[1]

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[2]Department of Physics, Tohoku University, Sendai, Japan.

Single holes are attractive as spin qubits due to their advantageous properties which include a reduced hyperfine interaction, a strong spin-orbit coupling for sub-nanosecond spin rotations, and the absence of valley complications. Here we report single hole electric dipole spin resonance (EDSR) measurements over the 10-50 GHz range taking advantage of the strong spin-orbit coupling. The experiment is performed in a GaAs double quantum dot device described in [1] tuned in such way that strong hybridization of the single dot orbitals occurs leading to the formation of quantum molecular states and only one of the dots contains a single heavy hole with the Fermi level of the adjacent lead positioned in between the Zeeman split spin states. We first show the high bias transport characteristics and the magnetic field dependence of states in the single-hole regime. A new signal due to EDSR is observed on application of micro-waves when the current is energy blockaded. The frequency of the EDSR signal is found to shift linearly with magnetic field and we show that the effective g-factor can be electrically tuned in the range of 30% by a small change of gate voltage. Because of the strong spin-orbit interaction, we are able to realize a tunable hybrid spin-charge system. As a function of dot detuning, the EDSR signal can be continuously changed from being mostly spin-like to charge-like.

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Kanta Asakawa (Yokohama National University)

Nanoscale Phase Change on $Ge_2Sb_2Te_5$ Induced by Laser-driven STM

Kanta Asakawa[1], Shotaro Yaguchi[1], Katsumasa Yoshioka[1], Ikufumi Katayama[1], Yusuke Arashida[1,2], Shoji Yoshida[2], Hidemi Shigekawa[2], Masashi Kuwahara[3], and Jun Takeda[1]

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[2]*University of Tsukuba,*
[3]*National Institute of Advanced Industrial Science and Technology (AIST)*

$Ge_2Sb_2Te_5$, which is a layered chalcogenide, is attracting interest for its topological band structure [1] and its light-induced phase change which can be utilized for future application for chalcogenide superlattice memory devices. In conventional optical storage devices, the capacity was determined by the mark diameter (~150 nm) which is governed by the wavelength of the laser. In the present study, we demonstrate that the near-field light generated by focusing laser pulses onto the STM tip can be utilized for producing few-nanometer-sized amorphous marks on $Ge_2Sb_2Te_5$ surfaces.

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Kazuya Saso (Keio University)

Fabrication and Evaluation of Stacked Quantum Dots Embedded in Fabry-Pérot Resonator for Improving Photon Echo Generation Efficiency

Kazuya Saso[1], Ryutaro Ide[1], Kouichi Akahane[2], and Junko Ishi-Hayase[1]

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Photon echo (PE) technique combining quantum dot (QD) ensemble is a powerful tool for implementing quantum interface with a large (10 THz) bandwidth. Recently, our group succeeded in a coherent transfer of broadband (1 THz) optical pulses at the single photon level by using PE technique in highly-stacked InAs QDs. However, PE generation efficiency was extremely low, because the efficiency is limited by low absorption of QD sample. In this presentation, we report on the improving PE generation efficiency from an ensemble of QDs embedded in Fabry–Pérot resonator. By performing numerical calculations, we designed an optimum sample structure to maximize absorption coefficient with keeping large (1 THz) bandwidth. We fabricated a sample including 50 layers of InAs QDs sandwiched between InP/InGaAlAs and TiO_2/SiO_2 DBRs. It is found that the absorption coefficient of the fabricated sample is increased more than 5 times as bare QDs (150 layers). As a result, PE efficiency can be increased by an order of magnitude compared with that in QDs (150 layers) without resonator. This work was supported by MEXT KAKENHI (Grants No. 15H05868,), and Spin-NRJ. The samples were fabricated at Advanced ICT Device Laboratory, NICT.

Hiroyasu Yamahara (University of Tokyo)

Flexoelectricity and Magnetism in Strain-gradient Rare-earth Iron Garnet Thin Films

Hiroyasu Yamahara[1], Sarker Md Shamim[1] and Hitoshi Tabata[1]

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Rare-earth iron garnets (RIGs) are ferrimagnetic insulators whose chemical formula is $R_3Fe_5O_{12}$ (R: rare-earth elements). They have been industrially available for optical devices such as optical isolators since they show large magneto-optical effect. On the other hand, they are unlikely to show remnant dielectric polarization in bulk, because their crystal structures are centrosymmetric cubic. If remnant magnetization and dielectric polarization co-exist in RIGs, multiferroic behaviors and magneto-electric correlation (ME-effect) are expected, which is promising material for future application on spintronics devices. In this research, $Sm_3Fe_5O_{12}$ (SmIG) films are grown on $Gd_3Ga_5O_{12}$ (GGG) substrates by a pulsed laser deposition. The lattice mismatch between SmIG and GGG is −1.2%, so that the critical thickness where misfit dislocation occurs is estimated to be 60 nm. SmIG films grown on GGG show tetragonal, strain-gradient, and cubic structures from the interface to the surface due to the epitaxial strain and the lattice relaxation. In the strain-gradient region, the inhomogeneous strain can generate flexoelectric polarization, $P_{flexo} = \mu(\partial u/\partial x)$, where μ and $(\partial u/\partial x)$ are flexoelectric tensor and strain-gradient, respectively. The inhomogeneous atomic displacement and the presence of dielectric polarization in the strain-gradient region are confirmed by a scanning transmission electron microscopy (STEM) and a scanning nonlinear dielectric microscopy (SNDM), respectively. We conclude that remnant magnetization and dielectric polarization co-exist in strain-gradient SmIG film, and the strain-engineering is one of the possible approaches to create novel multi-functional materials.

Chaopeng Wei (Osaka University)

Improvement of Carrier Transport Properties in Multilayer Graphene with Turbostratic Stacking Structure

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Graphene is attracting people's attention with its extremely high carrier mobility, which results in the promising potential for device applications. However, the electrical transport properties of the monolayer graphene are degraded by such surrounding environments as charge impurity and surface roughness on a substrate due to the thickness of a single carbon atom sheet. In order to overcome the issue, the turbostratic multilayer graphene (TMG) was synthesized by graphene layer growth on the monolayer graphene template. Conductivity of the TMG shows higher values than that of the monolayer graphene, meaning that the carrier scattering due to the charge impurities on the substrate is efficiently suppressed by the screening effect of the multi-stacking. Furthermore, the temperature dependence of the sheet resistance in the TMG is closer to that of the sheet resistance in monolayer graphene. This indicates that the TMG with a relatively weak interlayer coupling forms the linear dispersion similar to monolayer graphene. The screening effect and pseudo-linear dispersion in the

TMG result in higher carrier mobility as a comparison with monolayer graphene. This result means that the synthesized TMG has the potential to become an effective material to produce the device application with high electrical performance.

Toru Tomimatsu (Tohoku University)

Scanning Gate Experiment of Filling factor-dependent Incompressible Phase in Quantum Hall System

The quantum Hall system (QHS) is characterized by the universal quantization of resistance under a strong magnetic field, where the localization of electronic states plays an important role. Scanning gate microscopy (SGM) is one of the powerful tools for probing microscopic structures in QHS due to its high spatial resolution. This technique allows us to approach the local electron scattering event by mapping the global resistance as a function of local potential perturbation. Here, we show the SGM imaging of incompressible (IC) phases in QHS by modifying the rate of electron tunneling through the IC phases under non-equilibrium conditions. We assess the filling factor dependence of SGM patterns to discuss its relation to the formation of IC phases in non-dissipative QHS regime.

Koji Ishibashi (RIKEN)

Physics and Devices with Nanoscale Hybrid Systems: Research Overview of Advanced Device Laboratory in RIKEN

Koji Ishibashi[1,2], Russell S. Deacon[1,2], Keiji Ono[1,2], Akira Hida[1], Tomohiro Yamaguchi[1], and Masashi Nantoh[1]

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We are interested in quantum devices to control and manipulate electrons, spins, photons, excitons and cooper pairs in hybrid quantum structures. Current projects are,

1) Nanofabrication of quantum structures based on the carbon nanotubes and atom manipulations (Hida, Yamaguchi and Nantoh)
2) High temperature spin qubits with Si nanoscale transistors (Ono)
3) Superconductor/topological insulator hybrid structures to study Andreev and Majorana states (Deacon)

A brief outline will be presented in our poster.

Alex Bogan (NRC)

Theory of Gate-Tunable Single-Hole EDSR in a Lateral GaAs/AlGaAs Double Quantum Dot

Aviv Padawer-Blatt[1], Marek Korkusinski[1], Jordan Ducatel[1], Motoi Takahashi[1,2], Sergei Studenikin[1], Guy Austing[1], Alex Bogan[1], Louis Gaudreau[1], Piotr Zawadzki[1], Yoshiro Hirayama[2], and Andy Sachrajda[1]

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We theoretically study the tunability of the single-hole effective g-factor corresponding to the spin energy gap in a GaAs/AlGaAs double quantum dot. A significant tuning over a small range of gate voltages is predicted. Also, tuning of the effective g-factor can be engineered by changing the magnetic field and the inter-dot coupling. The effective g-factor directly quantifying the Zeeman splitting energy is extracted from data by fitting the position of the electric dipole spin resonance (EDSR) signal as a function of dot detuning and microwave frequency at constant magnetic field. Furthermore, we are able to demonstrate that the effective g-factors for the two dots differ slightly in value by ~5%. The ability to simultaneously extract the spin-conserving, t_N, and spin-flipping, t_F, tunneling matrix elements from the characteristics of the EDSR signal enables us to map the behavior of t_N and t_F over a wide range of magnetic field for different inter-dot couplings. Our theory accurately reproduces key features of the experimental data.

Jason Phoenix (NRC)

Full Polarisation Control of Fibre-delivered Light in a Dilution Refrigerator

While quantum repeaters have often been imagined in an all-optical scheme involving Bell state measurements at a beam splitter, we propose a novel type of quantum repeater which combines the long-distance advantages of photonic qubits with the long memory and manipulation capabilities of spin qubits in semiconductor quantum dots. This ‘photon-to-spin’ quantum repeater would enable the heralded transfer of quantum information from a photonic qubit to a spin qubit, which could then be stored, manipulated and read out. Photonic qubits in this scheme could be encoded in the polarization state of photons, which would be transmitted to their destination via optical fibre. Standard fibres, however, have birefringent cores which alter the polarization state of the light they transmit and may even cause random variations in the polarization over time. As part of our attempt to create a photon-to-spin system, we have therefore developed a method of fully controlling the polarization of light sent through a fibre and have demonstrated our ability to deliver arbitrary polarization states to our dilution refrigerator, which operates at milli-kelvin temperatures. Monitoring the polarization over

time has revealed that our system is highly stable and can deliver high-fidelity polarization states to the fridge over a period of several days.

David Northeast (NRC)

Integrating Quantum Dot Nanowires with Integrated Photonic Circuits

Future quantum technologies such as quantum computing and encryption will benefit from efficient and on-demand sources of quantum states. Semiconductor quantum dots have proven to be excellent sources of both single photon and entangled pair quantum states. Controlled incorporation of previously characterised quantum dots into integrated photonic circuits can provide bright light sources for experiments in optical quantum computing and metrology. We report on our progress towards integrating InAsP quantum dots in InP nanowires with SiN ridge waveguide structures. Photoluminescence and second order correlation measurements are made before and after integration to compare the effects of transferring using a nano-manipulator probe system.

Patrick Laferriere (NRC)

Multiplexed Single Photon Source from Quantum Dots Embedded in Nanowires

Optical-based information technologies require efficient sources of single photons and entangled photon pairs at high emission rates. Quantum dots embedded in nanowire waveguides have demonstrated high purity single photon and high fidelity entangled photon pair generation. Ultimate repetition rates, however, are limited by transition lifetimes of ~1ns. The selective-area vapor-liquid-solid epitaxial growth process allows for the integration of multiple quantum dots in the same nanowire waveguide coupled to the same optical mode. In this study we demonstrate such a multi-dot system. In particular, we show bright single photon emission from five quantum dots embedded in a single nanowire.

Jacques Lefebvre (NRC)

High Purity Semiconducting Single-walled Carbon Nanotubes: A Key Material for Emerging Electronics

Carbon nanotubes of semiconductor type (sc-SWCNT) sit amongst the most promising nanomaterials for a new generation electronic devices. Numerous laboratory demonstrations reveal the potential of sc-SWCNTs for logic circuits, radio-frequency devices, radiation hard memories, and sensors of all types on conventional substrates or flexible and stretchable surfaces. Progress towards commercial applications is combined with challenges related with materials development and its characterization, fabrication methods together with device modeling. I will describe recent improvements in sc-SWCNT material's quality which are the foundation of application prototypes in both large area printable electronics and high density integrated circuits.

Paul Finnie (NRC)

Intensity and the Environment: Simultaneous Photoluminescence Emission and Phonon Scattering from Individual (*n*, *m*) Air Suspended Single Walled Carbon Nanotubes

Paul Finnie[1], Yuichiro Tanaka[2], and Yoshikazu Homma[2]

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Single walled carbon nanotubes (SWCNTs) are ideal one dimensional materials. The electronic and excitonic states of SWCNTs are strongly changed by molecular adsorbates from the surrounding atmosphere. Water-adsorbed SWCNTs have different excitation and vibrational spectra than desorbed SWCNTs. The intensity of Raman scattering (RS) and photoluminescence (PL) emission from semiconducting SWCNTs is changed by changes in molecular adsorbates on and in SWCNTs. Here we perform optical spectroscopic measurements on pillar suspended chemical vapor deposition (CVD) grown SWCNTs in a controlled atmosphere environment. We identify individual (9,8) and (12,1) SWCNTs and compare their adsorbed and outgased PL and RS spectra, measured simultaneously. We show that the RS and PL intensities are affected differently by molecular adsorption. We explore how this difference can be rationalized using simple models of the quantum mechanical matrix elements for RS and PL processes.

Khabat Heshami (NRC)

Coherent Storage Based on Dynamical Autler-Townes Splitting

Photonic quantum information technologies rely on quantum memory for long-lived storage and coherent manipulation of short pulses of non-classical light. The optical quantum memories explored over the past two decades are based on various coherent light–matter interaction schemes, but despite impressive progress, practical memories featuring efficient, broadband and long-lived operation remain elusive, due to the technical demands and inherent limitations of the established schemes. Here, we introduce a technique for high-speed quantum memory and manipulation that overcomes these obstacles. This scheme relies on dynamically controlled absorption of light via the 'Autler–Townes effect', which mediates reversible transfer between photonic coherence and the collective ground-state coherence of the storage medium. We experimentally demonstrate proof-of-concept

storage and signal processing capabilities of our protocol in a laser-cooled gas of rubidium atoms, including storage of nanoseconds-long single-photon-level laser pulses for up to a microsecond. This approach opens up new avenues in quantum optics, with immediate applications on atomic and solid-state platforms.

Philip Bustard (NRC)

THz-bandwidth All-optical Switching of Heralded Single Photons

Connor Kupchak, Jennifer Erskine, Duncan G. England, and Benjamin J. Sussman

NRC, Canada

The ability to switch single photons rapidly, without introducing quantum noise, is important for applications in quantum technologies and optical gating. We present an ultrafast Kerr-gate technique in optical fibre, which allows picosecond-duration single photons to be switched with efficiencies of up to 97%.

Yasser Saleem (University of Ottawa)

Oscillations of the Bandgap with Size in Armchair and Zigzag Graphene Quantum Dots

We determine here the evolution of the bandgap energy with size in graphene quantum dots (GQDs). We find oscillatory behavior of the bandgap and explain its origin in terms of armchair and zigzag edges. The electronic energy spectra of GQDs are computed using both the tight binding model and *ab initio* density functional methods. The results of the tight binding model are analyzed by dividing zigzag graphene quantum dots into concentric rings. For each ring, the energy spectra, the wave functions and the bandgap are obtained analytically. The effect of inter-ring tunneling on the energy gap is determined. The growth of zigzag terminated GQD into armchair GQD is shown to be associated with the addition of a one-dimensional Lieb lattice of carbon atoms with a shell of energy levels in the middle of the energy gap of the inner zigzag terminated GQD. This introduces a different structure of the energy levels at the bottom of the conduction and top of the valence band in zigzag and armchair GQD which manifests itself in the oscillation of the energy gap with increasing size. The evolution of the bandgap with the number of carbon atoms is compared with the notion of confined Dirac Fermions and tested against *ab initio* calculations of Kohn–Sham and TD-DFT energy gaps.

Wei Cui (University of Ottawa)

Grating-assisted Non-collinear THz Detection

Electro-optic sampling (EOS) is an optical detection technique widely implemented to do sensitive time-resolved terahertz (THz) measurements to monitor ultrafast dynamics in materials. This technique depends on numerous experimental parameters, including the properties of a nonlinear crystal, called the EOS crystal, used to detect THz waves via their nonlinear interaction with a near-infrared femtosecond pulse. The thickness of such an EOS crystal is linearly correlated with the THz detection efficiency, but it is also inversely proportional to the spectral detection range. Experimentalists usually use a 100 µm thick crystal, which is a compromise between good detection efficiency and sufficient spectral range. Here we demonstrated that a contact grating fabricated on the front surface of an EOS crystal can be used to change phase matching conditions and overcome the thickness limitation to achieve a broadband detection range. In our experiment, a contact grating is plasma-etched on the front surface of a 1 mm thick GaP crystal used as an EOS crystal. We compare this new geometry with a standard configuration and demonstrate a larger detection bandwidth, by a factor of two, in addition to an enhancement of the detection efficiency. Our work paves the way towards new THz detection devices enabling broadband and high-sensitivity THz detection for many applications such as molecular sensing, security scan, and pharmaceuticals quality control.

Samantha Scarfe (University of Ottawa)

Exploring Graphene in the THz Regime

Samantha Scarfe, Alexei Halpin, Justin Boddison-Chouinard, Jean-Michel Ménard, Adina Luican-Mayer

University of Ottawa, Canada

Two dimensional materials refer to a class of crystals that are atomically thin. Since the isolation of the first 2D material, graphene, the study of such low-dimensional systems has attracted widespread attention with the goals of advancing fundamental knowledge and of facilitating the development of next-generation optoelectronic technologies. Crucial to realizing translations to industrial applications is understanding light-matter interactions in 2D materials. In this work, we report on experimental progress in investigating optical properties and interactions in the 2D material graphene. In particular, we use terahertz time-domain spectroscopy to study free-carrier dynamics in graphene. We discuss light-matter interactions in graphene samples that are supported by substrates with distinct optical properties.

2D Materials Quantum Structures and their Electronic Properties

Ryan Plumadore, Justin Chouinard, Adina Luican-Mayer

University of Ottawa, Canada

We seek to uncover novel quantum phenomena at the nanoscale by constructing custom-made hetero-structure material systems by stacking atomically thin layers of van der Waals bonded materials. To explore such structures, we use Scanning Tunneling Microscopy (STM) and Spectroscopy (STS) as experimental techniques that can spatially resolve both the local electronic and structural properties of materials down to atomic scale. We characterize the morphology, crystal structure and local density of states for various 2D materials including their defects and proximity effects at their boundaries. In addition, we are further reducing the dimensions of the 2D materials to create electrostatically defined quantum structures with the goal of understanding and manipulating their electronic states.