Materials and Processes for Quantum Information Science Focus Topic

Room On Demand - Session QS-Contributed On Demand

Materials and Processes for Quantum Information Science Contributed On Demand Session

QS-Contributed On Demand-1 Power and Temperature Dependence of High Q Superconducting Resonators*, **Ashish Alexander**, C. Weddle, C. J. Richardson,* Laboratory for Physical Sciences, University of Maryland, College Park, MD

An integrated temperature and power dependent model of a resonator internal quality factor predicts the loss contribution from two-level systems and quasiparticles simultaneously in a superconducting resonator. At millikelvin temperatures, the sub-gap microwave photons due to resonator readout signal drive the quasiparticle number and phonon density far from the thermal equilibrium corresponding to the bath temperature.

Here we propose a two-temperature, power and temperature dependent model to evaluate resonator losses that define the driven quasiparticle density by a distinct effective temperature than the bath temperature. The contribution of the readout power for different power and temperature is also explored. Resonators fabricated from epitaxial molecular beam epitaxy grown aluminum on float-zone refined silicon are evaluated to have quality factors above 1M. These results are analyzed with the proposed model and the contribution of various loss mechanisms is explored.

QS-Contributed On Demand-4 A Density-Functional Theory Study of the Al/AlO_x/Al Tunnel Junction*, **Chang-Eun Kim**, K. Ray, V. Lordi,* Lawrence Livermore National Laboratory

The aluminum oxide tunnel junction is a key component of superconducting quantum devices. The quantum coherence time of the aluminum oxide tunnel junction has seen five orders of magnitude improvement over the last twenty years, however, it is still too short to realize a scalable quantum computer. We asked what may be still limiting its further improvement. We used ab-initio calculations to develop a realistic model of the tunnel junction and compared to experimental observations known to date. The ab-initio electronic structure result shows that under-coordinated Al ion forms conducting channel, effectively rendering the true thickness of the insulating part of tunnel junction significantly thinner than what may be measurable under electron microscopes. The computed properties of amorphous junction are compared to a series of ideal crystalline junction models with variable thickness, highlighting what would be possible if we had better control over the interface microstructure of the tunnel junctions. Electron tunneling of model junction is probed by solving Schrödinger equations (SE) using the potential obtained from ab-initio result, revealing channel formation and inhomogeneous tunneling transport that is correlated to the thickness distribution. The detailed theoretical description of the widely used aluminum oxide tunnel junction, along with the ab-initio-based systematic approach to predict the performance of tunnel junction, will further strengthen our understanding of this critical materials system that is indispensable to realize superconductor-based quantum computing devices. (Prepared by LLNL under Contract DE-AC52-07NA27344)

QS-Contributed On Demand-7 A Cold Atom Interferometry Sensor Platform Based on Diffractive Optics and Integrated Photonics*, J. Lee, R. Ding, H. McGuinness, J. Christensen, R. Rosenthal,* Sandia National Laboratories, USA*; G. Biedermann,* University of Oklahoma*; S. Kemme, D. Gillund, A. Ison, G. Hoth, B. Little, D. De Smet, C. Walker, A. Kodigala, M. Gehl, E. Skogen, M. Eichenfield, A. Lentine, **Peter Schwindt**,* Sandia National Laboratories, USA

Keywords—atom interferometer; cold atoms; magneto-optical trap; integrated photonics

We report the current progress in the development of a compact, deployable cold atom interferometry sensor platform, which could be generally applied to cold-atom gravimeters, accelerometers, gyroscopes, and clocks. Our effort targets the miniaturization of key components of the sensor platform and includes significant engineering efforts in the development of grating-mirror magneto-optical traps (G-MOTs), vibration-resistant structural design, custom titanium vacuum package with passive pumping, silicon-photonic multi-channel on-chip single sideband modulators, and a feedforward technique to extend the dynamic range of the atom interferometer inertial sensors.

We will highlight the development of a compact cold atom sensor head for measuring acceleration. Laser light is brought to the sensor head via optical fiber to perform the functions of laser cooling and trapping, the atom interferometer three pulse laser sequence, and atomic state sensitive detection. The atoms are contained in a custom Ti vacuum chamber (volume of ~90 cm^3), and we demonstrated a G-MOT where the grating is inside the chamber. Finally, we discuss the results of the atom interferometric acceleration measurements with sensor head.

We have also developed the Ti vacuum chamber that it is only passively pumped; no active pumping is required to maintain the vacuum for a cold-atom trapping. Excluding the grating and using sapphire windows, we have demonstrated a MOT in the passively pumped chamber for nearly one year with no apparent degradation in the vacuum quality.

For extreme system miniaturization, there are significant efforts in the development of heterogeneously integrated photonic integrated circuits (PICs) for the cold atom sensor using silicon photonics, amplification with III-V gain materials, and second harmonic generation. We demonstrated a four-channel optical single sideband (SSB) modulator on a silicon PIC at 1560 nm with a high extinction ratio and a high carrier-injection modulation, which can dynamically control laser frequencies and intensities during the experimental sequence of a cold atom interferometer. We envision a fully integrated system, in which 30 on-chip SSB modulators can be applied to a 6-degree-of-freedom (DOF) matterwave inertial measurement unit (IMU). Such a PIC-based system could shrink the size of the typical laser system for an atom interferometer from the size of an optical table to tens of cm^3.

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QS-Contributed On Demand-10 Observation of the Two-Photon Transition and Bloch-Siegert Shift of the Electrically Detected Magnetic Resonance Spectrum of Interface Defects in 4H-SiC Metal-Oxide-Semiconductor Field-Effect Transistors*, **James P. Ashton**, P. Lenahan,* The Pennsylvania State University

We report on the observation of multiple-photon transitions in the electrically detected magnetic resonance (EDMR) spectrum of interface defects at the 4H-SiC/SiO_2 interface. Multiple-photon transitions are important for quantum engineering as they have been linked to spin-based quantum computation for coherent manipulation of spin-qubits [1]. These observations are made possible with the utilization of a new EDMR scheme that incorporates an RF frequency sweep with the sample held at constant ultra-low magnetic field B_0 instead of a magnetic field sweep at constant RF frequency. The latter is the traditionally utilized EDMR scheme known as continuous wave (cw) EDMR. In the frequency-swept (fs) EDMR spectrum, the two-photon transition emerges because of ultra-strong coupling effects between the spin system and the driving field B_1 which provides the RF radiation. fsEDMR measurements are made in the sub-mT regime, where the Zeeman interaction is weak. Sub-mT EDMR measurements using a cwEDMR approach would be difficult as there is an oftentimes pervasive near-zero field magnetoresistance (NZFMR) effect that occurs in the sub-mT range [2]. Thus, the fsEDMR scheme is useful in such measurements since the NZFMR response can be eliminated by sweeping the RF frequency instead of sweeping the B_0 field. We utilize the fsEDMR scheme to validate that the transitions we observe are caused by multiple-photon transitions. In a fsEDMR spectrum, these transitions occur at integer divisions of the resonant frequency where in a magnetic field sweep scheme, the transitions occur at multiples of the resonant magnetic field. In this way, we rule out the possibility of harmonic detection of the resonant frequency caused by the apparatus. The two-photon line shape is analyzed as a function of the B_1/B_0 and it is found that spectral narrowing occurs as the ratio B_1/B_0 is increased. This observation is consistent with recent theoretical work provided by Mkhitaryan *et al.* [3]. The fsEDMR response is also slightly shifted off resonance due to the Bloch-Siegert shift [4]. We confirm the observation of the Bloch-Siegert shift via an extraction of B_1 and compare it to the value B_1 extracted using a sniffer test coil. Within experimental error, the values of B_1 extracted using both techniques are the same.

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QS-Contributed On Demand-13 Tunable Filters and Parametric Amplifiers from NbTiN Transmission Line Resonators*, **R.M. Lewis**, W. Kindel, L. Tracy, C. Harris, T. Lu, D. Luhman,* Sandia National Laboratories, USA

Quantum computing applications require that control signals be carefully filtered to minimize noise reaching the qubits. Quantum limited amplification of output signals is also used to reduce readout time. We present measurements of non-linear NbTiN resonators which are useful as both tunable bandpass filters and as parametric amplifiers.

Transmission line resonators make excellent bandpass filters. Here we demonstrate that such filters made from NbTiN are tunable by pumping a higher or lower harmonic of the resonator. We present data for a resonator with a full line width of ~ 150 kHz which is tunable by several MHz. We demonstrate a tuning of many linewidths and achieve an on/off ratio of ~ 30 dB. Further exploiting the nonlinearity of the NbTiN, this resonator exhibits gain of nearly 15 dB when pumped near the critical power at which bifurcation occurs.

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QS-Contributed On Demand-16 Nv Center Generation by Electron Beam Excited Plasma*, **Akihito Saeki**, A. Chikamoto,* Meijo University Graduate School, Japan*; P. Abraha,* Meijo University, Japan

The nitrogen-vacancy (NV) centers, point defects in diamond, have a property of photoluminescence useful for sensors in the field of quantum life science. The NV centers must be highly sensitive for use in the measurements of exothermic energy of proteins such as enzymes in cells. The sensitivity of NV centers can be increased through the near-surface formation of NV centers and increased number density. This research details the simultaneous formation of the vacancy and annealing processes performed by electron irradiation.

Currently, NV centers have been created by annealing after electron irradiation of 200 keV to 10 MeV onto the synthetic diamond surface. However, the energy of the irradiated electron is excessively large, which severely damages the surface.

In this research, experiments were conducted by irradiating the diamond surface with accelerated electrons using an electron beam excited plasma system. The system allows for controllable delivery of energy and density of the accelerated electrons. Here, NV centers are formed by electron irradiation while simultaneously annealing the diamond surface through electron collision that heats the surface. Photoluminescence using a Raman spectrometer confirms the formation of NV centers. The treated diamond showed peaks of NV center emission at around 637 nm. The peak intensities increased gradually with the applied energy and density of the irradiated beam. In this presentation, the gradual increase in the fluorescence intensity at 637 nm for the varying electron energy and electron density of the electron beam excited plasma will be shown.

QS-Contributed On Demand-19 Strain-Induced Interdiffusion in III-V Compound Semiconductors for Quantum Structure Formation*, **Leonid Miroshnik**,* Chemical & Biological Engineering, University of New Mexico*; B. Rummel,* Nanoscience & Microsystems Engineering, University of New Mexico*; A. Li,* Chemical & Biomolecular Engineering, University of Pennsylvania*; G. Balakrishnan,* Center for High Technology Materials, University of New Mexico*; T. Sinno,* Chemical & Biomolecular Engineering, University of Pennsylvania*; S. Han,* Nanoscience & Microsystems Engineering, University of New Mexico

We demonstrated stress-directed compositional patterning in compound semiconductors as a novel method to form quantum structures[1-4]. This is a significant departure from the traditional methods of forming quantum structures, such as strain-driven Stranski-Krastanov growth or solvothermal synthesis. In this work by applying a thermo-mechanical stress field, we are expanding the idea to III-V compound semiconductors, where InGaAs on GaAs is our model system. The approach allows for 3D quantum structures to be scalably manufactured. We characterized the atomic interdiffusion in the InGaAs/GaAs model system. Understanding the behavior of non-Fickian diffusion as a function of strain provides a pathway to design systems where patterned stress fields under thermally activated conditions can be used to produce 3D spatially ordered quantum structures. Previous studies provided a large uncertainty in calculated Arrhenius diffusion coefficients, and there is a disagreement on the effects of strain in diffusion.Measuring the interdiffusion parameter is extremely sensitive to the processing and characterization conditions. Molecular beam epitaxy (MBE) was used to grow high-quality quantum wells with well-defined concentration profiles. The structures were annealed in a rapid thermal annealer (RTA) and analyzed using Secondary Ion Mass Spectroscopy (SIMS). This characterization technique provides precise information on the composition on the angstrom scale. In this presentation, we show our processing, annealing and characterization technique provides a high accuracy repeatable compositional profile. In addition, we have developed a multiscale computational model that couples continuum methods with coarse-grained lattice kinetic Monte-Carlo to extract stress mediated diffusion parameters and to predict the time evolution of technologically relevant compositions.

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