PCSI
Room Ballroom South - Session PCSI-MoM2
Materials for QIS

Moderator: Edward Yu, The University of Texas at Austin

11:00am **PCSI-MoM2-31 UPGRADED: Er:Si and SiC on Insulator for Quantum Information Processing***, Sven Rogge,* University of New South Wales, Australia

Optically active spins in solid-state systems present significant potential for a range of quantum information science applications, including their use as entanglement distribution nodes within quantum networks, single-photon sources for linear optical quantum computing, and as platforms for cluster state quantum computation. Furthermore, the inherent optical connectivity of these systems enables the implementation of low-density parity check (LDPC) error correction codes. Among these platforms, erbium ions implanted in silicon and silicon carbide are particularly promising due to their superior optical and electron spin coherence characteristics, erbium's emission compatibility with the Telecom C band, and the advanced state of silicon nanofabrication technology. In this work, we report on erbium sites in silicon that simultaneously exhibit extended optical coherence and long electron spin lifetimes. Specifically, we observed spin coherence times of 1 ms in nuclear spin-free silicon crystals. The measured homogeneous linewidths were below 100 kHz, with inhomogeneous broadening approaching 100 MHz [1]. Spectral hole burning and optically detected magnetic resonance techniques were employed to examine both the homogeneous linewidth and spin coherence properties. The demonstration of long spin coherence times and narrow optical linewidths in multiple sites underscores the exceptional suitability of erbium in 28Si for future quantum information and communication technologies, including single-photon frequency multiplexing schemes. Further discussions address the integration of these systems into silicon-on-insulator nanophotonic devices as well as thin-film 4H-SiC-on-insulator (SiCOI) devices. In silicon carbide, we observed an inhomogeneous broadening of 6.22 GHz and homogeneous linewidths as narrow as 440 kHz from a weak ensemble of emitters [2]. Site-selective spectroscopy identified that Er ions primarily occupy two distinct lattice sites in 4H-SiCOI. Additionally, we characterized the optical lifetimes and magneto-optical properties of these narrowband transitions. Collectively, these findings position Er-doped SiCOI as a highly promising solid-state platform for integrated, on-chip quantum information processing applications.

[1] Berkman, I.R., Lyasota, A., de Boo, G.G. et al. Long optical and electron spin coherence times for erbium ions in silicon. npj Quantum Inf11, 66 (2025). https://doi.org/10.1038/s41534-025-01008-x

[2] Alexey Lyasota, Joshua Bader, Shao Qi Lim, Brett C. Johnson, Jeffrey McCallum4, Qing Li, Sven Rogge, Stefania Castelletto, in preparation

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11:20am **PCSI-MoM2-35 Engineering Telecom-Wavelength Quantum Dots via Epitaxial Growth on Inp and Gaas for Single-Photon Applications***, Jesus Marquez,* Sandia National Laboratories

This work explores two promising approaches for fabricating single-photon emitters operating at telecom wavelengths (1.3–1.55 μm), using epitaxially grown quantum dots (QDs). The first approach involves the growth of InAs nanostructures on InP substrates, producing a mix of quantum dots and dashes. On standard InP (100) substrates, growth proceeds via a modified Stranski–Krastanov (SK) mechanism, where a thick, planar wetting layer forms prior to 3D island nucleation. These elongated dashes, preferentially aligned along the (1-10) direction, exhibit limited three-dimensional confinement, behaving more like quantum wells. In contrast, growth on (311)B-oriented InP yields discrete QDs with strong single-dot emission characteristics.[1]

The second approach leverages the GaSb/GaAs material system to realize both coherently strained SK-mode QDs and strain-relaxed islands, the latter mediated by interfacial misfit dislocation arrays. Despite its promise, this system faces challenges due to likely type-II band alignment and the complexity introduced by GaSb/GaAs interdiffusion during capping.

Growth experiments are conducted using a solid-source VG V80 MBE reactor. InAs QDs are deposited on n-doped InP (001) and (311B) substrates with $In_{0.53}Ga_{0.47}As$ buffer layers, while GaSb QDs are grown on semi-insulating GaAs (001) with GaAs buffer layers. Substrate desorption, growth temperatures, and layer thicknesses are carefully optimized.

This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. DOE's National Nuclear Security Administration under contract DE-NA-0003525. The views expressed in the article do not necessarily represent the views of the U.S. DOE or the United States Government.

[1] N. A. Jahan et al., Temperature dependent carrier dynamics in telecommunication band InAs quantum dots and dashes grown on InP substrates, J. Appl. Phys. 113, 033506 (2013).

11:25am **PCSI-MoM2-36 Epitaxy Growth of InSb and InAs Quantum Nanostructures on GaSb Substrate by Droplet Epitaxy***, Gyoung Du Park, Jong Su KIM,* Department of Physics, Yeungnam University, Republic of Korea*; Jin Dong Song,* Korea Institute of Science and Technology, Republic of Korea*; Sang Jun Lee,* Korea Research Institute of Standards and Science, Republic of Korea

In epitaxial growth, two main methods have been employed to form quantum nanostructures (QNs) over the past three decades: the Stranski–Krastanov (S–K) mode and the droplet epitaxy (DE) method [1, 2]. Among them, DE offers the unique advantage of enabling the formation of QNs even under lattice-matched conditions, unlike the S–K mode [3]. This technique has been successfully applied not only to lattice-matched systems such as GaAs/AlGaAs but also to lattice-mismatched systems such as InAs/GaAs [2,3]. Recently, it has been reported that QNs can also be formed in the type-II band alignment system of InAs/GaSb, which is lattice-mismatched [4].

In this work, we fabricated InSb and InAs QNs, including quantum dots (QDs) and quantum rings (QRs), by DE using molecular beam epitaxy (MBE). Surface reconstructions during the DE process were monitored using reflection high-energy electron diffraction (RHEED). For the formation of InSb QNs on GaSb (100) substrates, a buffer layer was first grown, showing streaky (2×5) RHEED patterns at a substrate temperature (T_s) of 50 °C, indicating a relatively flat surface. Upon supplying 2 ML of indium, the RHEED patterns changed from streaky to spotty and arrowhead-like, suggesting the formation of nanostructures (Fig.1(a-d)). Scanning electron microscopy (SEM) images revealed rectangular nanostructures elongated along the [-110] direction (Fig.1(e)). These nanostructures are attributed to the formation of InSb resulting from the reaction between indium and residual Sb atoms on the (2×5) reconstructed surface during indium deposition. These results demonstrate that high-quality InSb/GaSb nanostructures can be successfully fabricated using the DE. For the formation of InAs QNs on GaSb surfaces, indium droplets were first formed on a modified GaSb surface and then crystallized under an As_2 beam equivalent pressure (BEP) of 1.5×10^{-5} Torr at a T_s of 300 °C. In addition, InAs QDs were formed at T_s below 100 °C. The effects of T_s and modified growth conditions on the QNs morphology will be discussed.

11:30am **PCSI-MoM2-37 Revisiting Surface Conditions of H/Si(111) after Wet-Chemical Treatment through Different SPM Modes***, Ayumi Takahashi, Az Zahrah Fitriana Syafira, Naoko Momono, Marimi Kuwano, Kouji Inagaki, Kenta Arima,* The University of Osaka, Japan

High-performance solution processing is essential for next-generation electronic and optical devices, and Scanning Probe Microscopy (SPM) enables atomic-scale evaluation. This report aims to characterize wet-treated Si(111) surfaces in detail using multiple SPM modes.

Si(111) surfaces were treated by anisotropic etching in NH_4F [1]. These surfaces were first imaged in air by conventional amplitude-modulated Atomic Force Microscopy (AFM). Figure 1(a) shows a familiar step/terrace structure. The same surface was then examined by noncontact AFM (nc-AFM) and Scanning Tunneling Microscopy (STM). The nc-AFM/STM hybrid system was operated at room temperature under ultrahigh-vacuum conditions of 10^{-8}–10^{-7} Pa. For nc-AFM, the oscillation amplitude and frequency shift were set to 1.0 nm and −1.0 Hz, respectively, and for STM, the sample bias and tunneling current were −2.0 V and 0.6 pA. It is evident that the nc-AFM image in Fig. 1(b) resolves smaller particles or adsorbates with much higher resolution than Fig. 1(a). More importantly, these small particles visible in Fig. 1(b) are absent in the STM image in Fig. 1(c). A subsequent nc-AFM scan of the same area after acquiring Fig. 1(c) reproduced the result in Fig. 1(b), confirming that Fig. 1(c) does not arise

from probe-induced manipulation of adsorbates but rather from the different imaging mechanisms of nc-AFM and STM.

The X-ray Photoelectron Spectroscopy (XPS) spectrum in Fig. 2, obtained with the same sample, reveals carbon and oxygen signals in addition to Si. This indicates that the small particles in the nc-AFM image in Fig. 1(b) likely correspond to organic contaminants or water molecules with low conductivity. Their probable origin is sample preparation in air, ranging from the NH_4F treatment itself to the subsequent transfer process. In contrast, the fine particles observed in the STM image in Fig. 1(c) are attributed to Si dissolved in NH_4F and redeposited on the surface. These results demonstrate that the combination of nc-AFM and STM provides complementary insights into the molecular-level distribution of adsorbates, which will be valuable for advancing solution-based processes such as wet cleaning.

11:35am **PCSI-MoM2-38 Characterizing Point Defect Damage from Proton Irradiation in Narrow Bandgap Materials**, ***Evan M. Anderson,*** Sandia National Laboratories*; Rigo A. Carrasco, Christopher P. Hains, Alexander T. Newell,* Air Force Research Laboratory*; Marcos Calva, Austin Shipley,* New Mexico State University*; Devika Mehta,* Sandia National Laboratories*; Preston T. Webster,* Air Force Research Laboratory*; Aaron J. Muhowski, Lilian K. Casias, John M. Cain, Victor J. Patel,* Sandia National Laboratories*; Boris Kiefer,* New Mexico State University*; Christian P. Morath,* Air Force Research Laboratory*; Eric A. Shaner, Peter A. Schultz,* Sandia National Laboratories

Narrow bandgap semiconductor heterostructures are used for a wide variety of applications, including infrared sensing in space. However, sensor performance can suffer in the space environment through the formation of point defects caused by ion irradiation. This degradation is often studied to derive an empirical damage factor characterizing the decline in performance as a function of dose for a given epitaxial detector stack. A key metric in evaluating these detector materials is the minority carrier lifetime, which directly corresponds to leakage current and detectivity. While this approach is crucial for evaluating detectors and predicting their useable service life, it does not identify the precise defect trap states that are created and decrease minority carrier lifetime. Thus, identifying the atomic scale defects and their energy levels that are present both from materials growth are critical for characterizing and improving the performance of infrared detectors.Identifying defects in narrow bandgap materials presents a distinct challenge: all defects are shallow and are difficult to resolve from band edges. Further, these defects are active even at cryogenic temperatures. Thus, we take a multifaceted approach combining theory and experiment, focusing on InAs as a model system to build a foundation for understanding more complex alloys and heterostructures. We use electronic device measurements including deep level transient spectroscopy, and material characterization such as time-resolved microwave reflectance and time-resolved photoluminescence to measure minority carrier lifetime, and compare these results to candidate point defects predicted by ab initio calculations. This approach allows us to resolve the ambiguities in experimental data that can only quantify defect activation energies without knowledge of their atomic structure, while sifting out the variety of defects that might be predicted to be stable but that do not correspond to experiments.SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

11:40am **PCSI-MoM2-39 High-Frequency Shunt Behavior in Granular Metals**, ***Matthew Landi,*** *Michael McGarry, Simeon Gilbert, Jacob Eisbrenner, Michael Siegal, Laura Biedermann,* Sandia National Laboratories, USA

Granular metals (GMs) are a class of disordered materials comprising metal nanoparticles (NPs) dispersed within an insulating matrix. As a result of theirnanostructure, GMs exhibit complementary resistive tunneling and capacitive charge transport properties. These parallel processes give GM's a high-pass filter like behavior[1], such that the conductivity displays a power-law behavior as a function of the drive frequency. Due to their high breakdown electric-field strength and high-pass nature, GMsmake for attractive shunt devices for high-power, high-frequency applications In this work, GMs are grown via radiofrequency co-sputtering using molybdenum (Mo)and silicon nitride (Si3N4) targets[2]. We show that the Mo NP size, density, and spacing is controllable via the growth conditions and post-growth annealing recipes (Fig. 1A).Manipulating the intercalation of the Mo NPs enables great control of the GM electrical properties. The effect of Mo metal fraction and annealing temperature on GM conductionis investigated via temperature-controlled impedance spectroscopy (Fig. 1B, C). Here, a universal power-law distribution in the conductivity is observed, characteristic ofmany disordered material systems [3,4]. These GMs exhibit conductivity swings on the order of sMHz/sDC of 106. Vertical shunt devices with 0.5 cm2 GM active area arefabricated on antimony-doped conductive silicon (N-type). These films shunt 25 Amps at 2.25 MV/cm (Fig. 1D). This systematic investigation and fabricationof functional GM films serves to bridge the gap between the processing, structure, and electrical properties of GMs and more generalized disordered systems.[1] H. Bakkali, M. Dominguez, X. Batlle and A. Labarta, Sci. Rep. 6, 29676 (2016)[2] M. McGarry, et al. J. Appl. Phys. 136, 055101 (2024)[3] A. Jonscher, Thin Solid Films 36 (1), 1-20 (1976)[4] L. Merle, A. Delpoux, A. Mlayah and J. Grisolia, J. Appl. Phys. 132 (1), 015107 (2022)

11:45am **PCSI-MoM2-40 Enhancement of Superconductivity in Cryogenically Grown Ultra Thin Al Films**, ***Teun van Schijndel,*** *Yu Wu, Wilson Yánez-Parreño, Tawshia Chowdhury, Julian Choi, Christopher Palmstrøm,* UC Santa Barbara

Superconductivity in thin films can deviate significantly from bulk behavior, especially as dimensionality and disorder come into play. This is particularly true for aluminum, where critical temperature (T_C) and film morphology are highly sensitive to thickness and growth conditions. Here, we present an *in-situ* scanning tunneling microscopy (STM) study, performed at 78 K, of Al thin films grown on atomically clean Si(111) substrates by molecular beam epitaxy at cryogenic temperatures down to 6 K. The morphology is characterized across a wide range of coverages, from sub-monolayer up to 20 monolayers (ML). Cryogenic growth results in oriented hexagonal islands that begin to coalesce into a continuous film around 5 ML, with a typical roughness of a few monolayers. This roughness is constant up to 20 ML. Upon annealing to room temperature, the surface becomes nearly atomically smooth, though grain boundaries remain visible in STM. In contrast, room temperature growth produces significantly rougher films with large, disconnected islands of varying shape and orientation. We also investigated the superconducting properties of cryogenically grown films after exposure to atmospheric conditions, as required for ex-situ transport measurements. To stabilize the films, we used different post-growth treatments, including low temperature capping, cold oxidation, and room temperature oxidation. The films show critical temperatures approaching 3 K and critical fields above 5 T, which are significantly above the bulk value of 1.2 K.

11:50am **PCSI-MoM2-41 Plasma-Induced Surface Modification of Indium for Improved Bonding**, ***Kristen Steffens,*** *Sujitra Pookpanratana, Junyeob Song, Marcelo Davanco, Tammy Lucas, John Biesecker, Daniel Schmidt,* National Institute of Standards and Technology (NIST)

Bonding plays an important role in advanced microelectronics integration and packaging by bringing together components and devices produced separately.Surface-pretreatments on bonding materials have been consistently found to be crucial to achieving a high-quality bond, despite incomplete understanding of why certain treatments have greater success than others.Our project aims to improve understanding of some of these bonding pre-treatment effects to provide information to enable more efficient development of bonding protocols.

Indium is a critical material for conductive contacts in the fabrication of cryogenic low-temperature electronics and optical detectors for infrared and microwave applications, because In is a superconducting material which retains its ductility and adhesion properties during thermal cycling.Certain pre-bond plasma treatments increase the success of In-In bond adhesion.We have observed that plasma chemistries such as H_2/He, which do not include N_2 as a plasma gas, promote more successful In-In bonding.To understand why, we investigate the effects of atmospheric plasma exposure on In surfaces for several plasma chemistries including $He/H_2/N_2$, He/H_2 and He/N_2.X-ray photoelectron spectroscopy (XPS) and ultraviolet photoelectron spectroscopy (UPS) are used to characterize In surfaces prior to and after ambient pressure plasma treatment.All plasma treatments decreased the amount of carbon and increased the amount of In-oxide present when compared to an untreated film.N_2-containing plasmas resulted in the appearance of an additional high binding energy peak in the N 1s XPS spectrum.We postulate that this may be due to nitrate species formed on the In native oxide surface. Additional experiments are planned to assess the plausibility of this explanation.In foil was measured prior to and after Ar sputter cleaning for comparison to treated samples.

UPS measurements showed that all plasma chemistry treatments lowered the work function compared to the non-treated control.Greater spatial variation in work function was observed for chemistries with high N_2 versus those with little to no N_2.This finding possibly correlates with poorer bonding for N_2 containing plasmas.

11:55am **PCSI-MoM2-42 Imaging Field-Induced Metastable DX Center Formation in Near-Surface Region of *n*-type InAs by Scanning Tunneling Microscopy**, ***Kiyoshi Kanisawa***, Basic Research Laboratories, NTT, Inc., Japan

Control of semiconductor nanostructures becomes more important to achieve the further device miniaturization [1]. Especially, critical significance of charge and spin states becomes evident at atomic-scale precision [2]. Donor-related defect-complex, DX center, in III-V semiconductors is one of lattice defects. Charge states of this defect as well as the bistable switching on the long lifetime were studied for Si-doped *n*-GaAs [3]. In the case of InAs, static transition of acceptor charge states in Mn-doped *p*-InAs is only reported [4].

In this presentation, the DX center in the near-surface region of *n*-type InAs is demonstrated as a quasi-equilibrated metastable state by using the scanning tunneling microscope (STM). After obtaining the cleaved (110) surface of sulfur-doped *n*-InAs (N_S : 4 × 10^{17} cm^{-3}) in ultra-high vacuum, the sample was transferred to the STM stage kept at 77 K. First, it is found that donor charge states showed striking dependence on the STM tip at the same scan condition. This suggests that the degree of the tip-induced band bending plays the crucial role of the charge state determination. Second, it is found that electrons tunneled from the STM tip cause an impact-ionization by the tip-induced electric field acceleration at the sample bias voltage $V > 0$ (tip is neutral). When the electric field exceeds the Avalanche breakdown field (～8 × 10^{-5} V/nm) [5], such hot electrons cause the impact-ionization. Generated secondary electrons are spread by radially diverging tip-induced field. At this non-equilibrium situation, the electron quasi-Fermi level becomes locally dominant to charge states of donor-related defects [6] beneath the tip. This quasi-Fermi level effect is detected as the bias voltage dependent topography. No evident bistable switching among charge states is imaged. These suggest that the imaged DX center in the *n*-InAs is a quasi-equilibrated metastable state available at the non-equilibrium condition and the lifetime of the captured electron by such DX center is expected much shorter than that of *n*-GaAs.

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