Session J Abstracts

Structure and composition optimization of $FeWO_4$ photoanodes enhance photoresponse in PLD grown thin films

Ann E. Alekseenko
Mentors: Harry A. Atwater, Jr., and John Hylak

$FeWO_4$ holds promise as a photoanode based on its 1.9 eV band gap, n-type electrical conductivity, and Pourbaix stability in bulk aqueous electrolyte. We investigate the relationships between crystal structure, composition, and opto-electronic properties of epitaxial $FeWO_4$ (100) thin films grown on sapphire (001) using pulsed laser deposition (PLD). Additionally, we investigate photoanode device performance metrics using $FeWO_4$(100)/Pt(111) PLD grown heterostructures. We utilize PLD process variables, namely substrate temperatures from 500-800°C and target compositions of Fe^{3+} containing Fe_2O_3/WO_3 and Fe^{2+} containing $FeWO_4$, to induce structural and compositional variations in $FeWO_4$ thin films. $\omega/2\theta$ scans confirm $FeWO_4$ (100) out-of-plane crystal orientation, while Φ and ω scans characterize the in-plane epitaxial alignment and coherence, respectively. Additional structural characteristics are analyzed from transmission electron microscopy (TEM) of the $FeWO_4$ thin films on sapphire, and X-ray Photoelectron Spectroscopy spectra assess Fe^{2+}:Fe^{3+} ion ratios. Preliminary chopped light linear sweep voltammetry and chronoamperometric analysis measurements performed on $FeWO_4$(100)/Pt(111) heterostructures with 100 mW/cm2 sunlight intensity in a SO_3 bulk liquid electrolyte (pH=9) show photocurrent and stability characteristics comparable to published $FeWO_4$ work. Successful synthesis of $FeWO_4$(100)/Pt(111) photoanodes from PLD is a major step towards understanding the compositional aspects of metal oxide absorber layers underpinning ideal photoanode performance.

Low-cost multilayer antireflective coating for extra-atmospheric photovoltaics

Carlton G. Passley
Mentors: Harry A. Atwater, Jr., and Susana Torres-Londono

The efficiency of photovoltaic (PV) solar cells, particularly for space applications, is fundamentally limited by light lost due to surface reflection. This project aims to develop a low-cost, multilayer antireflective coating (ARC) optimized for Gallium Arsenide (GaAs) PVs used in the Space Solar Power Project (SSPP), where stringent mass, cost, and durability requirements must be met for extra-atmospheric operation. The approach leverages "wet chemical" spin-coating methods, focusing on sol-gel-derived SiO_2 and TiO_2 layers to reduce reflectance across the 400–900 nm spectrum to below 5%, with a special emphasis on maximizing transmission in the 700–900 nm range crucial for our GaAs cells. The project systematically evaluated nanoparticle and sol-gel methods, iteratively refining synthesis and deposition parameters based on transfer matrix method (TMM) simulations, surface microscopy, and optical measurements. Early experiments highlighted challenges with nanoparticle adhesion and sol-gel film uniformity, leading to improvements in precursor chemistry, spin-coating, and annealing processes. Theoretical modeling and preliminary experimental results indicate that a properly optimized dual-layer SiO_2/TiO_2 ARC can outperform more complex multilayer designs, offering an effective and scalable path to meet SSPP requirements. Future work will focus on achieving reproducible sol-gel recipes and validating performance gains directly on functional PV devices.

Mode-resolved study of electron-phonon interactions in monolayer and bilayer MoS_2

Siam Sarower
Mentors: Marco Bernardi and David Abramovitch

MoS_2 is a two-dimensional (2D) direct band gap semi-conductor from the transition metal dichalcogenide (TMD) family, and it can be arranged into a bilayer to provide a transition to an indirect band gap semi-conductor. Recently, we found that electron-phonon (e-ph) interactions in MoS_2 at the valence band maxima is primarily mediated by longitudinal-acoustic (LA) and z-optical (ZO) modes for intervalley scattering, while intravalley scattering is dominated only by the ZO mode. However, a

detailed understanding of which phonon modes control electron-phonon scattering and pairing interactions is lacking for both monolayer and bilayer structures. This motivated us to explore the role of mode-dependent e-ph interactions on scattering and coupling strengths in monolayer and bilayer MoS_2 via first-principles calculations. Here, we investigate which phonon modes contribute significantly to intra and intervalley coupling at the valence and conduction band extrema. Moreover, we provide what phonon modes contribute to intra and interlayer coupling in AA and AB stacked bilayer MoS_2.

Designing CMOS fabricated microrobotic actuators with origami folding motion
Henrik N. Barck
Mentors: Chiara Daraio and Xiaoxiao Xiong

The introduction of CMOS fabrication to the field of microscopic robots brings mass scalability and integration with a variety of sensor and actuator technologies. Combining integrated circuits with CMOS fabricated actuators can lead to new biomedical and environmental applications, but most work is still in a proof of concept stage. Surface electrochemical actuators have demonstrated high curvature at low voltages and shape morphing capability, but has only been used for locomotion with microrobotic chips. We introduce a simulation method to test origami patterns of actuators that morph between planar and 3D shapes. These simulations motivate designs to be fabricated and tested experimentally. We began the fabrication process of lattice designs, but didn’t finish due to time constraints. This work pushes the integration of CMOS circuits and microactuators along the path to addressing biomedical and environmental challenges like microsurgery and pollutant collection.

Mechanical characterization and eutectic impact on additively manufactured ceramic composites for space exploration
Fernando Milach Teixeira
Mentors: Katherine T. Faber and Zachary C. Ahmad

Space exploration poses many challenges for material performance. Materials expected to endure these challenges require extreme thermal, radiation, and corrosion resistance. A novel, hybrid process combines laser-powder bed fusion and reaction bonding manufacturing techniques, creating advanced ceramic composites comprised of alumina and yttria-stabilized zirconia. Mechanical characteristics of the material produced via this route are unknown, particularly with the addition of an indium-gallium eutectic to the material during the sintering process to enhance the wetting of alumina and reduce porosity. I aim to characterize the mechanical properties of the composite and the impact of the eutectic on such properties: specifically, the material’s flexure strength, hardness, and elastic moduli using testing methods such as equibiaxial flexure, Vickers hardness, and impulse excitation of vibration testing in conjunction with eutectic diffusion experiments. Initial eutectic diffusion experiments show no gravitational influence on the diffusion of the eutectic but reveal unexpected cracking, linked to inconsistencies with the laser-powder bed fusion process. Preliminary mechanical tests indicate a low flexural strength due to porosity, cracking, and challenges with sample preparation of the material. Despite complications, this research lays the groundwork for optimizing ceramic composites manufactured for extreme environments and drives innovation for novel fabrication strategies for aerospace-grade materials.

Design of an electromagnetic cat qubit and development of Josephson junction fabrication process
Parthorn Ammawat
Mentors: Oskar J. Painter and Piero Chiappina

Superconducting quantum processors are inherently susceptible to decoherence due to unavoidable interactions with their environment, leading to frequent bit-flip and phase-flip errors. While the theory of quantum error correction (QEC) and its fault-tolerant implementation addresses this issue, the required hardware overhead remains challenging. Cat qubits, which encode quantum information in superpositions of coherent states in a resonator, have recently emerged as a promising alternative as they allow for exponential suppression of bit-flips, significantly reducing the need for active correction. In this work, we design and fabricate an electromagnetic-based cat qubit with a modified architecture to further reduce the hardware overhead and to establish the group’s cat qubit measurement capabilities. This will also serve as a first step toward realizing a hybrid acoustic-electrical cat qubit incorporating a mechanical quantum memory, which offers significantly longer lifetimes and smaller footprints and thus presents a promising new direction for building scalable and robust quantum processors. We also developed a new Josephson junction fabrication process to enhance the coherence and overall performance of future superconducting devices in the group.

Long-range simultaneous two-qubit gates using dual-rail transmons with in situ erasure detection
Alan Zhu
Mentors: Oskar J. Painter and Gihwan Kim

Current super-conducting qubit implementations typically struggle to perform long-range two-qubit gates, instead necessitating chains of nearest-neighbor interactions. This restriction has prevented the use of more efficient quantum error correction codes requiring long-range interactions. To address this, we present a novel platform built on dual-rail transmons coupled to a long-range metamaterial bus. Utilizing cross-cross resonance interactions and multiple modes of the bus, long-range Controlled-Z (CZ) gates can be simultaneously applied to pairs of qubits with minimal leakage into non-participating qubits. Moreover, the dual-rail allows for in situ erasure detection with ancillary qubits, which increases post-selected fidelities and can further improve the efficiency of quantum error correction codes. To quantitively characterize our device's performance, we will perform two-qubit Clifford randomized benchmarking of the CZ gate. Thus far, we have simulated the performance of randomized benchmarking with our native gate set. However, further work is required to experimentally realize and characterize these gates on the device.

Study of erbium doping in germano-silicate photonic integrated circuits
Avani Ranka
Mentors: Kerry J. Vahala and Haojing Chen

Germano-silicate, a mixture of silica (SiO_2) and germania (GeO_2), is a promising substrate for the fabrication of ultra-low-loss optical circuits known as photonic integrated circuits (PICs) due to its ultra-low material loss window extending from the low-visible to near infrared bands (400 nm-2000 nm). The material's ability to host erbium ions, which generate optical gain in the 1550 nm telecommunications band, with excited-state lifetimes consistent with erbium-doped optical fibers makes it a favorable platform for erbium-doped optical devices. These devices have applications ranging from wavelength-division multiplexing (WDM) in data centers to high pulse power mode-locked lasers and frequency combs. We present erbium-doped optical resonators and spiral amplifiers in a novel germano-silicate platform designed to recreate the response of erbium-doped fiber amplifiers (EDFAs) of fiber optic technology on a chip-based scale.

Probing spin-orbit coupling in bilayer graphene via symmetric proximity coupling from WS_2 encapsulation
Matthew J. Cantor
Mentors: Stevan Nadj-Perge, Ankan Mukherjee, Nastasija Conic, and Siu Chi Wang

Two-dimensional van der Waals heterostructures provide a highly tunable platform for investigating novel quantum phenomena, as charge carriers are confined to atomically thin planes and interlayer coupling can be controlled. The studied device architecture sandwiches bilayer graphene (BLG) between two monolayer WS_2—a transition metal dichalcogenide (TMD)—which allows dual-side proximity coupling. Previous studies have shown that a single WS_2 device can induce strong Ising spin-orbit coupling in BLG, lifting spin degeneracies and generating nontrivial Berry curvature. A consequence of this Berry curvature is a nontrivial Chern number, enabling topological phenomena such as the anomalous Hall effect, fractional quantum Hall states, and fractional Chern insulating states that have anyonic excitations.

Low-temperature magnetotransport measurements are conducted to map Landau fan diagrams and identify signatures of symmetry-broken quantum Hall states and gate-tunable topological insulators with chiral edge states. Dual graphite gates enable independent tuning of carrier density and displacement field, allowing access to spin-polarized and valley-polarized electronic states in BLG. This dual WS_2 device provides a controlled system to study spin-orbit induced topological phenomena in BLG, giving a path to investigate exotic quantum Hall physics, including fractional Chern insulating behavior and the emergence of anyonic quasiparticles with Abelian statistics.

Fabrication of helical trilayer graphene, a two-dimensional material with exotic electronic and topological properties

Jamie Talmor
Mentor: Stevan Nadj-Perge

Helical trilayer graphene (HTG) is a two-dimensional material formed by stacking three layers of graphene, with a twist angle between each layer. The rotational misalignment between layers results in moiré patterns; with lattice relaxation, the moiré patterns form a supermoiré lattice and intrinsically break C_{2Z} symmetry at the moiré scale. L. Xia *et al*. showed that, at a magic angle of 1.8°, HTG forms topological flat bands, leading to exotic electronic and topological properties such as the anomalous Hall effect and correlated states at multiple integer and fractional fillings. This makes HTG a promising platform in the study of strongly correlated electronic systems in quantum materials. Here, we demonstrate the experimental realization of HTG devices. Graphite is exfoliated to obtain atomically thin graphene flakes, which are stacked using a stacking stage to form HTG. Additional graphite flakes and hexagonal boron nitride layers form the bottom gate, which dopes electrons and induces a displacement field into the device. Future work will use scanning tunneling microscopy to directly image the supermoiré lattice and measure the density of states in HTG.