Session J Abstracts

Cryogenic Packaging for Transmon Qubits: Sample Holder and PCB Design
Ali Ahmad
Mentors: Mohammad Mirhosseini, Parth Shah, and Chaitali Joshi

Superconducting qubits provide a scalable framework for quantum computing and a testbed investigating many-body physics. For experiments involving multiple qubits, it is essential to have a means of delivering and reading classical control signals from an on-chip device, while maintaining a clean, low-loss electromagnetic environment. In practice, this is achieved by designing a metal packaging entailing the measurement chip and a printed circuit board (PCB) that includes microwave waveguides. This project aims to design a packaging capable of accommodating the control signals for five qubits, for future experiments in Mirhosseini’s lab. To do this, we initially model the existing packaging in the lab using electromagnetic simulation tools (COMSOL) to map out any possible spurious box modes near the superconducting qubits’ operational frequency. The packaging is subsequently modified using Pogo pins, which are used to ensure adequate grounding of the PCB and adjust the boundary conditions to increase the frequencies of the spurious modes well above the measurement operating range (4-8 GHz). In the second part of this project, we design a new PCB to support a larger number of control and readout lines. To do this, we employ KiCAD to substitute coplanar waveguides (CPWs) with buried striplines, a variant that effectively minimize crosstalk and provides a more compact footprint. Furthermore, we redesign the packaging to accommodate the new PCB and cable connectors, and the Pogo pins. Future work in the lab will focus on the fabrication and experimental validation of the designed packaging.

Evaluation of the Mechanical Properties and Behaviors of Interlocked Knots
Payal Patel
Mentors: Chiara Daraio and Wenjie Zhou

Architected materials are materials with repeating geometries, sometimes consisting of periodic arrangements of unit cells. Introducing unit cells in structured materials arms researchers with new variables to modify, allowing for the creation of new mechanical, material properties. Most modern research concerning architected materials considers the evaluation of continuous structures or “strut-based lattices,” where unit cells are placed adjacent to each other as fashioned by the traditional beam-and-junction model. While these structures typically have high stiffness and strength-to-weight ratios, this of constrained kinematics, these structures often fail catastrophically due to the accumulation of stress at their junctions. Here we propose an interlocking hierarchical structure that is formed by periodically linking prime knots. Interlocking knots eliminates the presence of conventional vertices while also permitting for unit cell manipulation. Due to the novelty of this type of structure, the goal of this project was to mechanically characterize various knot-based structures to attempt to understand how the knots can influence their behaviors and properties. Included in our methods were tensile and compressive tests on interlocking chain particles, cyclic shear tests on cubic specimens, and oscillatory amplitude sweeps on cylindrical specimens. The resulting data illuminates the complex behaviors displayed by knot-based structures. Particularly, they display tunable mechanical properties based on the direction and magnitude of forces applied and the presence of both liquid-like and solid-like behaviors simultaneously, offering profitable applications in soft robotics and energy-absorbing structures.

Design and Characterization of Citrus Peel Bioinspired Composites for Enhanced Energy Absorption
Kyle Chen
Mentors: Chiara Daraio, Chelsea Fox, and Tommaso Magrini

Our project centers on designing novel synthetic composite materials inspired by citrus fruit peels. Composite materials are made up of different components that combine to yield distinct characteristics from the original constituents. These materials offer many applications due to their unique attributes of high strength-to-weight ratios, cost-effectiveness, and the ability to be shaped. Nevertheless, their applications are hindered by limited energy absorption and poor fracture toughness. To overcome these limitations, we turn to bioinspiration from nature. Through evolution, citrus fruit peels protect the fruit even after falling from great heights off a tree, showing incredible energy absorption. In this project, we create tile features that mimic the peel material structures and utilize them to build new designs using our virtual growth program. Upon 3D printing the designs as polymer composites, we conduct quasistatic compression and tensile tests on the samples to measure the material's strength. We then perform dynamic testing by dropping masses onto the samples to assess their energy absorption. During these tests, we gather images of the deformation process for digital image correlation analysis. Citrus peel bioinspired composites could have the potential to represent a significant advancement in the development of enhanced composite material energy absorption.
Subham Sahoo  
Mentor: Axel Scherer

The future of powering households lies in moving away from centralized power plants and moving towards distributed power grids. The main challenge with a distributed power grid system is devising a system that allows each household to know how much power they’re consuming at any point during the day. Currently, this is done by paying an electrician thousands of dollars for hours of labor and installation of very intrusive current measuring tools (oftentimes cutting into the wires themselves). It’s also quite difficult to get a reading out on the instruments. As such, we have utilized the topology of power carrying multi-core wires and emergent properties of phase differences between different currents to non-intrusively measure the current going through the wire. Since we want multiple sensors around the house for accurate readings and want it all to read out to some central display on the user’s phone or a website, all the sensors need to be able to communicate with one another on a network. If the sensors are networked, we need to ensure that it consumes very little power (longevity of product) and that all the sensors are on the same clock at the current measurement is time dependent. The results and conclusions we’ve come to is that a network like this is feasible, but we just need to make it functional for all kinds of wire topologies.

Mapping Local Reaction Dynamics in CO₂ Reduction Gas Diffusion Electrodes via Laser Scanning Confocal Microscopy
Cristian Reynaga Gonzalez  
Mentors: Harry Atwater and Annette Boehme

Electrochemical reduction of carbon dioxide (CO₂) with gas diffusion electrodes (GDEs) has emerged as a promising approach towards generating sustainable value-added chemicals and fuels. Carbon monoxide (CO) is one prominent CO₂ reduction product and is particularly important because it is used as a feedstock for many key chemical processes. Understanding local reaction dynamics inside operating GDEs is crucial for optimizing the CO₂ conversion process. Our research goal is to map the local CO concentration around operating CO₂ reduction GDEs. To this end, we measure the fluorescent signal emitted by a CO-detecting dye, NCCA, via laser scanning confocal microscopy (LSCM). Initial dye calibration procedures utilized a CO-releasing molecule, CORM-3, but the inconsistent release of CO prompted a shift to gaseous CO. Utilizing LSCM we examined NCCA’s behavior under operating CO₂ reduction conditions with different catalysts such as gold, silver, and copper. These experiments revealed a persistent dye reduction and hence, change in fluorescent signal, at the catalyst surface. To overcome this challenge and enable the imaging of the local CO concentration, we deposited a semi-permeable Nafion layer on the catalyst to prevent premature dye reduction. Despite these efforts, initial results suggest that dye reduction persists, indicating the need to investigate different additive materials, layer thicknesses or appropriate potential windows. Our findings mark significant progress in understanding the dye’s behavior around operating CO₂ reduction cathodes and underscore the need for further investigations. The ultimate goal is to establish a consistent and reliable way to measure the local CO concentration around operating gold and copper CO₂ reduction GDEs.

Characterizing the Energy Release Rate of Bi-material Interfaces Present in Nanoarchitected Composites
Belle Chen  
Mentors: Julia Greer and Kevin Nakahara

The Greer Group has previously utilized holographic lithography to prepare nanoarchitected materials at the macroscale. These materials possess extraordinary properties and are commonly bolstered with epoxy, creating a composite material. To better understand and model this composite system, a study of the adhesive strength between the two components is necessary. Oxygen plasma treatment is known to affect the adhesive strength of the system through surface functionalization and roughening. ASTM-compliant mode 1 fracture samples were plasma treated and assembled. These samples were then fractured with a dynamic mechanical analyzer and filmed. The load/displacement data and video recording were used to calculate an energy release rate, which describes the adhesion, for stick and slip regimes. An analytic estimate of the energy release rate was also calculated with a J-integral. These energy release rates will play an integral role in capturing the true performance of a computationally modeled the nanoarchitected composite matrix.

MagnetoFilter: Manufacturing Magnetic Nanoparticle Capture Devices via Hydrogel Infusion Additive Manufacturing (HIAM)
Faiza Shabibi  
Mentors: Julia Greer and Sammy Shaker

A non-surgical approach to advanced liver cancer treatment, transcatheter arterial chemoembolization (TACE), utilizes chemotherapeutics with significant off-target adverse events. Chemotherapeutic capture could mitigate this risk; however, currently proposed high surface area-functionalized capture filters can induce blood flow stagnation. Functionalized magnetic nanoparticles could provide improved capture of therapeutics, but require architected
magnetic lattices to avoid the same stagnation issue that is often difficult to manufacture with traditional metal manufacturing techniques. A novel synthetic method, hydrogel infusion additive manufacturing (HIAM), allows for the creation of intricate 3D structures using magnetic metal alloys without the limitations of traditional manufacturing methods. We explored the synthesis of magnetic Fe-Co alloys of a range of compositions via HIAM for potential use as capture filters. The synthetic process was characterized using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Powder X-ray diffraction (pXRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) were used to analyze the composition and structure of the intermediate metal oxides and metals, and the magnetic properties of the samples were determined via vibrating sample magnetometer. These values were compared with respect to composition and the Fe-Co phase diagram and represented a further extension of the HIAM method to magnetic alloys.

**Designing Reconfigurable Architected Materials for Thermal Applications: A Numerical Study**

Alemayouh Snyder  
*Mentor: Julia R. Greer and Cyrus J.B.M. Fiori*

Reconfigurable materials allow for the rapid change of material properties, which can have exciting applications in emergency cooling technologies. By breaking lattice connections, an architected material could be transformed from a conductor to an insulator. We use the pore network modelling approach to examine the transient and steady state changes in temperature and conductance while the connectivity of the architected material changes during fracture. Multiple simulations were run with different crack paths and crack propagation rates. Pillar defects were designed to best guide fracture through the lattice while maintaining a similar thermal response to a lattice without defect pillars. Four defect geometries were modeled and simulated to determine the effective diffusivity, then the lattice was simulated with these specific defect pillars. Simulations show that small edge-notch defects result in the smallest change in the temperature profile. After fracture, a large temperature jump is observed at and around the crack. When compared to a crack perpendicular to the initial temperature gradient caused by the boundary conditions, cracks that are diagonal or have sections both perpendicular and parallel to the gradient disrupt the temperature profile more. This makes these configurations more effective for manipulating lattice thermal conductivity.

**Optical Parametric Amplifiers on Lithium Niobate for Single Photon Detection**

Eleanor Kim  
*Mentors: Alireza Marandi, Elina Sendonaris, and James Williams*

Photonic quantum systems often require the detection of a single photon. Superconducting nanowire single-photon detectors (SNSPDs) are the current state-of-the-art device being used for this process. However, SNSPDs lack bandwidth and require time for the current in the nanowire to reset. Recent developments in on-chip optical parametric amplification (OPA) have made OPA devices a promising possibility for single photon detection. By amplifying single photons with sufficient gain, the resulting photocurrent can be read out on a fast photodetector to infer the presence of a single photon. Here, we present a parametric amplifier capable of distinguishing single photons from a vacuum state.

**Optimize Burst Wave Lithotripsy: MFC and Strain Energy**

Xuezhen Li  
*Mentors: Tim Colonius, Jean Sebastien Spratt, and Haeyoung (Chloe) Choi*

Kidney stones affect a significant proportion of the American population and pose a heavy burden to the healthcare system, necessitating effective and safe treatment methods. Shock wave lithotripsy (SWL) is a commonly used non-invasive method, which lowers the risk of wound infection but is plagued by a high retreatment rate. The single-cycle high-amplitude shock wave also generates cavitation bubbles which collapse violently and may injure the nearby tissues. Therefore, researchers are investigating burst wave lithotripsy, which uses low-amplitude, multi-cycle, sinusoidal ultrasound waves. BWL limits the growth of cavitation bubbles and provides more flexibility for urologists to control the parameters. Although there have been clinical trials, the optimization of BWL is still not clear. While it is difficult to conduct experiments, Multi-component Flow Code (MFC), a high-performance software, can numerically analyze BWL. This research aims to use strain energy to predict the fragmentation of stones and find the optimized case with MFC.