Cornell Quantum Day (July 17, 2023)

Book of Abstracts

Speaker: Michael Fanto
Affiliation: USAF/Air Force Research Laboratory
Title: Foundry-scale Quantum Photonic Integrated Circuits (QPICs) for the Heterogeneous Integration of Qubit Technologies
Abstract: Integrated photonics has grown in the last decade to fill the market with classical devices that offer tremendous SWaP benefits over conventional bulk optics and fiber components. For quantum systems the device losses were still too large to allow for large system scaling as well as too narrow a transparency window to cover all the qubit technologies. Over the last couple years, both industry and government laboratories have worked closely with commercial institutions to address both issues by reducing the waveguide losses, developing low-loss components, and initiating the process to include ultrawide-bandgap photonic materials into the fabrication process. These research areas, the results, and the next steps forward for integrating other materials and qubit systems into the platform will be the subject of my talk.

Speaker: Yifei Geng
Advisor(s): Farhan Rana
Title: Defect single-photon emitters in GaN
Abstract: Single-photon emitters (SPEs), especially those in technologically mature wide bandgap semiconductors are attractive for realizing integrated platforms for quantum applications. GaN hosts bright and stable defect SPEs in the 600–700nm wavelength range with strong zero phonon lines (ZPL) even at room temperature. The nature and origin of these defects remain elusive. In this talk, I will present our two main studies: dephasing mechanism and optical dipole structures and orientations of those SPEs.
Broadening of the ZPL caused by dephasing in SPEs limits the use of defect states in quantum information processing, sensing, and metrology. We study the temperature dependence of the ZPL spectra of GaN SPEs integrated with solid immersion lenses with the goal of understanding the relevant dephasing mechanisms. We then propose a model in which dephasing caused by absorption/emission of optical phonons in an elastic Raman process determines the temperature dependence of the lineshape and the linewidth.
[Sci Rep 13, 8678 (2023). https://doi.org/10.1038/s41598-023-35003-z]
Optical dipole structure and orientation can say a lot about the nature of those defects. We study the optical dipole structures and orientations of these defect emitters using the defocused imaging technique. Our experimental results, backed by numerical simulations, show that these defect emitters in GaN exhibit a single dipole moment that is oriented almost perpendicular to the wurtzite crystal c-axis whereas the in plane orientations correspond to the nearest Ga-N bonds and also the nearest Ga-Ga (or N-N) directions. We then suggest possible candidates for those defect SPEs in GaN.
[https://arxiv.org/abs/2306.17339]

Speaker: Jialun Luo
Advisor(s): Gregory Fuchs

Title: Room temperature optically detected magnetic resonance of single spins in GaN
Abstract: Optically detected magnetic resonance (ODMR) is an efficient mechanism to read out the spin of solid-state color centers at room temperature, thus enabling spin-based quantum sensors of magnetic field, electric field, and temperature with high sensitivity and broad commercial applicability. The mechanism of room temperature ODMR is based on spin-dependent relaxation between the optically excited states to the ground states. Thus it is an intrinsic property of a defect center. Stable but unidentified defect centers in GaN have been found to emit bright single photons at room temperature with strong zero-phonon lines, making it an attractive quantum platform. In this talk, we present our discovery of room temperature ODMR and corresponding spin properties. We report that two distinct defect types exist in GaN based on their ODMR signatures. One group has small negative ODMR contrast based on a spin in a metastable state. The second and the more common group has positive ODMR contrast as large as ~30% based on ground-state spin. As a third-generation semiconductor, GaN is a mature platform with well-developed electronic technologies, and this defect platform is promising for integrated quantum sensing applications. [https://arxiv.org/abs/2306.12337]

Speaker: Hemant K. Mishra
Advisor(s): Mark M. Wilde
Title: Pretty good measurement for bosonic Gaussian ensembles
Abstract: The pretty good measurement is a fundamental analytical tool in quantum information theory, giving a method for inferring the classical label that identifies a quantum state chosen probabilistically from an ensemble. Identifying and constructing the pretty good measurement for the class of bosonic Gaussian states is of immediate practical relevance in quantum information processing tasks. Holevo recently showed that the pretty good measurement for a bosonic Gaussian ensemble is a bosonic Gaussian measurement that attains the accessible information of the ensemble [*IEEE Trans. Inf. Theory*, 66(9):5634–564, 2020]. In this paper, we provide an alternate proof of Gaussianity of the pretty good measurement for a Gaussian ensemble of multimode bosonic states, with a focus on establishing an explicit and efficiently computable Gaussian description of the measurement. We also compute an explicit form of the mean square error of the pretty good measurement, which is relevant when using it for parameter estimation.

Generalizing the pretty good measurement is a quantum instrument, called the pretty good instrument. We prove that the post-measurement state of the pretty good instrument is a faithful Gaussian state if the input state is a faithful Gaussian state whose covariance matrix satisfies a certain condition. Combined with our previous finding for the pretty good measurement and provided that the same condition holds, it follows that the expected output state is a faithful Gaussian state as well. In this case, we compute an explicit Gaussian description of the post-measurement and expected output states. Our findings imply that the pretty good instrument for bosonic Gaussian ensembles is no longer merely an analytical tool, but that it can also be implemented experimentally in quantum optics laboratories. Joint work with Ludovico Lami, Prabha Mandayam, and Mark M. Wilde and available at https://arxiv.org/abs/2303.04949.

Speaker: Eliott Rosenberg
Advisor(s): Paul Ginsparg and Peter McMahon (this work advised by Pedram Roushan)
Title: Dynamics of magnetization at infinite temperature in a Heisenberg spin chain
Abstract: Understanding universal aspects of quantum dynamics is an unresolved problem in statistical mechanics. In particular, the spin dynamics of the 1D Heisenberg model were conjectured to

belong to the Kardar-Parisi-Zhang (KPZ) universality class based on the scaling of the infinite-temperature spin-spin correlation function. In a chain of 46 superconducting qubits, we study the probability distribution, P(M), of the magnetization transferred across the chain's center. The first two moments of P(M) show superdiffusive behavior, a hallmark of KPZ universality. However, the third and fourth moments rule out the KPZ conjecture and allow for evaluating other theories. Our results highlight the importance of studying higher moments in determining dynamic universality classes and provide key insights into universal behavior in quantum systems. Pre-print available at https://arxiv.org/abs/2306.09333.

Speaker: Saswata Roy
Advisor(s): Valla Fatemi
Title: Quantum information processing of bosonic modes with superconducting circuits
Abstract: There is an emerging interest in using bosonic modes for quantum information processing. cQED takes advantage of multiple photon states in superconducting cavities for bosonic encoding of quantum information. It has appeared as a platform for hardware efficient quantum error correction with several bosonic codes (like GKP) crossing the breakeven point. However, efficiently controlling these systems remains a challenge in this field. Controlling the cavity states requires additional nonlinear components which introduce decoherence. In this talk, I will discuss the concept of bosonic encoding with some examples. I will introduce the experimental package and talk about how to experimentally characterize and control these systems with some exemplar experiments performed in our lab.

Speaker: Mandar Sohoni
Advisor(s): Peter McMahon
Title: Image sensing with an end-to-end optimization framework for classical and quantum states of light
Abstract: Optical imaging is commonly used for both scientific and technological applications across industry and academia. In image sensing, a measurement, such as of an object's position or contour, is performed by computational analysis of a digitized image. An emerging image-sensing paradigm relies on optics which are designed not as conventional imaging systems, but instead as optical encoders—computational pre-processors that extract relevant information from an image. Typically, in most optical image sensors the light-source is either left unoptimized or only the mean photon field is trained (such as in structured illumination).

However, both the mean-field and higher-order statistics carry important yet distinct information about images. Second-order photon statistics, which characterize the fluctuation of photons in a single pixel and the correlation between photons in different pixels, provides additional valuable information about the image to be sensed which is unattainable from the mean field. This is especially useful when squeezed or thermal light are used to generate structured illumination patterns for imaging or sensing. Here we propose an end-to-end optimization framework that leverages trained first- and second-order photon number statistics of quantum and classical light sources to enhance image sensing efficiency. This framework has the potential to design illumination patterns that can optimally extract image features through both pixel covariance and mean photon number. While our simulations strongly suggest that correlations improve accuracy in image sensing, it is an open question what benefit entanglement could bring. I will discuss some of our thoughts on this and welcome discussion and suggestions from the audience.

Speaker: Yiqing Zhou

Advisor(s): Eun-Ah Kim
Title: Detecting quantum complexity using transformer-based neural network
Abstract: Various data-driven attempts with classical agents have been made to analyze and capture the properties of quantum circuits, primarily to understand the region of quantum supremacy. Here, we also introduce a data-driven supervised-learning approach for our question of the quantum complexity of the given quantum circuit outputs. In particular, we focus on the transformer-based neural network model, consisting of several attention modules. With the conjecture that single circuit output will not solely demonstrate system property, a set of measured bit-strings from the wave function is fed into the neural network. As the experimental circuit data has a high level of noise, we first focus on the noiseless data to see whether there is a significant signal in the circuit data. We present a model performance on depth classification with varying noise levels, further discussing the possibility of quantum complexity.