Worster 2019 Application

Understanding Surface Quantum Interactions on Diamond Shallow Nitrogen-vacancy Centers

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Ania Jayich Lab
Quantum Sensing and Imaging Group

Physics Department, University of California, Santa Barbara, CA 93106

Principle Investigator  Professor Ania C. Bleszynski Jayich
Graduate Student  Simon Meynell
Undergraduate Student  Yuanqi Lyu

In collaboration with David Weld Group and Kunal Mukherjee Group.
PROJECT DESCRIPTION

Recent breakthroughs in the field of quantum mechanical experiments have enabled novel two-state quantum systems to enter the realm of technological utility [1, 4, 7, 9, 13, 17]. These novel systems are being employed in a variety of areas, most notably in the fields of sensing, computation and communication. Though sensing is the most mature of these quantum technologies, there are substantial outstanding obstacles in the way of realizing the full potential of quantum sensors. For example, as the sensitivity of a quantum system increases, it inevitably gets affected deleteriously by environmental sources of decoherence. To relieve this tension, there has to be a paradigm shift away from simply isolating the quantum system, and instead focus on tailoring the extrinsic environment to selectively remove decoherence (unwanted interactions) while enhancing the desired interactions. This approach, which has seen initial success in recent years motivates our desire to find novel ways of controlling and mitigating the problem of decoherence in sensitive quantum probes.

The nitrogen-vacancy (NV) center in diamond is a two-state quantum system formed by a point defect whereby two carbon atoms in the diamond are replaced by a nitrogen atom and a neighbouring vacancy. It has become particularly useful as a sensor in recent years, owing to its ease of addressability and exceptionally long coherence times in ambient conditions. However, charges and spins on the surface remain a major limiting factor in achieving ultrahigh sensitivity and spatial resolution in NV centers and other quantum systems in general [2, 10, 11, 14–16]. For example, the ambitious goal of nanoscale magnetic resonance imaging with NV centers has not yet to be realized. Our aim is to explore methods and techniques to control and even leverage charges and spins on the surface to increase the coherence time of near-surface NV centers. The Jayich group at UCSB is especially well-suited to address this problem because of the experience we have in material synthesis and diamond growth [3, 8]. In our previous Worster project we were able to realize near-surface NVs under UHV conditions. We successfully deposited single indium atoms on the diamond surface, measured the change in decoherence times and found that the T1s of the NVs decreased while the T2s remained the same. This, in conjunction with our observation of an increase in charge unstable NVs, [suggests that the charge environment of the surface was changing upon the deposition of indium]. In this project, we will extend these results by conducting a systematic study into the surface chemistry of diamond with the goal of better controlling the spin and charge state of the surface and the NV.

Broadly, the goals of our project will be twofold. Firstly, we will extend the results of the previous Worster project by using our experience constructing the first UHV chamber to build a cryogenic apparatus with surface preparation tools, including a pulsed laser, a plasma source, atom deposition sources, and electron beams. As this new chamber is being completed, we will in parallel work to generate controlled diamond surfaces with minimal decoherence to serve as a...
starting point for future studies of surfaces with intentionally adsorbed atoms. These experiments will leverage our collaboration with the Mukherjee group and their UHV chambers that allow sample heating, surface termination, and the deposition of a protective capping layer.

The second avenue of research in this project, will be to study the surface chemistry of diamond with the goal of controlling the NV-surficial atom interaction. Utilizing the experience and experimental capabilities of Professor Mukherjee’s group, we will test the effect of surface terminations and crystallographic orientation. These treatments will be informed by recent experimental and theoretical results that suggest methods for passivating the diamond such as: alumina deposition [5], nitrogen termination [6] and the investigation of alternative crystallographic surfaces [12]. Using the techniques available to us through the MRL and CNSI, we will gain insight into the chemistry at the diamond surface by using atomic force microscopy (AFM) and scanning electron microscopy (SEM) to characterize any surface roughening or etching. Following this, a recently purchased, state-of-the-art X-ray photoelectron spectroscopy (XPS) system will be used to study the first few monolayers of our diamond surface. These techniques will allow us to probe both the species of atoms on the surface and their surrounding chemical environment to guide our NV sensing experiment toward an optimal surface configuration and long coherence times.

This project benefits from close collaborations with Professor David Weld as well as Professor Kunal Mukherjee. Professor Weld’s group has extensive experience in the field of highly coherent cold atom systems and has manipulated them with techniques requiring ultra-high vacuum (UHV). Professor Mukherjee’s group has an abundance of expertise in the field of molecular beam epitaxy (MBE), a UHV technique that involves deposition of atoms layer-by-layer on to a controlled surface. Our group and our two collaborators provide unique insights and expertise that are prerequisite to realizing the challenge of deposition and measurement in a UHV environment.

Yuanqi is an exceptional undergraduate student who has already shown great initiative with the project in question. The Quantum Interfaces experiment is an ideal undergraduate project because it will allow Yuanqi to experience several major aspects of being a professional scientist and will form the backbone of his senior undergraduate thesis. Namely, he will be involved in the construction of a material apparatus, the taking of data on this apparatus and the usage of common materials science tools. In addition to this, through the collaboration with Professor Mukherjee, Yuanqi will gain valuable insight into the sample synthesis aspect of condensed matter research and materials engineering. While this project provides him with a broad introduction to a wide variety of areas of physics and engineering, his role will be focused on the construction of a new setup and the characterization of diamond samples for that setup. This funding will allow him to work full time and have the opportunity to guide an experiment from the initial design stage to the final measurement using his existing knowledge to help make key decisions in the experimental process and gaining valuable real-world research experience along the way.
REFERENCES


