NV Centre Microscopy based Quantum Sensing: Testing Theoretical Predictions with Experiments

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Summary: This PhD project seeks to explore quantum sensing experiments to test and validate theoretical predictions, thus merging unique experimental and theoretical capabilities at QUB. By definition, a quantum sensor exploits properties of quantum mechanics such as quantum entanglement and quantum interference to achieve unprecedented precision in sensing technology. Such sensors are usually based on photonic systems or solid-state systems. The Nitrogen-vacancy defect centre in diamond is an ideal solid-state quantum sensor with stable quantum states at room temperature and provides an excellent platform to test theoretical predictions. We aim to combine theoretical and experimental expertise across Centre for Quantum Materials Technologies to explore experiments using the recently commissioned NV-centre microscope in QUB, one of the only kind of instrument in UK.

Background and Context: No quantum system is perfectly isolated. The surrounding environment would continuously "observe" the system and, by doing so, deplete its quantum properties and drive its physical configuration towards one consistent with classical mechanics [1]. The characterisation of such a process is, at the same time, one of the most pressing and difficult problems of modern quantum physics [2]. On one hand, the successful understanding of how an environment affects the dynamics of a quantum system will provide crucial information for the development of reliable quantum-enhanced technologies and will help understanding the limits of validity of the quantum framework. On the other hand, the process of system-environment interaction is often too complex to find a microscopic modelling and can be rigorously characterised only by means of clever experimental methods [3].
A potentially successful strategy in this respect is the paradigm of *quantum sensing[4]:* by attaching a fully controllable quantum probe to the environment that we aim to characterise, and exploiting the freedom to engineer suitable states of the probe and perform the most informative measurements, it is possible to acquire key information on the behaviour and influences of the environment, such as its ability to kick-back energy to the system.

This Project: We will aim to evaluate the transience of quantum states towards classicality as a result of the interaction of a quantum system with various forms of environments. Informative figures of merit in this respect will be built by tracking the temporal evolution of quantum coherence of such states. The sensor that we will use is based on the spin degrees of freedom of a controllable nitrogen-vacancy (NV) defect. Utilising the exquisite sensitivity of such system, we will extract experimental data on room-temperature environments that will then be validated and interpreted with theoretical models with the aim of capturing signatures of kick-back of excitations/energy/information from the environment to the NV defect. We will explore the influences on the sensing capabilities of the device as its initial quantum state is varied. Our investigations will thus address the impact that such initial states have on the phenomenology of the irreversible processes stemming from the interaction of the NV sensor with the chosen environment to study, and will extend all the way to the provision of a thermodynamic analysis of the resulting irreversible process. The project will be supported through relevant EPSRC and US-Ireland grants running within the research group.

References:

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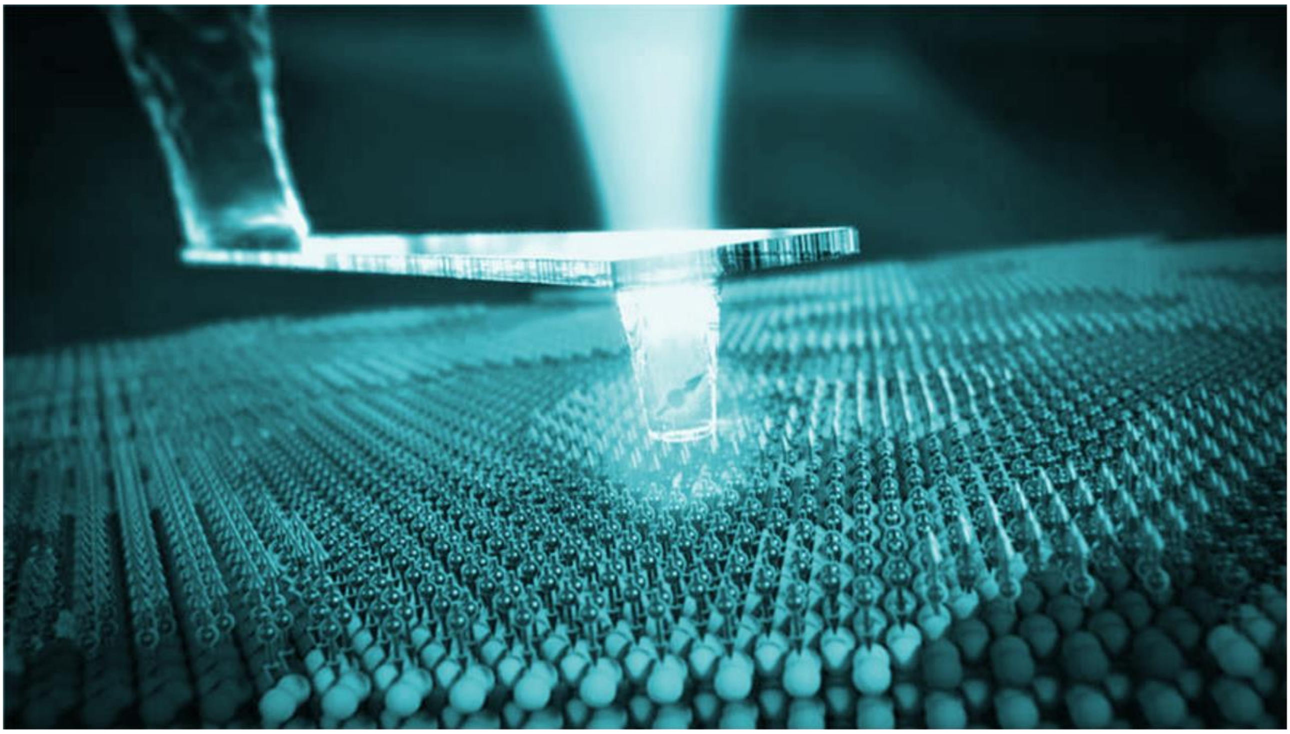

An illustration of NV-Centre microscope, an excellent tool for quantum sensing.