Quantum Photonics with Hexagonal Boron Nitride Quantum Emitters

by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Simon J. U. White, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Mathematical and Physical Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Controlling and manipulating individual quantum systems underpins the development of scalable quantum technologies. These new technologies enable more precise and sensitive metrology and have the potential to revolutionise computing, enabling functionality inconceivable using classical technologies. Hexagonal boron nitride (hBN) is emerging as an exceptional platform for applications in quantum photonics. Defects within hBN's two-dimensional crystalline lattice can form an atom-like two-level system, which when excited can only release one photon at a time. The quantum emission from defects in this material is promising as single photons are ideal candidates for information carriers, flying qubits, integral to the future of advanced quantum technologies. Furthermore, due to the interaction between these defects and their local environments, they can be excellent quantum sensors on an atomic scale.

The focus of this thesis is to control, manipulate, and study hBN quantum emitters to understand their applicability today and their potential in future quantum technologies. Beginning with a proof of principle demonstration of quantum random number generation, it is shown that the room temperature quantum emission from a single hBN defect can be coupled to an integrated photonic circuit. By measuring the collapse of a single photon at the output of the photonic circuit, we demonstrate a scalable architecture for quantum random number generation.

The next sections of the thesis uncover how these defects are applicable more broadly in future quantum technologies. Aware of the requirements for the ideal single photon emitter (SPE), we detail the cryogenic properties of hBN quantum emitters, specifically under resonant excitation. Using this technique, we study the control and manipulation of these emitters under optical and electrical fields, as well as quantify how the emitters couple to their environments. Here, it is shown that the emission from these defects can be significantly enhanced under a co-excitation regime, and the mechanism behind the increased pho-

toluminescence is explained by studying the temporal photophysics of the defect. To further detail the interaction between hBN single photon emitters and their local environment we uncover the dominant broadening mechanisms using resonant photoluminescence excitation (PLE). It is found that hBN emitters suffer from spectral diffusion and, interestingly, suffer homogeneous broadening even at 5 K. Finally, we take advantage of the two-dimensional nature of hBN crystals and fabricate a >100 nm thick van der Waals heterostructure device. Using this device, we show that the photoluminescence from hBN emitters can be electrically modulated; the emission can be gated on and off, the brightness can be controlled, and the wavelength can be tuned. These findings demonstrate that hBN is an exceptional platform for developing photonic quantum technologies and further show that hBN quantum emitters have applications from advanced sensing to quantum communication and information processing.

Publications

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