Publishable summary

1.1 Summary description of the project objectives

The objectives of the project described in the proposal were:

- Aim 1: Develop a theoretical framework for cluster state generation from diamond defect centres.
- Aim 2: Achieve high-efficiency coupling of light from diamond defect centres into single-mode fibre.
- Aim 3: Achieve a high level of spin-qubit control for diamond-based single photon sources.
- Aim 4: Obtain one-dimensional strings of highly-entangled photons that allow arbitrary one-qubit operations.
- Aim 5: Investigate the implementation of diamond-based quantum light sources for use in photonic quantum information technologies.

1.2 Description of the work performed since the beginning of the project

One of the first tasks in the experimental work was to make sure that we collected enough fluorescence from the nitrogen-vacancy (NV) centre to, in principle, be able to detect strings of sequentially emitted photons. We went about this by fabricating solid immersion lenses around single NV centres using focussed ion beam lithography [1]. This has enabled us to boost our collection efficiency up to 17 times and achieve greater than the necessary 2 % total emission collection. With the intention of boosting the collection further, we have continued to work on our Fabry-Perot microcavity project, which will eventually be used to place an NV centre in a tuneable external cavity [2].

Our low temperature experimental setup was constructed. Initially, in year 1, all low temperature measurements were performed in our bath cryostat on NV centre ensembles. However, complications associated with coupling fluorescence from single NV centres out of the bath cryostat led us to switch our experimental setup to a flow cryostat, which has direct optical access. We constructed an optical setup around this cryostat to enable low temperature optical measurements on single NV centres involving: resonant and non-resonant excitation (CW or pulsed); phonon side-band and zero-phonon line detection, with single photon resolution and temporal gating. A microwave antenna has been integrated into the cryostat for manipulation of the NV spin-state. The electronics and software to control the pulse sequences for our measurements have also been developed.

With the majority of the experimental infrastructure in place, we have been performing experiments to control a single NV centre. Optically detected magnetic resonance and Rabi measurements were run to show control over the electron spin. Using our narrow-band tuneable laser we resonantly excited the ground-to-excited state transition. Furthermore, using two electro-optics modulators in series allows us to create short (~ 1 ns), resonant pulses capable of π-flips and coherent readout of the spin state. We have also controlled the energy of the excited-to-ground state transition using a lateral electric field applied through electrodes fabricated around an NV centre [3].

We have developed a theoretical framework for the generation of strings of highly-entangled photons from NV centres. We have continued to look for improvements in this scheme. Our theory collaborators in Imperial College, London (Rudolph group) have been working on a way to reduce the resources required for multi-partite entanglement measures.

Our collaborators at the University of Vienna have been working on developing superconducting nano-wire detectors to improve our photon detection efficiency. The cryostat was setup for the detectors and many prototype devices have been measured. A maximum detection efficiency of 88 % has now been measured.

1.3 Description of the main results achieved so far

- Factor of 17 increase in counts measured from a single NV centre by fabricating a free-space SIL around it;
- Flip time of NV centre electron spin 600 ns at low temperature (~ 5 K);
- Linewidth of ground-to-excited state optical transitions measured down to ~ 30 MHz;
- Short, on demand laser pulses produced (~ 1 ns duration (FWHM)) for resonant NV excitation, with suppression better than -40 dB for zero phonon line detection with minimal noise;
- Electrostatic tuning of the NV centre resonance shown, with tuning of up to 8 GHz easily possible;
- We have fabricated high quality mirrors for our Fabry-Perot microcavities, with finesses up to 70,000;
- Our theory collaborators have devised a way to reduce the number of photon detectors required to characterise multi-partite entanglement to just two. They have also calculated that only a three qubit measurement is necessary to demonstrate long-range entanglement across the entire n-qubit cluster state;
- We have measured a maximum detection efficiency of 88 % from our superconducting nanowire single photon detectors.

1.4 Expected final results and their potential impact and use

This research project will continue to run, funded through various grants. Consequently we will continue to strive towards our original goals. With the benefit of 2 years of research through the Marie Curie Programme it is possible to give a more accurate picture of what the final results will be:

- Correlations between the NV centre spin and polarisation of an antecedently emitted photon;
- Generate strings of entangled qubits of length ≥ 3 from an NV centre;
- Implementation of diamond-based quantum light source for use in photonic quantum information technologies.

Our expected final results will have an impact in the field of quantum information processing. The project still ultimately aims to create a photon source suitable for scalable measurement-based quantum computation. This is one of the most promising architectures for large-scale quantum computation, as it is resource efficient [4]. The establishment of large-scale quantum computation would lead to a revolution in scientific research, as it has the potential to solve certain classes of important problems that are currently intractable.

1.5 References

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