

Quantum Diamond Workshop – Tuesday 17th July:

FINAL VERSION

Tuesday 17 th July	9.30-11.30am	11.30-12.00am	12.00-1.30pm	1.30-2.30pm:	2.30-4.00pm	4.30-4.15pm:	4.30-6.00pm:	6.45-8.00pm	8pm
Time: 9.00 – 9.30am	Session 1	Morning Break	Session 2	Lunch	Session 3	Afternoon Break	Session 4		
<i>Coffee</i>	9.30am: Steven Praver <i>Welcome & Workshop Overview</i>		12pm: Andy Greentree & Lloyd Hollenberg <i>Diamond Defect Centres: From Solid-State To Solid-Light</i>		2.30pm: Andrew White <i>Single Photon States For Quantum Information Processing</i>		4.30pm: Sean Barrett <i>Scalable Quantum Computing Using Isolated Nitrogen Vacancy Centres And Single Photon Interference</i>	<i>Evening Meal</i>	<i>DEST Grant Holders Meeting</i>
	10.00am: Jean-François Roch <i>Practical Quantum Cryptography With Diamond-Based Single-Photon Sources</i>		12.45pm: Harald Weinfurter <i>Optical Spectroscopy Of Single Siv Centers In Diamond</i>		3.15pm: Jeremy O'Brien <i>Quantum Interference With Photons And Its Applications</i>		5.15pm: Fedor Jelezko <i>Single Electron And Nuclear Spins In Diamond: A Resource For Quantum Memory, Repeater And Computing Schemes.</i>		
	10.45am: Phil Hemmer <i>The Role of Plasmonics in Quantum Information Processing</i>								

Dinner will be served at 6.45pm

Quantum Diamond Workshop – Wednesday 18th July:

FINAL VERSION

Wednesday 18th July Time:	9-10.30am	10.30-11am	11-12.30pm	1.00pm	2-3.30pm	4.45pm	5-6.30pm:	6.30-8pm	8pm
	Session 1	Morning Break	Session 2	Social activity			Session 3		
	9.00am: Neil Manson <i>The Excited State Structure of NV & the Effects of Strain</i>		11.00am: Daniel Twitchen <i>Growth of Diamond & the Properties of Element 6 low N Materials</i>	Picnic	At Rock	Hanging	5.00pm: Steven Praver <i>Ion Implantation for Nanofabrication</i>	Evening Meal	8.00pm: <i>EQUIND Meeting</i>
	9.45am: Mikhail Lukin <i>Scalable Quantum Registers With Nuclear Spins In Diamond</i> <i>* By teleconference link</i>		11.40am: Marko Loncar <i>Waveguides & Photonic Structures in Diamonds</i> <i>* By teleconference link</i>				5.45pm: Bill Munro <i>Topic to be advised</i>		
			12.20pm: Francois Ladouceur <i>Diamond processing at UNSW</i>						

Dinner will be served at 7.00pm

Quantum Diamond Workshop – Thursday 19 July:

FINAL VERSION

Thursday 19th July Time:	9-10.30am	10.30-11am	11-12.30pm	12.30-2pm:	2-3.30pm	3.30-4pm:	4pm:
	Session 1	Morning Break	Session 2	Lunch	Session 3	Conclusions/debriefing	Departure
	9.00am: Charles Santori <i>Coherent Population Trapping And Electromagnetically Induced Transparency In Diamond</i>		11.00am: Kae Nemoto <i>Qubus Computation And Its Applications</i>		2.00pm: Felix Waldermann <i>A Broadband Quantum Memory Using NV-Center Ensembles In Diamond</i>	3.30pm: Closing Session	
	9.45am: Jason Smith <i>Prospects For Measurement- Based Quantum Computing Using Nitrogen-Vacancy Centers In Diamond.</i>		11.45am: Steven Cooper, Mark J. Fernée, Brad Littleton, Halina Rubinsztein- Dunlop <i>Microcavity QED For Improved Single Photon Sources</i>		2.45pm: Sergei Ya Kilin <i>Late News; Brainstorming; Debriefing</i>		

Abstracts:**SEAN BARRETT:**

Title: *“Scalable quantum computing using isolated nitrogen vacancy centres and single photon interference”*

Abstract:

I describe a scheme for distributed, scalable quantum computation using matter qubits, single photon interference effects, and single qubit measurements. The scheme is ideally suited to defect centres in diamond. Entanglement between spatially separated qubits is generated using a non-deterministic parity measurement via quantum interference of single photons. The scheme has the potential to overcome many of the problems inherent in scaling more conventional approaches to quantum computation, and is remarkably robust to many imperfections.

As well as presenting the original scheme (Barrett and Kok, Phys. Rev. A 71, R060310 (2005)), I will also describe more recent work extending the scheme to the situation where the emitted photons are not identical (e.g. they have different frequencies). This significantly broadens the range of systems in which this scheme can be implemented, to include sources where there may be considerable variation in the frequencies of the relevant optical transitions. This is particularly relevant for defect centres in diamond, where the relevant optical transitions can be significantly shifted from one another.

Further Reading:

(Barrett and Kok) Phys. Rev. A 71, R060310 (2005).

STEVEN COOPER, MARK J. FERNÉE, BRAD LITTLETON & HALINA RUBINSZTEIN-DUNLOP:

Title: *“Microcavity QED for improved single photon sources”*

Abstract:

We present a procedure for producing transform limited single photon pulses from an arbitrary solid-state system coupled to a micro-cavity. This procedure is introduced in order to eliminate the stochastic pumping of the upper transition level, which otherwise introduces a timing jitter in the photon wave packet. This jitter manifests itself as a reduction in the Hong-Ou-Mandel interference minima. Our simple procedure, based on Stark tuning, can completely restore the non-classical interference. Furthermore it also can be employed to modify the photon wave packet. In a simple demonstration, we show how an optimal Gaussian wave packet can be obtained following a simple modification to the Stark tuning voltage.

The procedure we describe is generic and so is applicable to a wide range of solid-state systems and cavity geometries. In particular we briefly discuss application to whispering gallery mode cavities and the use of nickel colour centres in diamond.

GURUDEV DUTT:

Title: *“Scalable quantum registers with nuclear spins in diamond”*

Abstract:

I will discuss experiments that demonstrate addressing, preparation, and coherent control of individual nuclear spin qubits in the diamond lattice at room temperature. We have measured spin coherence times exceeding milliseconds, and observed coherent coupling to nearby electronic and nuclear spins. Robust initialization of a two-qubit register and transfer of arbitrary quantum states between electron and nuclear spin qubits has been achieved. Our results show that coherent operations are possible with individual solid-state qubits whose coherence properties approach those for isolated atoms and ions. The resulting electron-nuclear few-qubit registers can potentially serve as small processor nodes in a quantum network coupled by optical photons.

ANDY GREENTREE & LLOYD HOLLENBERG:

Title: *"Diamond defect centres: from solid-state to solid-light"*

Abstract:

We present a summary of recent theoretical work on diamond centres and possible applications within the Quantum Communications Victoria and Centre for Quantum Computer Technology. On the solid-state side, the electronic structure of the NV and Ni related defect centres have been studied by Density Functional Theory, and optical properties computed. Photonic simulations have been carried out to estimate the coupling of nanocrystal emitters to fibres, which together with the effects of attenuation and dispersion determine the overall single photon transmission rate through fibre. Anticipating the use of cavities in such systems we have investigated the NV-cavity system in detail to determine the secure bit rates attainable in realistic settings. Going beyond single photon emission, diamond presents itself as a powerful candidate medium for exploring cavity Quantum Electrodynamics in the strong coupling limit. We have begun exploring the possibilities afforded by NV diamond for the purposes of Q-switched single photon sources, media exhibiting quantum phase transitions, and as generic resources for entangled state generation.

PHIL HEMMER:

Title: *"The role of plasmonics in quantum Information processing"*

Abstract:

Entanglement between qubits at arbitrary locations is best accomplished using photons. However, the storage and local processing of this information is best accomplished using spins in solids. To interface these very different quantum systems, strong atom-cavity coupling has been proposed. However, implementation of this strong coupling can often be difficult due to sometimes conflicting material requirements for stable qubits and high finesse optical cavities. To relax the cavity requirements, and thereby greatly simplify implementation, we are looking at the possibility of using optical plasmon coupling between single emitters and nano-scale metallic structures.

Speaker:

FEDOR JELEZKO:

Title: *"Single electron and nuclear spins in diamond: A resource for quantum memory, repeater and computing schemes"*.

FRANÇOIS LADOUCEUR:

Title: *"Diamond processing at UNSW"*

Abstract:

This talk covers the work done at UNSW covering the first 12 months of diamond processing. We review the progress so far accomplished by the processing team by detailing the processes developed, the facilities used and the main obstacles surmounted. We focus on the processing of diamond in its nanocrystal form and review the main experimental results linked to optical guidance.

KAE NEMOTO:

Title: *"Qubus computation and its applications"*

Abstract:

Quantum computation requires two types of operations: single-qubit manipulation and two-qubit operation. However, it is very difficult to realize these two types of operations, keeping quantum coherence at the same time. We propose a new scheme that computational qubits are connected via continuous-variable bus mode, and show that quantum computation via quantum bus (Qubus computation) is universal in QIP. The scheme exploits the advantages both qubits and continuous variables (CV). We discuss the feasibility of the scheme and its applications.

Further Reading:

Hybrid quantum repeater using bright coherent light, Phys. Rev. Lett. 96, 240501 (2006)

Quantum Computation by Communication, New J. Phys. 8, 30 (2006)

JEREMY O'BRIEN:

Title: *"Quantum interference with photons and its applications"*

Abstract:

Quantum interference of two photons at a beam splitter---Hong-Ou-Mandel interference---has been widely studied in quantum optics, and is the basis of quantum logic gates for optical quantum computing and schemes for generalised measurements with photons. I will briefly review the progress in these two areas. I will then describe several higher-order generalisations of this effect, with several modes and several photons. I will show how these generalised quantum interference effects can be used for non-linear Fock state absorption and for quantum metrology applications.

STEVEN PRAWER:

Title: *"Ion Implantation for Nanofabrication"*

Abstract:

Ion Implantation, especially when combined with focused ion beam processing holds enormous promise as means for the fabrication of devices in the diamond at the nanoscale. In this talk, I will review the use of ion implantation in the fabrication of (i) qubits in diamond based on NV centres and (ii) diamond microstructures such as cantilevers, waveguides, mirrors and optical cavities. The prospects for combining these technologies to produce quantum information processing devices based on diamond will be discussed.

JEAN FRANÇOIS ROCH:

Title: *"Practical quantum cryptography with diamond-based single-photon sources"*

Abstract:

Quantum cryptography has evolved from early proof-of-principles experiments (1) to the real world of application (2). I will report a full implementation of the BB84 quantum key distribution (QKD) scheme with the open-air transmission of polarization-encoded single photons (3). The single-photon source relies on the pulsed excitation of a single Nitrogen-Vacancy color center in a diamond nanocrystal (4). The attenuation on the transmission channel allows to infer long-distance performance of the system. For large attenuation, the use of pure single-photon light pulses gives a measurable advantage over systems that rely on faint laser pulses. This result agrees with theoretical models developed to assess QKD security (5). I will report the promising improvement of the single-photon source with optically active Nickel-related color centers (6,7) which can be incorporated in chemical vapor deposited diamond nanocrystals (8). I will finally describe the European-funded EQUIND project which gives a framework for the development of a diamond-based quantum toolbox.

References:

- (1) C. H. Bennett and G. Brassard, "Quantum cryptography: public key distribution and coin tossing", Int. Conf. on Computers, Systems and Signal processing (Bangalore, India, Dec. 1984) pp. 175-179.
- (2) N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, "Quantum cryptography", Rev. Mod. Phys., vol. 74, 145 (2002).
- (3) R. Alléaume, F. Treussart, G. Messin, Y. Dumeige, J.-F. Roch, A. Beveratos, R. Brouri-Tualla, J.-P. Poizat, and P. Grangier, "Experimental open air quantum key distribution with a single photon source", New J. Phys., vol. 6, 92 (2004).
- (4) A. Beveratos, S. Kühn, R. Brouri, T. Gacoin, J.-P. Poizat, and P. Grangier, "Room temperature single photon source", Eur. Phys. J. D, vol. 18, 191 (2002).
- (5) N. Lütkenhaus, "Security against individual attacks for realistic quantum key distribution", Phys. Rev. A, vol. 59, 052304 (2000).
- (6) T. Gaebel, I. Popa, A. Gruber, M. Domhan, F. Jelezko, and J. Wrachtrup, "Stable single-photon source in the near infrared", New J. Phys., vol. 6, 98 (2004).
- (7) E. Wu, V. Jacques, F. Treussart, H. Zeng, P. Grangier, and J.-F. Roch, "Narrow band single photon emission in the near infrared for quantum key distribution", Opt. Exp., vol. 14, 1296 (2006).
- (8) J. Rabeau, Y. Chin, S. Praver, F. Jelezko, T. Gaebel, and J. Wrachtrup, "Fabrication of single nickel-nitrogen defects in diamond by chemical vapor deposition", Appl. Phys. Lett., vol. 86, 131926 (2005).

CHARLES SANTORI:

Title: *"Coherent population trapping and electromagnetically induced transparency in diamond"*

Abstract:

The nitrogen-vacancy center in diamond seems to be a promising solid-state qubit, with a long-lived electron spin that can be initialized and read out optically. However, for scalable quantum information processing we must find a way to couple spatially separated qubits. Optics can, in theory, be used to produce a deterministic interaction between qubits if the physical system has the right kind of optical transitions (a 3-level Lambda system) and if one of these optical transitions can be coupled efficiently to a single-mode waveguide.

In this talk I will describe experiments demonstrating that a weak strain can modify the excited-state structure of the NV center so non-spin-conserving transitions become allowed, and a Lambda system can be obtained as needed for optical spin manipulation. These experiments include coherent population trapping in both NV ensembles and single NV centers. The main challenge ahead of us is how to couple NV centers efficiently to optical microcavities, and I will briefly describe experiments in this direction.

JASON SMITH:

Title: *"Prospects for measurement-based quantum computing using Nitrogen-Vacancy centres in diamond"*

Abstract:

The negatively charged nitrogen vacancy defect in diamond is a leading contender as a quantum register for use in the new field of measurement-based quantum computing. In this talk I will highlight three aspects of the relevant science: control of the optically excited state to facilitate different measurement-based protocols; the role of dephasing processes and phonon emission; and brokering schemes using two-qubit systems. I will also describe the work being carried out in Oxford to realize measurement-based entanglement between remote NV spins, and discuss some of the key scientific and technological hurdles that we expect to encounter en route to a fully scaleable measurement-based quantum computer.

FELIX WALDERMANN:

Title: *"A broadband quantum memory using NV-center ensembles in diamond"*

Abstract:

The NV-center appears as a suitable quantum emitter in the solid due to its high optical interaction strength and its temporal stability. Several remarkable papers have already proved its usability for coherent manipulation. However, these schemes all involved the spin state of the NV-center ground state and were therefore limited to nanosecond-pulses. Here, we introduce a different scheme for the coherent storage of ultrafast single photons, utilising an off-resonant Lambda-transition between the vibrational subbands of the ground states in an NV-center ensemble. We show that, due to the off-resonant nature of the transition and its weak interaction strength, very high densities of NV-centers are necessary, and we also regard the effect of microcavities on the storage fidelity.

HARALD WEINFURTER:

Title: *"Optical spectroscopy of single SiV centers in diamond"*

Abstract:

We report on our work on the optical spectroscopy of single colour centres in diamond. The SiV centre was considered to have several advantageous properties for single photon generation, e.g. the narrow spectrum and short luminescence lifetime. However, the rather low brightness of the single SiV centres found in bulk IIa diamond revealed a poor quantum yield. Additionally, the second-order correlation function of the fluorescence of a single SiV centre indicates the existence of a shelving level, which further reduces the photon emission rate at a given excitation. In nitrogen-doped samples, single SiV centres with different brightness were observed. The brightness of individual SiV centres was found to correspond to the photon bunching effect shown by $g^{(2)}(\tau)$. The phenomenon can be explained by the inhomogeneous distribution of the Fermi-level induced by the nitrogen doping. If a single SiV centre is located near a nitrogen atom, the coupling to the shelving level is reduced as suggested by the weakening photon bunching effect, and consequently the brightness of this SiV centre is enhanced. The shelving level is thus determined as the more positively charged state of the SiV centre, which does not exhibit fluorescence. Beside the SiV centre several unknown single colour centres with remarkable properties were observed. They demonstrate the impressive variety of the colour centres in diamond and might give motivation for the search for a colour centre with more suitable properties for single photon generation.

On the other side, methods of fabrication of single colour centres were explored. Ion implantation is proven to be an efficient way to create colour centres in bulk sample. It allows a precise control of the localization and concentration of the desired colour centres. However, only the colour centres involving one impurity atom and vacancies can be easily created. In contrast, colour centres with more complicated structure can be formed during the CVD process. Diamond nanocrystals grown by the CVD method were found to contain single colour centres.

Furthermore, possibilities to improve the photon collection efficiency of fluorescence of single colour centres were investigated. Using a diamond solid immersion lens higher photon count rate of single SiV centres was observed at comparable excitation. Due to the limited surface roughness there is an air gap between the SIL and sample, therefore the enhancement of the photon collection efficiency is not uniform for individual SiV centres. In the best case, the brightness of a single SiV

centre was improved by a factor of 5 which agrees with the theoretical prediction quite well. In another approach, the small size of diamond nanocrystals promises to remove the refraction which prevents an efficient collection of the fluorescence light.

ANDREW WHITE:

Title: *"Single photon states for quantum information processing"*

Abstract:

We will discuss the requirements for applying single photons states to quantum information processing and some schemes for achieving them. We will look at the performance of the current state of the art sources, highlight their shortcomings, and discuss the ideal photon source for quantum information processing.

Delegates:

Name:
Andy Greentree - UofM
Phil Hemmer – Texas A&M
Steven Praver - UofM
Brant Gibson - UofM
Jim Rabeau – Macquarie University
Lloyd Hollenberg - UofM
Steve Trpkovski - UofM
François Ladouceur - UNSW
Fedor Jelezko – University of Stuttgart
Bill Munro - HP
Kae Nemoto - National Institute of Informatics
Julius Orwa - UofM
Jean-Francois Roçh - ENS Cachon
Jeremy O'Brien - University of Bristol
Daniel Twitchen - Element 6
Neil Manson - ANU
Lachlan Roger - ANU
Matt Sellars – ANU
Halina Rubinsztein-Dunlop - UQ
Andrew White – UQ
Steve Cooper – UQ
Harald Weinfurter – Munich
Sean Barrett – Imperial College London
Jason Smith - Oxford
Felix Waldermann - Oxford
Mark Hiscocks – UNSW
Charles Santori – HP
Rafi Kalish – Technion Israel
Mark Ferntree - UQ
Brad Littleton – UQ
David Simpson – UofM
Alastair Stacey – UofM
Barbara Fairchild – UofM
David Jamieson – UofM
Faruque Hossain - UofM

UofM = University of Melbourne

UNSW = University of New South Wales

UQ = University of Queensland

ANU = Australian National University