Quantum Dot 1 day meeting

25 October 2024

University of Bristol, Bristol, UK

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Programme

9:00 AM - 9:30 AM	Arrival and Refreshments
9:30 AM - 10:30 AM	Session 1 9:30 AM - 10:00 AM Anthony Bennett (Invited Speaker) Temperature Quantum Light emission from Colour Centres in Aluminium Nitride 10:00 AM - 10:15 AM Alex Clark Continuous-Wave Characterisation of Photon Indistinguishability and Nanophotonic Coupling 10:15 AM - 10:30 AM Teymour Talha-dean Single electron tunneling in 2D vdW heterostructures via thermo-mechanical cleaning of interfaces
10:30 AM - 11:15 AM	Morning Break, Posters and Exhibition
11:15 AM - 12:30 PM	Session 2 11:15 AM - 11:45 AM Evgeny Chekhovich (Invited Speaker) Nuclear spins in GaAs/AlGaAs quantum dots: magnetic resonance perspective 11:45 AM - 12:00 PM Zhe Xian Koong Optical Control of an Electron Spin in an InGaAs Quantum Dot with Magnetic-field induced Cycling Transitions 12:00 PM - 12:15 PM Petros Laccotripes High-fidelity spin-photon entanglement using an InAs/InP quantum dot emitting in the telecom C-Band 12:15 PM - 12:30 PM Mark Hogg Fast optical control of a coherent hole spin in a microcavity
12:30 PM - 1:45 PM	Lunch and Photo
1:45 PM - 3:00 PM	Session 3 1:45 PM - 2:15 PM Kouichi Akahane (Invited Speaker) Ultra-low density InAs quantum dot grown on an InP(311)B substrate via interdiffusion epitaxy 2:15 PM - 2:30 PM Akshay Kumar Verma Wafer Scale Ultra-low Density InAs Quantum Dots on GaAs(100) 2:30 PM - 2:45 PM Guoliang Zhou Site-control of InAs quantum dots by droplet epitaxy in MOVPE 2:45 PM - 3:00 PM David Binks Singly Mn-doped colloidal quantum dots grown from molecular seed clusters
3:00 PM - 3:30 PM	Afternoon Break, Posters and Exhibition

3:30 PM - 4:45 PM	Session 4 3:30 PM - 4:00 PM Julian Wiercinski (Invited Speaker) Theory of cooperative emission from quantum dots 4:00 PM - 4:15 PM Dominic Hallett Controlling cooperative emission and superradiance in waveguide-coupled quantum dots 4:15 PM - 4:30 PM Sheena Shaji Cooperative emission from multiple, remote indistinguishable quantum dots 4:30 PM - 4:45 PM Ella Mann-Andrews An emerging security technology: using CuInS/ZnS quantum dots for optical physically unclonable functions
4:45 PM - 5:00 PM	Closing

Invited Speakers

Ultra-low density InAs quantum dot grown on an InP(311)B substrate via interdiffusion epitaxy

Kouichi Akahane[1]
[1]*National Institute of Information and Communications Technology (NICT), Japan*

Session 3, October 25, 2024, 13:45 - 15:00

Single-photon generators are important components of quantum information processing and communication. When self-assembled quantum dots (QDs) are used as emission media for single photons, their density should be sufficiently low to avoid interactions between neighboring QDs and ensure flexibility for device fabrication. Additionally, a 1550-nm emission wavelength is preferable for quantum communications over long distances. To satisfy these demands, we developed a new growth technique to reduce the density of self-assembled QDs using interdiffusion epitaxy (IDE). Using this technique, we successfully grew ultra-low density InAs QDs (below 108 /cm2) on an InP(311)B substrate.

Temperature Quantum Light emission from Colour Centres in Aluminium Nitride

Anthony Bennett[1]
[1] *University of Cardiff, United Kingdom*

Session 1, October 25, 2024, 09:30 - 10:30

Wide bandgap semiconductors often contain defects that exhibit luminesce at room temperature. While much attention has been given to vacancy-ion complexes in diamond, such as SiV and NV-, which possess internal spin-sub-levels useful for various applications like sensing external fields, hosting spin qubits, or generating single photons, the presence of an intersystem crossing in their energy levels limits their saturated intensity. In contrast, point-like emitters in the commercially important AlxGa1-xN semiconductors have received much less scrutiny, but have been found in as-grown epilayers and created using ion-implantation. These emitters exhibit anti-bunched light emission at room temperature and it was recently shown that defects in GaN can also host single spin qubits amenable to optical detected magnetic resonance spectroscopy.   I will discuss our recent work on the formation and physical properties of a class of emitters in Aluminium Nitride. We discuss the photodynamics of emission in these structures and how that affects the saturated intensity. Furthermore, we show that a solid immersion lens can increase the intensity by a factor of 4 making these among the brightest room temperature quantum light sources yet reported.

Nuclear spins in GaAs/AlGaAs quantum dots: magnetic resonance perspective

Evgeny Chekhovich
[1] *University of Sussex, United Kingdom*

Session 2, October 25, 2024, 11:15 - 12:30

Epitaxial quantum dots (QDs) have long been investigated in the context of quantum physics and quantum information processing (QIP). The few thousand spins of the QD atomic nuclei were usually considered to be a source of noise, limiting the purity of the electron and photon qubits. The introduction of a new generation of low-strain optically-active GaAs/AlGaAs QDs has changed the paradigm. The advances of the past few years include demonstrations of efficient emitters of quantum light [1-3], electron [4] and nuclear [5] spin qubits, and reversible transfer of quantum states between electron and nuclear spins [6].

Here, I will discuss recent advanced both in fundamental physics and prospective applications of GaAs QDs in QIP. Optically-detected magnetic resonance of QDs provides experimental answers to long-standing physics questions. Spin diffusion in a central spin model has long been though to be suppressed through the so called Knight-field-gradient barrier, whereas recent experiments on individual QDs show that central spin only accelerates spin diffusion [7], resulting in nuclear spin lifetimes of 1 – 10 s. Nuclear spin polarisations exceeding 95% have been achieved recently [8], defying the long-standing predictions that coherent nuclear dark states would make this impossible. In more recent experiments, mechanical strain engineering has been used to extend high nuclear polarizations to magnetic fields as low as tens of mT, opening prospect for operation of QD spin qubits without bulky superconducting magnets.
Quantum memory with long storage is a key element in QIP. We show that strain-engineering and dynamical decoupling can be used to store coherent superposition state of QD nuclear spin ensemble for >100 ms. Moreover, nuclear spin ensemble can be used to perform quantum nondemolition measurement of a QD electron spin [9] with high single-shot fidelities exceeding 99.85%.

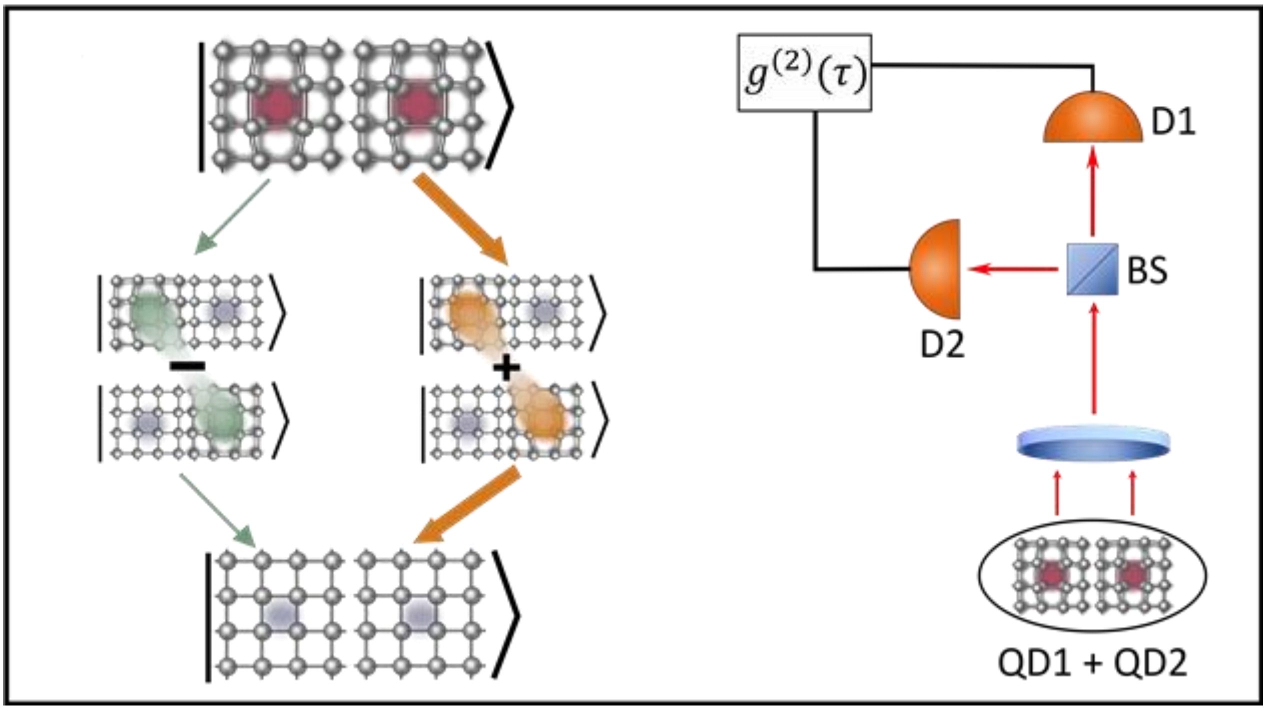
[1] J. Liu et al., Nature Nano 14, 586 (2019)
[2] L. Zhai et al., Nature Comm. 11, 4745 (2020)
[3] L. Zhai et al., Nature Nano 17, 829 (2022)
[4] L. Zaporski et al., Nature Nano 18, 257 (2023)
[5] E. A. Chekhovich et al., Nature Nano 15, 999 (2020)
[6] M. Appel, et al., arXiv:2404.19680 (2024)
[7] P. Millington-Hotze, et al., Nature Comm. 14, 2677 (2023)
[8] P. Millington-Hotze, et al., Nature Comm. 15, 985 (2024)
[9] H. Dyte et al., Phys. Rev. Lett. 132, 160804 (2024)

Theory of cooperative emission from quantum dots

Mr Julian Wiercinski[1], Dr Moritz Cygorek[2], Prof Erik M. Gauger[1]
[1]Institute of physics and quantum sciences, Heriot-Watt University, United Kingdom, [2]Condensed Matter Theory, Department of Physics, TU Dortmund, Germany

Session 4, October 25, 2024, 15:30 - 16:45

Collective light-matter interactions, leading to enhanced transition rates and altered photon statistics, find many potential applications in future quantum technologies. Quantum dots are a promising platform due to their excellent light emission properties.
As a solid-state platform, quantum dots suffer from spectral inhomogeneity, a low emitter density, and decoherence, mainly due to lattice vibrations. Thus, a meticulous theoretical understanding of collective effects in noisy systems is needed to disambiguate different types of collective effects and to address questions about noise robustness.
This contribution presents the theoretical framework relevant for analysing recent collective emission experiments on quantum dots. I will introduce two distinct phenomena, namely measurement-induced collective emission and superradiance. Also, the impact of phonons [Wiercinski et. al. PRR 2023, Wiercinski et. al. PRR 2024], which are treated on the master equation level, as well as utilizing state-of-the art process tensor methods [Cygorek et. al. PRX 2024], will be addressed.



Oral Contributed Speakers

Singly Mn-doped colloidal quantum dots grown from molecular seed clusters

Prof David Binks[1], Dr Julian Schneider[3], Dr Chris Page[3], Dr James Harris[3], Dr Nigel Pickett[3], Ms Nathalie Gresty[3], Mr Christopher Waby[3], Mr Charles Biddlecombe[3], Dr Rachel Barrett[1], Dr Adam Brookfield[2], Dr Patrick Parkinson[1], Dr Floriana Tuna[2], Dr Simon Fairclough[4]

[1]Department of Physics and Astronomy, The University Of Manchester, United Kingdom, [2]Department of Chemistry, The University Of Manchester, United Kingdom, [3]Nanoco Technologies Ltd, United Kingdom, [4]Department of Material Science and Metallurgy, The University of Cambridge, United Kingdom

Session 3, October 25, 2024, 13:45 - 15:00

Colloidal quantum dots (CQD) containing single dopant atoms are promising spin-photon interfaces. The suite of synthesis technique developed for CQDs over the last 30 years means they have excellent and size-tunable optical properties. Furthermore, as discrete substrate-free nanocrystals, they are well suited to pick-and-place nano-positioning techniques. However, conventional doping methods result in a statistical distribution of dopants per CQD and in the position of the dopant within the CQD. Here, we describe a synthesis route for growing InP/ZnSeS core-shell CQDs from central zinc sulphide-based seed clusters containing single Mn(II) ions. The resulting CQDs exhibit photoluminescence quantum yields of 68%, and spin-lattice and spin coherence lifetimes that can be extend to 22 ms and 2.7 μs, respectively, for the largest seed cluster used. These lifetimes are greater than and similar to the best yet reported for Mn-doped CQD systems, respectively, and were achieved despite the high nuclear spin of InP.

Continuous-Wave Characterisation of Photon Indistinguishability and Nanophotonic Coupling

Dr Alex Clark[1]
[1]University Of Bristol, United Kingdom

Session 1, October 25, 2024, 09:30 - 10:30

We measure quantum interference of photons from a single molecule under continuous-wave (cw) and pulsed excitation. We find that integration of the correlation functions allows measurement of the full temporal wavepacket indistinguishability for the pulsed case. In the cw case, we need to measure correlation functions for two illumination intensities and then extrapolate to zero-power to extract indistinguishability. The two cases agree well [1]. We also show that continuous-wave light can be used to determine the coupling of quantum emitters to arbitrary nanophotonic structures. We demonstrate the coupling of molecules to gapped nanophotonic silicon nitride waveguides using microcapillaries. The interference of laser light that passes the molecule and light that is resonantly scattered by the molecule allows the characterisation of the waveguide coupling [2].

[1] R. C. Schofield et al., Phys. Rev. Research 4, 013037 (2022).
[2] S. Boissier et al., Nature Communications 12, 706 (2021).

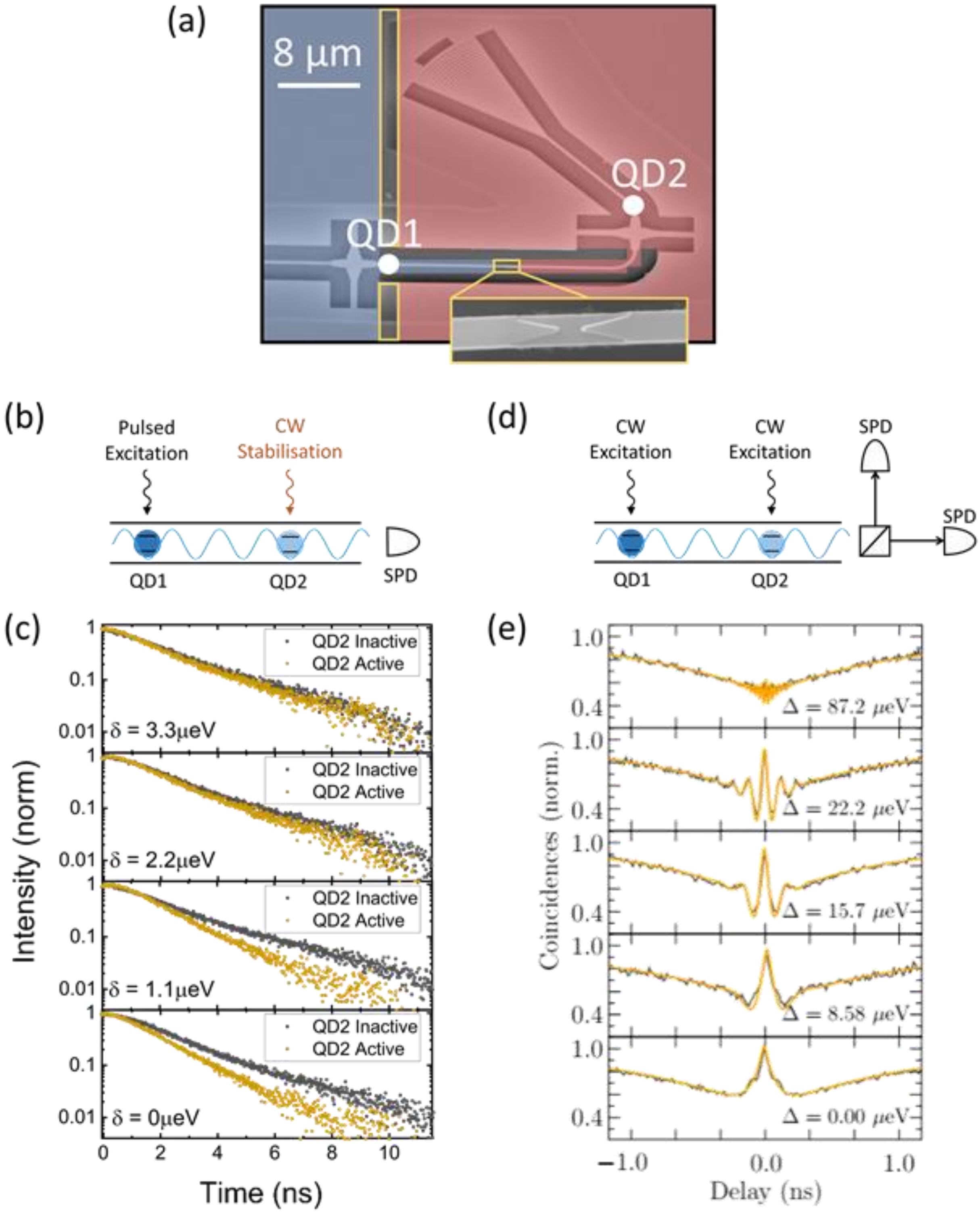
Controlling cooperative emission and superradiance in waveguide-coupled quantum dots

Dr Dominic Hallett[1], Luke Hallacy[1], Julian Wiercinski[2], Dr Samuel Sheldon[1], Dr Rene Dost[1], Dr Nicholas Martin[1], Aspen Fenzl[1], Dr Ian Farrer[3], Dr Moritz Cygorek[4], Professor Erik Gauger[2], Professor Maurice Skolnick[1], Professor Luke Wilson[1]
[1]Department of Physics and Astronomy, University Of Sheffield, United Kingdom, [2]SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University, United Kingdom, [3]Department of Electronic and Electrical Engineering, University of Sheffield, United Kingdom, [4]Condensed Matter Theory, Department of Physics, TU Dortmund, Germany

Session 4, October 25, 2024, 15:30 - 16:45

Multiple identical quantum emitters coupled to a single optical mode can act as a single entity. This coupling can create enhanced light-matter interaction, correlated emission, and entanglement between the emitters. Semiconductor quantum dots are an ideal platform to study this effect, combining excellent optical properties with the practicality of solid-state emitters. Nanophotonic waveguides allow efficient coupling of spatially separated QDs to a single propagating optical mode.

This work studies a system of two independently electrically tuneable InAs QDs, which are efficiently coupled through a nanophotonic waveguide. We investigate both super-radiant and co-operative interactions, in the same waveguide-coupled QD system, through measurements of the decay rate of the emitters and autocorrelation function of the emitted photons. When the two QDs are resonant, we see correlations in the emitted photons, and an increase in the system decay rate. This work explores the transition from super-radiant, through merely co-operative, to fully independent behaviour.

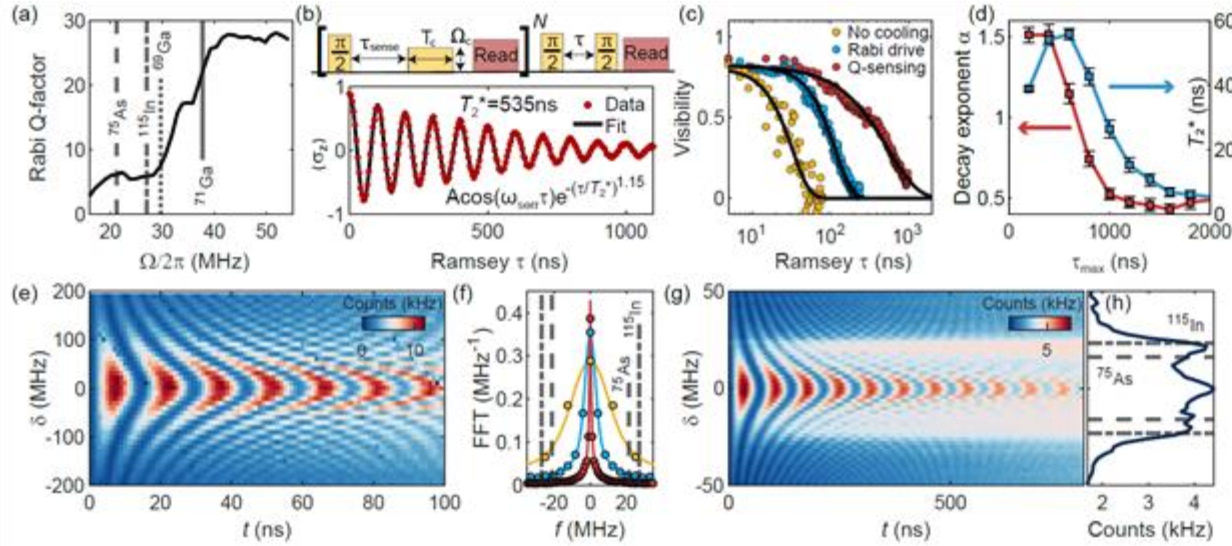

(a)
8 μm
QD2
QD1
(b)
Pulsed Excitation
CW Stabilisation
QD1
QD2
SPD
(d)
CW Excitation
CW Excitation
SPD
SPD
QD1
QD2
(c)
QD2 Inactive
QD2 Active
δ = 3.3μeV
δ = 2.2μeV
δ = 1.1μeV
δ = 0μeV
Intensity (norm)
Time (ns)
(e)
Δ = 87.2 μeV
Δ = 22.2 μeV
Δ = 15.7 μeV
Δ = 8.58 μeV
Δ = 0.00 μeV
Coincidences (norm.)
Delay (ns)

Fast optical control of a coherent hole spin in a microcavity

Dr Mark Hogg[1], Dr Nadia Antoniadis[1], Ms Malwina Marczak[1], Dr Giang Nam Nguyen[1], Mr Timon Baltisberger[1], Associate Professor Alisa Javadi[1], Dr Ruediger Schott[2], Mr Sascha Valentin[2], Professor Andreas Wieck[2], Dr Arne Ludwig[2], Professor Richard Warburton[1]
[1]University Of Basel, Switzerland, [2]Ruhr-Universitaet Bochum, Germany

Session 2, October 25, 2024, 11:15 - 12:30

A spin-photon interface is one of the key components of a quantum network. Currently, the best on-demand single-photon sources use a semiconductor quantum dot in an optical microcavity. However, an ideal spin-photon interface requires coherent spin control, currently lacking in a state-of-the-art single-photon source. Here, we combine high-fidelity all-optical spin control with an InGaAs quantum dot in an open microcavity. Using a Raman process, we demonstrate coherent control of a hole spin around an arbitrary Bloch sphere axis, achieving a maximum π-pulse fidelity of 98.6%. The cavity enhances the Raman field, enabling ultra-fast spin Rabi frequencies. The slow magnetic noise is addressed by laser cooling the nuclear spins using the hole as a central spin, extending the hole-spin T2* time from 28 ns to 535 ns. Cooling the nuclei to below 200 µk enables the observation of magnons, collective nuclear spin-excitations, opening up new avenues in the central spin problem.



Optical Control of an Electron Spin in an InGaAs Quantum Dot with Magnetic-field induced Cycling Transitions

Dr. Zhe Xian Koong[1], Dr. Urs Hauesler[1], Dr Dorian Gangloff[1], Prof. Mete Atature[1]
[1] *University of Cambridge, United Kingdom*

Session 2, October 25, 2024, 11:15 - 12:30

Despite inherent coupling to the solid-state environment, InGaAs/GaAs quantum dots are one of the leading platforms towards realizing an efficient spin-photon interface for quantum networking. This is attributed to the improved spin coherence via cooling of the nuclear spin ensemble [1], along with improved photon coherence and brightness via coupling to an optical cavity . It is widely considered that the selection rules prohibit the combination of efficient spin control and optical cyclicity in this platform. Here, we defy such preconception by demonstrating both optical control and high cyclicity with an electron spin in an InGaAs quantum dot, embedded in a planar cavity device. We perform electron spin resonance on a cycling transition with a cyclicity of ~1:200, showing full optical control and the narrowing of the nuclear spin ensemble. This marks a critical step towards realizing efficient, long-lived quantum repeaters.

[1] Science 364, 62-66 (2019)

High-fidelity spin-photon entanglement using an InAs/InP quantum dot emitting in the telecom C-Band

__Petros Laccotripes__[1], Petros Laccotripes[2], Tina Müller[2], Joanna Skiba-Szymanska[2], Mark Stevenson[2], David Ritchie[1], Andrew Shields[2]
[1]University Of Cambridge, Cavendish Laboratory, United Kingdom, [2]Toshiba Europe, United Kingdom

Session 2, October 25, 2024, 11:15 - 12:30

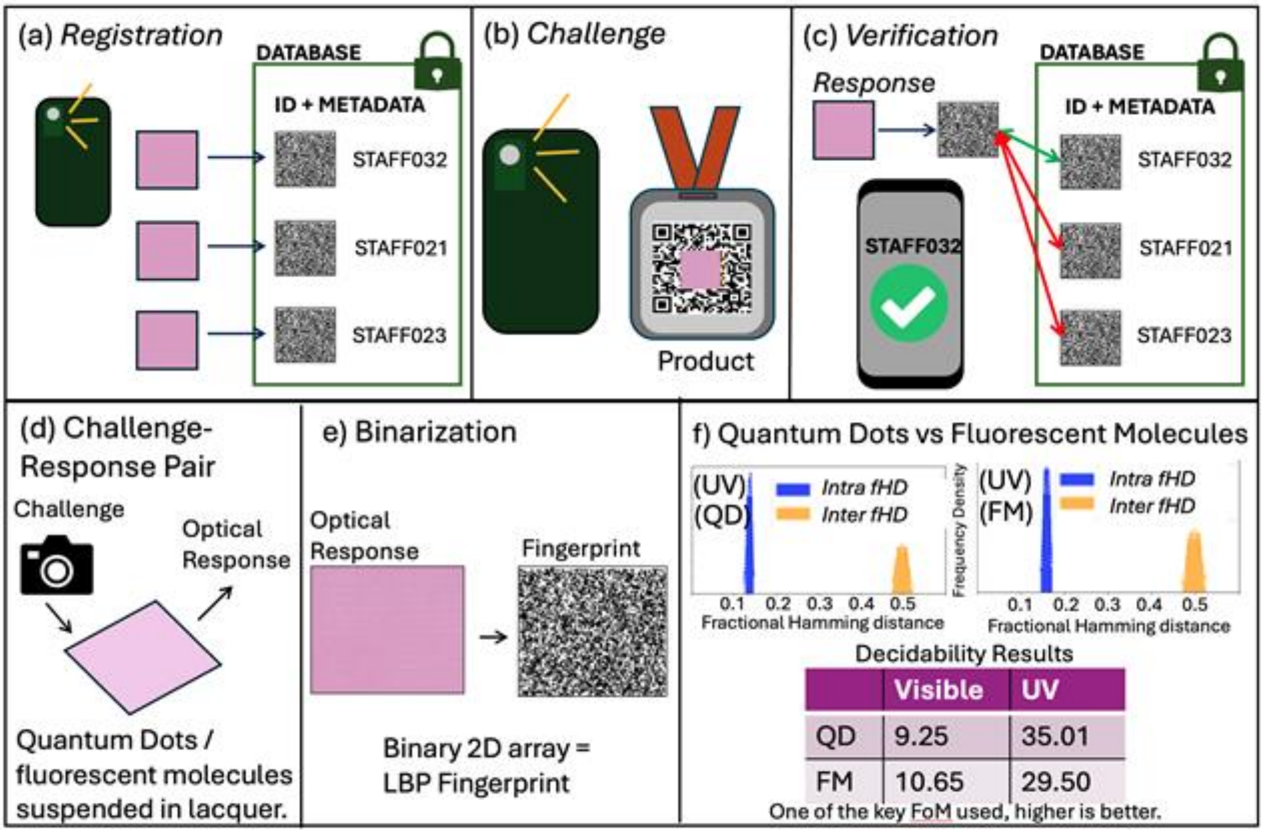
Efficient entanglement generation between a stationary matter qubit and a propagating photonic qubit is crucial for quantum networks and has the potential to transform quantum computation and secure long-distance quantum communication. Solid-state quantum emitters in the telecom C-band, the lowest-loss transmission window, are particularly promising due to minimal photon absorption and compatibility with existing fibre-optic infrastructure. In this work, we use an InAs/InP quantum dot to implement an optically active spin qubit, demonstrating high-fidelity spin initialisation and coherent control using picosecond pulses. We also utilise these tools to assess the coherence of an isolated electron spin within our system. For the first time, we achieve high-fidelity spin-photon entanglement in a solid-state system with direct emission into the telecom C-band, achieving an entanglement fidelity of 80.07 ± 2.9 %, well above the classical limit. These results highlight the potential of our versatile system for a range of entanglement-based quantum networking applications.

An emerging security technology: using CuInS/ZnS quantum dots for optical physically unclonable functions.

Ella Mann-Andrews[1]
[1]*Lancaster University, United Kingdom*

Session 4, October 25, 2024, 15:30 - 16:45

Optical Physically Unclonable Functions (O-PUFs) are emerging as potential candidates for hardware security, leveraging the inherent randomness of optical phenomena to generate unique identifiers. This study focuses specifically on quantum dots (QDs) as a canditiate for O-PUFs, particularly CuInS/ZnS QDs, and compares their performance to rhodamine-based fluorescent dyes. Both materials are assessed for their scalability, stability, and high-fidelity security, offering challenge-response pairs (CR pairs)(d) in both the UV and visible spectra (f). Despite significant progress, the O-PUF field still lacks consensus on key metrics and standardised testing protocols. To address this gap, a unified test plan is proposed, supported by an open-source Python package to ensure reproducibility in future studies. This plan allows for a direct comparison between well-established QDs and novel fluorescent tags. The successful deployment of O-PUFs on documents and objects could provide a robust solution for counterfeiting mitigation (a)(b)(c) as the technology advances toward commercial adoption.



	Visible	UV
QD	9.25	35.01
FM	10.65	29.50

Cooperative emission from multiple, remote indistinguishable quantum dots.

Ms Sheena Shaji[1]
[1] *Heriot-Watt University, United Kingdom*

Session 4, October 25, 2024, 15:30 - 16:45

Photon mediated interactions can arise between emitters via coupling to a common electromagnetic mode or by quantum interference. Here, we engineer and probe cooperative emission arising via path erasure from multiple distant but indistinguishable quantum dots. The primary signature of cooperative emission, the emergence of bunching at zero delay in an intensity correlation experiment is used to characterize the indistinguishability of emitters, their dephasing and the degree of correlation in the join system that can be coherently controlled. To achieve photon emission in a scalable fashion with multiple indistinguishable quantum emitters, we introduce the use of spatial light modulators to independently control excitation and collection of an arbitrary number of quantum dots . We present results for upto 5 indistinguishable quantum dots. These results establish techniques to rapidly characterize indistinguishability of multiple emitters, to multiplex quantum light sources, to achieve scalable quantum light sources as inputs for programmable optical circuits.

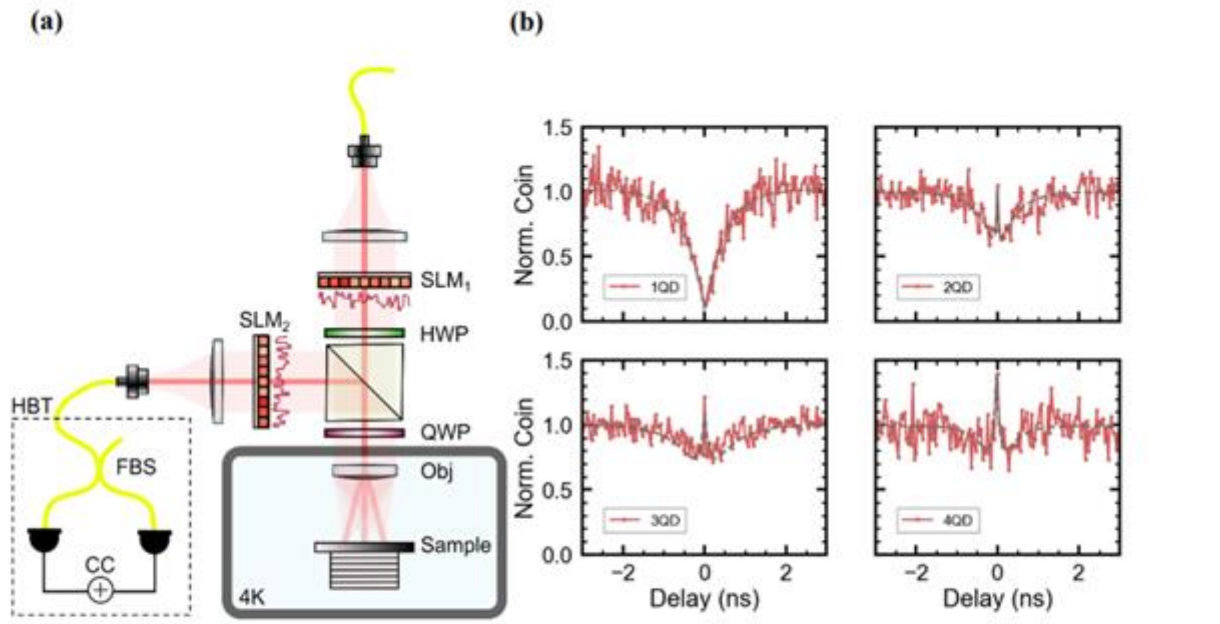


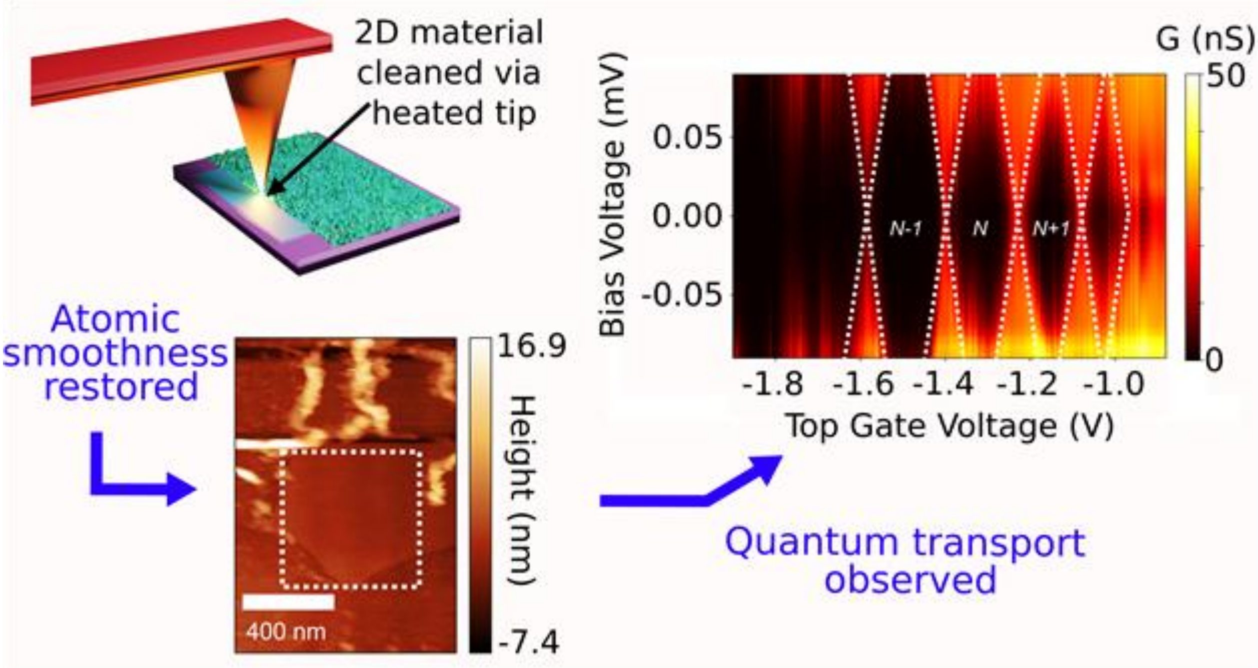
Figure 1: (a) Schematic of the experimental set-up. SLM1 is used to modulate the excitation laser so that it can be used to excite multiple spatially separated quantum dots on the sample that are chosen due to their spectrally indistinguishability. SLM2 is used to collect emission from the dots into a single mode fibre which erases the which-path information of the photons creating an entangled Dicke state. The collected photons are then sent to a Hanbury-Brown Twiss set-up for second order correlation measurements. **(b)** Experimental results for the second order correlation measurements are shown for 2, 3 and 4 indistinguishable quantum dots where the emergence of anti-dip confirms cooperative emission.

Single electron tunneling in 2D vdW heterostructures via thermo-mechanical cleaning of interfaces.

Mr Teymour Talha-dean[1], Mr Yaoju Tarn[2], Dr Subhrajit Mukherjee[2], Dr John Wellington[2], Dr Ding Huang[2], Dr Ivan Verzhbitskiy[2], Dr Dasari Venkatakrishnarao[2], Dr Sarthak Das[2], Mr Rainer Lee[2], Dr Abhishek Mishra[2], Dr Shuhua Wang[3], Dr Yee Sin Ang[3], Dr Johnson Kuan Eng Goh[2], Dr Chit Siong Lau[2]
*[1]Queen Mary University Of London, United Kingdom, [2]Agency for Science, Technology and Research (A*STAR), Singapore , [3]Singapore University of Technology and Design , Singapore*

Session 1, October 25, 2024, 09:30 - 10:30

Creating a two-dimensional electron gas is required to observe quantum transport in gate-defined two-dimensional van der Waals (vdW) material based quantum dots. In the device fabrication workflow, this means achieving damage and residue free interfaces throughout the device architecture to maintain low interface disorder. Current methods for achieving clean heterostructure interfaces involve techniques such as thermal annealing and pre-defining device elements prior to vdW material assembly. However, these approaches can induce unwanted damage or are limited in operational flexibility. Herein we demonstrated a site-selective interface engineering technique to create high quality heterostructure devices. The low disorder in our devices facilitates the observation of single electron tunneling at cryogenic temperatures. Namely, Nanoironing, where a thermal scanning probe combines heat and mechanical forces to reduce disorder at the 2D material surface. These results are important for the continued research toward quantum information processing in two-dimensional materials beyond graphene.



Wafer Scale Ultra-low Density InAs Quantum Dots on GaAs(100)

Dr Akshay Kumar Verma[1], Dr Chak Lam Chan[1], Dr Dominic Hallett[2], Dr. Savvas Germanis[2], Dr Edmund Clarke[3], Dr. Ian Farrer[1], Prof. Maurice S. Skolnick[2], Prof. Jon Heffernan[1,3]

[1]Department of Electronic and Electrical Engineering, University of Sheffield, United Kingdom, [2]Department of Physics and Astronomy, University of Sheffield, United Kingdom, [3]EPSRC National Epitaxy Facility, University of Sheffield, United Kingdom

Session 3, October 25, 2024, 13:45 - 15:00

We present on the growth of uniform low densities of self-assembled InAs quantum dots (QDs) on GaAs (100) using the Stranski-Krastanov growth mode employing solid source molecular beam epitaxy. We could realise tailored wafer scale ultra-low density QDs (<1 QD/um2) distributed uniformly over a 3" wafer utilising sub-critical In-deposition for QD formations. Preliminary measurements show that single QDs have low-resolution limited linewidths in the range 20-30 μeV for non-resonant excitations. These high-quality ultra-low-density single QDs have been incorporated into nanophotonic devices to study their characteristics further. This growth approach can be used to enhance the transfer and scaling of more advanced quantum photonics structures.

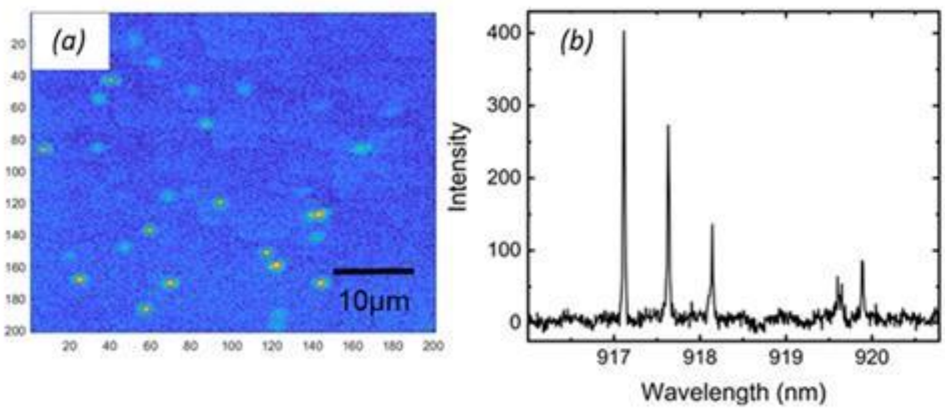


Figure (a): PL imaging of S-K InAs QDs on GaAs (100) with QD density in the order of 1 QDs/μm^2. (b) micro-PL spectra of S-K InAs QDs.

Site-control of InAs quantum dots by droplet epitaxy in MOVPE

<u>Mr Guoliang Zhou</u>[1], Dr Elisa M. Sala[1,2], Young In Na[1,2], Paul Fry[1,2], Jon Heffernan[1,2]
[1]Department of Electronic and Electrical Engineering, The University of Sheffield, United Kingdom, [2]EPSRC National Epitaxy Facility, The University of Sheffield, United Kingdom

Session 3, October 25, 2024, 13:45 - 15:00

We investigate the site-control of InAs/InP quantum dots fabricated by droplet epitaxy in metal-organic vapour phase epitaxy . InAs/InP QDs can emit photons around 1.55 µm. The optical signal has the smallest attenuation at this telecom window which is also known as the C-band. Therefore, InAs/InP serves as an ideal quantum light source capable of emitting single photons, making it suitable for applications in quantum computing and quantum key distribution as single photon emitters. The purpose of site-control QDs is to achieve the low densities required for single photon sources and to scale up quantum devices.

Here, we present the results of achieving site-control of QDs. A QD positioned within a nanohole is realized. The µPL results show a broad emission from 1300 to 1600 nm in correspondence with the patterns, and single line emission around C-band is detected in low power measurement, which we ascribe to QDs.

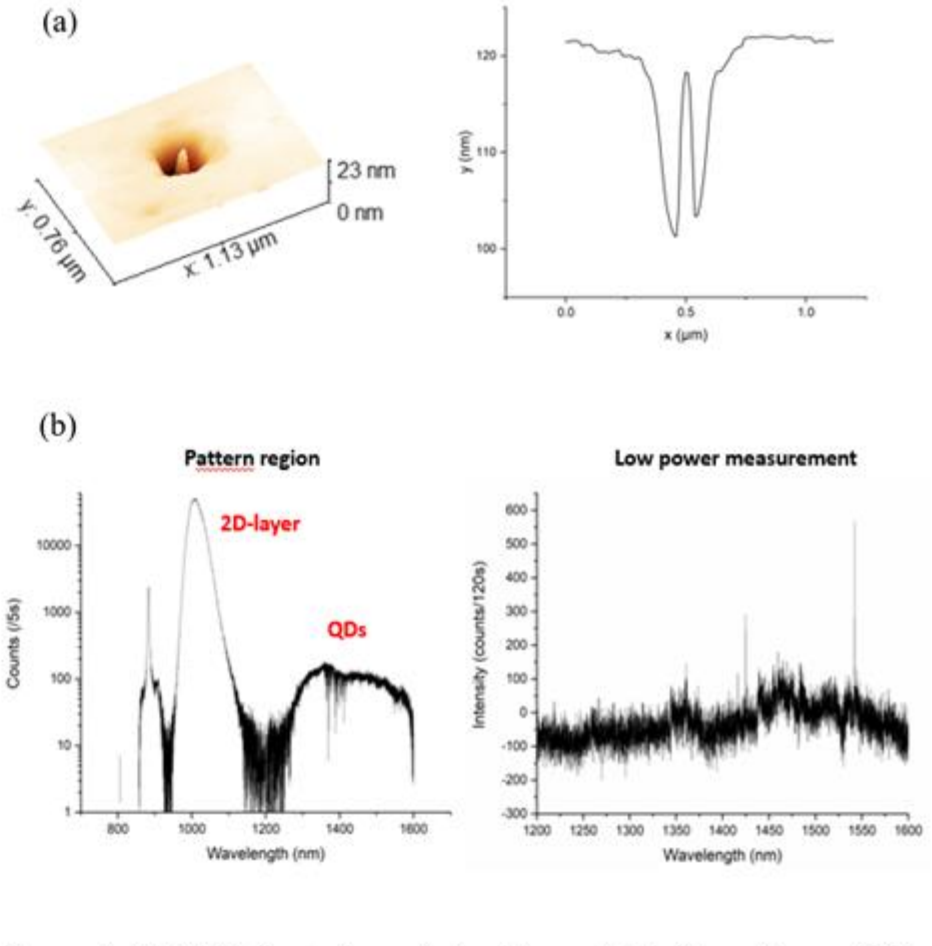


Figure 1: **(a)** A 3D of a single nanohole with one dot inside and its profile line
(b) µPL measurement of site-controlled QD.

Poster Presentations

Emission Polarisation Switching in Single CuInZnS3 Quantum Dots

Nasser Alhazmi[1,2], Vikramdeep Singh[1], Owen Evans[1], Aisling Stewart[1], William Solari[1], Alexander Osypiw[1], Bo Hou[1], Wolfgang Langbein[1]
[1]School of Physics and Astronomy, Cardiff University, UK, [2]Physics -college of applied science, Umm Al-Qura University, Saudi Arabia

CuInZnS3 quantum dots (QDs) might play a significant role in future of solar technology. However, missing knowledge regarding the carrier dynamics in these QDs is a challenge for optimising their performance and the commercial progress using this technology. This study investigates single QDs to understand the emission spectra and carrier dynamics.

A dipole like emission pattern was measured from single QDs which showed switching of dipole direction over seconds to minutes. This provides insight into the interaction between the hole and the phonons, previously seen in spectrally and time-resolved studies. It is believed to be due to polaron formation which provides multiple localised states for holes, enabled by the Cu d-bands, which show different dipole orientation due to varying p-band admixtures which form the dipole-allowed transitions. Varying local electric fields, created by local charge trapping under optical excitation, selects the stable emitting polaron, resulting in state switching over time.

[1] S.O.M. Hinterding et al., Nano Lett.21, 658 (2021), 10.1021/acs.nanolett.0c04239
[2] H.D. Nelson and D.R. Gamelin, J. Phys. Chem. C, 122, 18124 (2018) 10.1021/acs.jpcc.8b05286

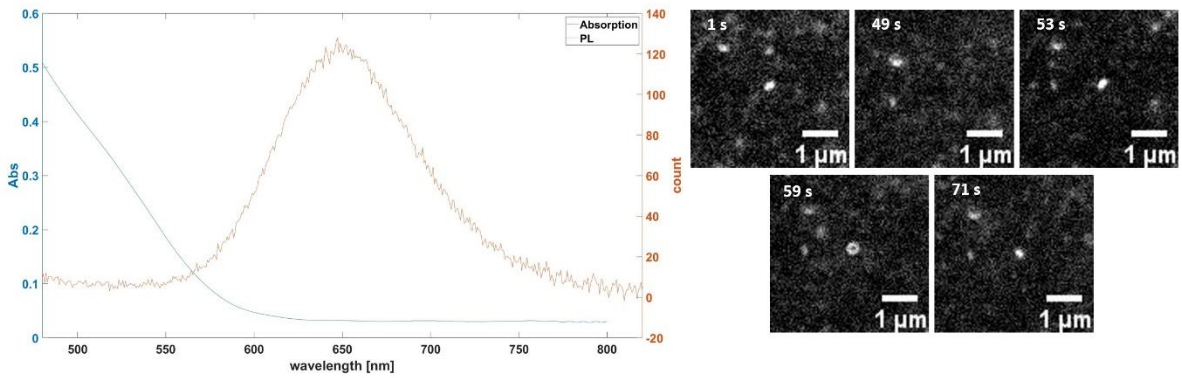


Figure 1: Graph of absorption / emission of QDs, and a crop of emission images of a dot which is switching at different times.

Indistinguishable single photons from direct-write projection lithography of quantum dot micropillars

Miguel Alvarez Perez[1,2], Petros Androvitsaneas[1,2], Rachel Clark[1,2], Matthew Jordan[1,2], Aristotelis Trapalis[5], Ian Farrer[3,4], Wolfgang Langbein[5], Anthony Bennett[1,2,5]
[1]School of Engineering, Cardiff University, United Kingdom, [2]Translational Research Hub, United Kingdom, [3]Department of Electronic and Electrical Engineering, University of Sheffield, United Kingdom, [4]EPSRC National Epitaxy Facility, University of Sheffield, United Kingdom, [5]School of Physics and Astronomy, Cardiff University, United Kingdom

We present a scalable and efficient method for fabricating quantum dot (QD) micropillar cavities using direct-write projection lithography, designed to yield high-performance single-photon sources with strong optical confinement, and coupling of these to the cavity mode. Our technique enables the precise formation of high-aspect ratio micropillars with smooth, defect-free sidewalls, which is essential for preserving the high-quality optical properties of the structure.

The quantum dots embedded within these micropillar cavities act as quantum emitters of indistinguishable single photons, a property crucial for quantum information processing. We measured second-order correlation function values of g^((2)) (0)=(1.91±0.01)×10^(-3), indicating near-perfect single-photon purity. Additionally, the measured high interference visibility of 0.941±0.008 highlights the indistinguishability of the photons, which is essential for interference-based quantum gates

Quantum modulation of a coherent state by a single electron spin

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The interaction of quantum objects lies at the heart of fundamental quantum physics and is key to a wide range of quantum information technologies. Photon-quantum-emitter interactions are among the most widely studied. Two-qubit interactions are generally simplified into two quantum objects in static well-defined states. In this work we explore a fundamentally new dynamic type of spin-photon interaction.

We demonstrate the modulation of a coherent narrowband laser by a coherently evolv-ing spin in the ground state of a quantum dot [1]. What results is a quantum modula-tion of the output phase (either 0 or π but no values in between), and a new quan-tum state of light that cannot be described classically.

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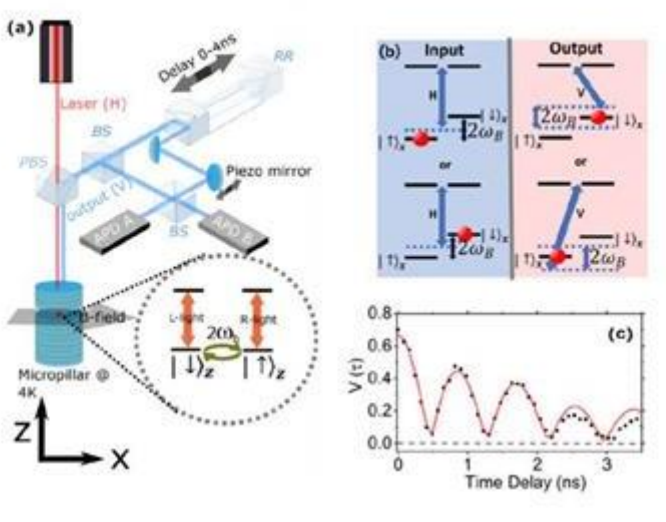

Figure 1. (a) The experimental setup used. (b) The level dia-gram with the input and output light noted. (c) The visibility of the light after it has been scattered by the charged Quantum dot.

Design principles for >90% efficiency and >99% indistinguishability broadband quantum dot cavities

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Quantum dot micropillars are an established device technology for producing on-demand single photons, entangled pair photons, cluster states and non-linear interactions such as photon number sorting and spinbased switching [1,2]. We have developed a design strategy for broadband micropillars by using structural effects to suppress decay into leaky channels, allowing
for high efficiencies beyond previous theoretical limitations in broadband cavities. We show that precise control of the side losses with the diameter and avoidance of propagating Bloch modes [3] in the DBR structure can result in extremely high active efficiency β > 0.99. We also show that such cavities naturally decouple from the phonon sideband, with the phonon sideband reducing by a factor of 5-33 allowing us to predict that the ZPL constitutes 98.2-99.7% of the field spectrum.

Further to the potential for single photon devices to get indistinguishabilities of > 0.999 and efficiencies of >0.96, the broad cavity is also capable of supporting high brightness biexciton cascade entangled pair sources: pair efficiencies of 75% are possible and the cavity mode should show no linear mode splitting that would otherwise destroy the polarization entanglement of the pair. Furthermore, the low-Q cavity can accommodate very short pulses, allowing for high single photon purity with projected g(2)~10-5 [4]. These low Q-factor designs are undemanding to manufacture compare to other very high brightness designs proposed. Due to their plausibility as deterministic sources with potential generation rates of 10GHz, overall efficiencies of > 95% or more, and near-perfect indistinguishabilities that are comparable to SPDC, carefully designed low Q-factor micropillars promise the prospect of using QDs widely as sources, switches and cluster state generators.

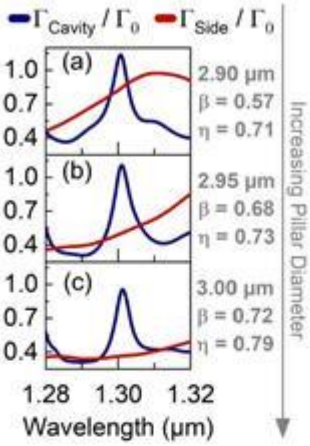

Figure 1 – Decay through the micropillar sides (red) can be tuned away by changing the diameter, increasing the ß-factor from 0.57 (a) to 0.72 (c).

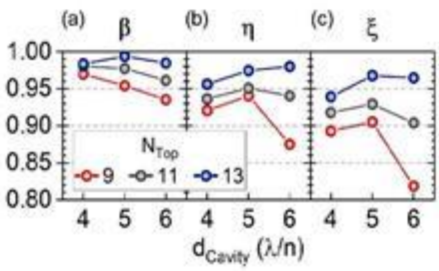

Figure 2 – Figures of merit for (a)active-, (b)passive-, and (c)internal-efficiencies of micropillars for varying structural parameters.

References

[1] P. Androvitsaneas et al., Phys. Rev. B **93**, 241409(R)(2016)
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On-Chip Spin Initialisation of Chiral Coupled InAs Quantum Dots in Glide-Plane Waveguide Devices.

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[1]Department Of Physics And Astronomy, University Of Sheffield, United Kingdom, [2]Center for Quantum Materials and Technologies, School of Mathematics and Physics, Queen's University Belfast , United Kingdom, [3]EPSRC National Epitaxy Facility, Department of Electronic and Electrical Engineering, University of Sheffield, United Kingdom

Chiral photonic devices provide the ultimate platform for on-chip interaction between the spin of charge carriers in quantum dot (QD) excitons and photons opening a new era of scalable, photon-mediated quantum spin network. By introducing a specially designed spin-photon interface, the spin of the QD can be entangled with the propagation direction of emitted photons via the chiral light-matter interaction. Our study, explores a GaAs glide-plane photonic crystal waveguide (GPW) with embedded InAs QDs, demonstrating strong Purcell enhancement and high directionality for individual QDs. Here we present a dramatic increase in chirality when a QD is driven on-chip and achieves a near-unity chiral contrast in the transmission geometry. This indicates a polarization-dependent spin transfer between the QD and the waveguide mode. The directional coupling also gives rise to a non-linear single-photon phase shift, forming the basis for scalable quantum phase gates and other on-chip spin-photonics applications in chiral quantum optics.

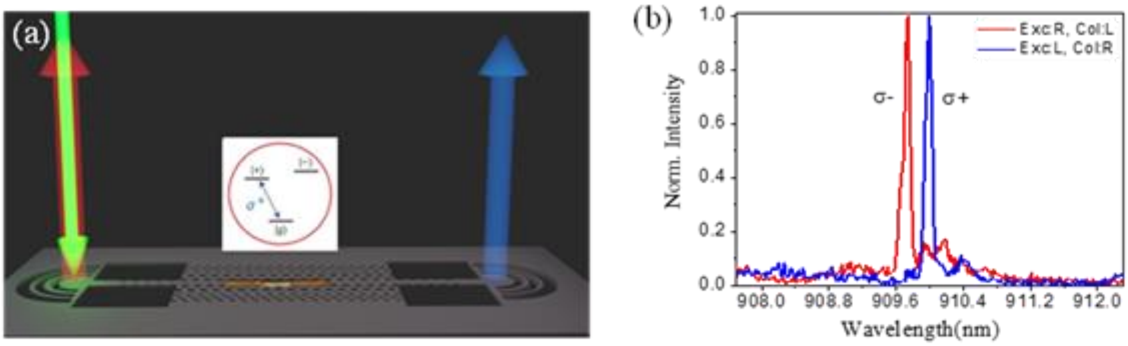

Fig.1(a): Schematic diagram of on-chip spin initialization. A resonant laser is sent from the left out-coupler, exciting only one spin component. (b): Photoluminescence spectra of the emission from a quantum dot exciton driven by a quasi-resonant CW laser (p-shell excitation) under a +3T magnetic field in Faraday geometry. The experiment is done by exciting the QD from one out-coupler and collecting the PL signal from the other.

The identification and population of energy levels of InAs on GaAs quantum dots under reverse and forward bias

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The Burt-Foreman 8-band k.p description has been used to identify the wavefunction and energy levels of InAs on GaAs quantum dots (QD). That description is used to identify the absorption and gain spectra of a QD ensemble. By calibrating the dot dimensions and the extent of material mixing, and by including traditionally forbidden transitions a match between experiments and simulations is achieved. Leading to dots of width 18.7 nm and 4.3 nm in height described by a parabolic confining potential due to material mixing. The calibrated model allows the simulation of reverse and forward bias effects. The reverse bias simulations capture the measured redshift, however fail to qualitatively replicate the reduction in absorption due to decreasing wavefunction overlap for increasing reverse bias. The forward bias effects are replicated by the model and discrepancies between model and experiment are attributed due to many-body effects, which are not included in the model.

Advanced Excitation Techniques for Quantum Dots

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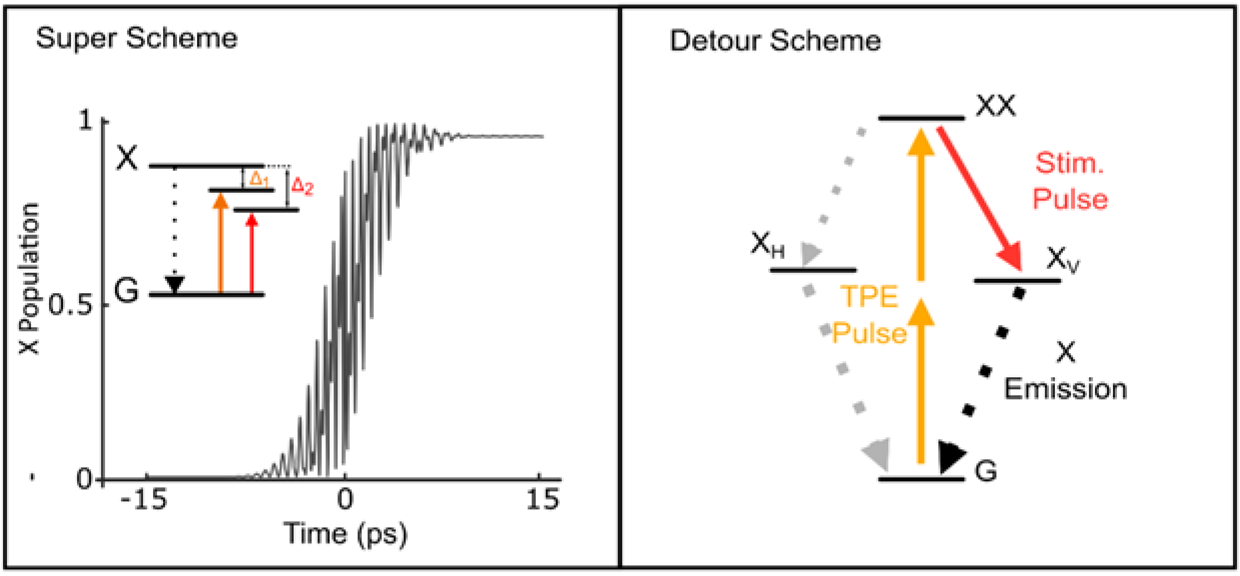
We present advanced excitation techniques for semiconductor quantum dots to enhance their utility as high-quality indistinguishable single-photon sources for quantum technologies. We analyze well-established excitation methods, highlighting their limitations in practical applications due to complex experimental setups and potential sensitivities to experimental imperfections. To overcome these challenges, we introduce innovative excitation strategies: below-bandgap excitation (SUPER scheme), the Detour scheme (Stimulated Two-Photon Excitation), and enabling Adiabatic Rapid Passage process by chirping the laser pulses. These techniques demonstrate improved robustness, efficient population transfer, enhanced photon indistinguishability, and higher single-photon purity, paving the way for breakthroughs in photonic applications.



Measure of charge noise on micropillar single photon sources

Thibaut Pollet[1], Dario Fioretto[1], Albert Adiyatullin[2], Prashant Ramesh[1], Anton Pishchagin[2], Pascale Senellart[1]
[1]Centre de Nanosciences et Nanotechnologies (C2N), France, [2]Quandela, France

Epitaxial quantum dots embedded in a micropillar cavity have proven to be high-performance single photon sources with high purity, high indistinguishability and high brightness. The next technological challenge relies on the emission of indistinguishable photons from independent sources. One of the main limitations comes from the fluctuating charges around the quantum dot, known as charge noise, that vary differently over time for independent micropillars. The charge noise results in a wandering of the resonance frequency and causes the detuning of the quantum dot relative to the micropillar cavity mode. In this study, we investigate the charge noise in our micropillars devices by using the resonant fluorescence of the quantum dot. We study both the influence of laser power and excitation time on the noise density spectra on various devices presenting different doping structures.

Phonon Coupling in Nanowire Quantum Dots

<u>Toby Rawlings</u>[1], Alistair Brash[1], Catherine Phillips[1], Philip J. Poole[2], Dan Dalacu[2], Jake Iles-Smith[3]
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Semiconductor quantum dots (QDs) are a leading platform for a bright source of indistinguishable single photons. However, due to their solid-state nature, interactions with their environment cause dephasing. These include the coupling of the QD to phonon modes of the host material, which occurs on picosecond timescales and even at cryogenic temperatures [1].

QDs grown in nanowires have several potentially advantageous attributes; the nanowire can act as a waveguide to achieve efficient collection of the emitted photons, whilst the QD emission wavelength can also be broadly tuned to various wavelengths of interest by modification of the growth conditions [2].
To directly resolve the QD-phonon interaction, measurements have been made in the frequency domain, under resonant excitation (Fig. 1), with a signal-to-background ratio exceeding 500:1 under optimal conditions. Time-domain measurements have also been made through recording the first-order coherence function (Fig. 2). In both cases excellent agreement is observed with a model based on the polaron master equation. These results present an important step towards realising the full potential of the nanowire QD platform for applications in fundamental quantum optics and optical quantum technologies.

References:
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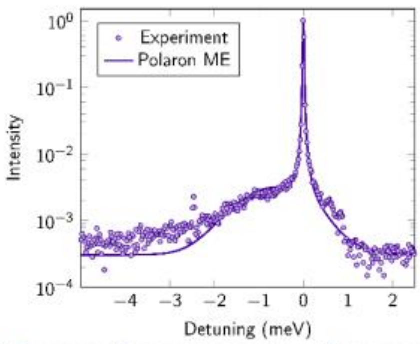

Figure 1: Resonance fluorescence spectrum from a nanowire quantum dot showing the PSB and ZPL. Inset showing laser rejection from detuned spectrum.

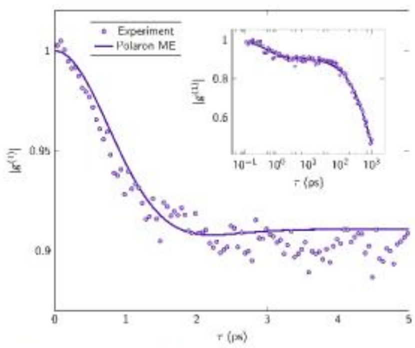

Figure 2: First-order correlation function of quantum dot emission

Designing the electron g-tensor in GaAs quantum dots

Christian Schimpf[1], Michal Gawelczyk[2], Ailton Garcia[3], Zhe Koong[1], Ahmed Hassanen[1], Martin Appel[1], Noah Shofer[1], Giang Nguyen[4], Richard Warburton[4], Mete Atatüre[1], Armando Rastelli[3], Dorian Gangloff[1], Niccolo Somaschi[5], Arne Ludwig[6], Andreas Wieck[6]
[1]University Cambridge, United Kingdom, [2]Wroclaw University, Poland, [3]Johannes Kepler University, Austria, [4]University of Basel, Switzerland, [5]Quandela, France, [6]University of Bochum, Germany

Semiconductor quantum dots (QDs) have demonstrated striking performance as near-deterministic sources of quantum light. Highly symmetric GaAs QDs obtained by local Al droplet etching (LDE) enabled proofs-of-concept in quantum communication, such as entanglement-based quantum key distribution and entanglement swapping. Recently, GaAs QDs have also been discovered as exceptional platforms for spin-physics, with potential spin-qubit memory times beyond 100 ms in the QD's nuclear ensemble. A single electron is the central proxy qubit between the light field and the nuclear spin-qubits. Controlling the electron g-tensor is hereby of vital importance. The strain-free growth of LDE GaAs QDs allows us to upfront design the g-tensor by tuning material composition and geometry. We fully identify the g-tensor components via polarimetry of emitted light while probing the directionality of the hyperfine interaction, exposed by g-factor anisotropy. We conclude that tailoring the g-tensor to the specific application is feasible.

Fabrication of Q-Dot Glass/2D Heterostructures for thermal Energy Harvesting

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[1]*University of Leeds, United Kingdom*

The pursuit of sustainable energy has driven significant research into thermal energy harvesting. This study focuses on fabricating Q-Dot Glass/2D heterostructures for potential integration onto SOI substrates in thermal energy applications. A three-layered heterostructure was developed using pulsed laser deposition. A thick layer of Bi2S3 Q-Dot silicate glass, synthesized via a high-temperature melt-quench technique at 1250°C, was deposited on silicon, serving as a heat sink. A few-nanometer-thick MoS2 layer was then added, with graphene sandwiched between the Q-Dot glass and MoS2 layers to enhance thermal energy conversion. Raman spectroscopy confirmed successful integration through distinct A1g and E2g bands and clear D and G bands of graphene. TEM imaging revealed smooth integration of 2D materials. These heterostructures present a significant advancement in thermal energy harvesting, promising enhanced efficiency and scalability, which could revolutionize energy use in the ICT sector and beyond.

Spin and vibrational effects in molecular quantum dots

Dr James Thomas[1]
[1]*Queen Mary University Of London, United Kingdom*

Quantum dots are typically lithographically defined or are comprised of mesoscopic (e.g. carbon nanotube) systems. In this presentation I will describe the challenges and opportunities of using individual molecules as quantum dots, allowing access to nanometre-scale dimensions and correspondingly, room temperature operation. In particular I will discuss electron-phonon coupling with both thermalized[1] and non-equilibrium distributions[2], and the exchange interactions that arise when studying molecules that coordinate paramagnetic lanthanide ions.[3]

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Poster Presentations

Poster No.	First Name	Last Name	Paper Title
1	Nasser	Alhazmi	Emission Polarisation Switching in Single CuInZnS3 Quantum Dots
2	Miguel	Alvarez Perez	Indistinguishable single photons from direct-write projection lithography of quantum dot micropillars
3	Savvas	Germanis	On-Chip Spin Initialisation of Chiral Coupled InAs Quantum Dots in Glide-Plane Waveguide Devices
4	Ben	Jakobs	The identification and population of energy levels of InAs on GaAs quantum dots under reverse and forward bias
5	Yusuf	Karli	Advanced Excitation Techniques for Quantum Dots
7	Thibaut	Pollet	Measure of charge noise on micropillar single photon sources
8	Christian	Schimpf	Designing the electron g-tensor in GaAs quantum dots
9	Geeta	Sharma	Fabrication of Q-Dot Glass/2D Heterostructures for thermal Energy Harvesting
10	James	Thomas	Spin and vibrational effects in molecular quantum dots
11	Toby	Rawlings	Phonon coupleing in NW
12	David	Dlaka	Design principles for >90% efficiency and >99% indistinguishability broadband quantum dot cavities
13	Petros	Androvitsaneas	Quantum modulation of a coherent state by a single electron spin

Quantum Dot 1 day meeting

25 October 2024

University of Bristol, Bristol, UK