Book of abstracts

3rd International GaAs Quantum Dot Workshop

Wrocław University of Science and Technology

7-9 May 2025

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About

About the Conference

3rd International GaAs Quantum Dot Workshop will take place May 7-9, 2025, at Wrocław University of Science and Technology. Following the success of previous editions held at the University of Oxford and Traunkirchen/JKU Linz, this year's workshop promises to continue fostering groundbreaking advancements in GaAs QD-based quantum technologies.

The focus of the workshop will be on (but not limited to) GaAs quantum dots (QDs) grown by local droplet etching, addressing key areas such as:

- QD Growth and Modeling
- Quantum Optics and Photonics
- Spin and Charge Physics
- Nuclear Spin Coupling and Environmental Interactions
- Excitations in Nuclear Spin Ensembles
- State Preparation, Control, and Decoherence
- Applications in Quantum Computing and Technology

Committees

Organizing committee
Michał Gawełczyk (chairman), WUST
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Doris Reiter, TU Dortmund
Armando Rastelli, JKU Linz

Timetable

T: Invited Tutorial, I: Invited Talk, C: Contributed Talk.

Wednesday, May 7th

09:00–09:30	**Registration**		
09:30–09:40	**Opening**		
WeA: Photons, emitters, and scaling			**Chair:** Armando Rastelli
09:40–10:05	I	**Arne Ludwig** Ruhr-Uni Bochum	Wafer scale GaAs quantum dot growth control for scalable single photon sources technology
10:05–10:30	T	**Doris Reiter** TU Dortmund, Germany	Theory of time-bin entangled photons
10:30–10:45	C	**Yusuf Karli** Cambridge University, UK	Passive Demultiplexed Two-photon State Generation from a Quantum Dot
10:45–11:00	C	**Jan Kaspari** TU Dortmund, Germany	Theoretical insights into dynamically dressed states via nonlinear optical signals
11:00–11:20	**Discussion**		
11:20–11:50	**Coffee**		
WeB: Spins and acoustics			**Chair:** Dorian Gangloff
11:50–12:15	T	**Evgeny Chekhovich** University of Sussex, UK	Few-electron states in optically active GaAs quantum dots probed by nuclear spins
12:15–12:40	I	**Matthias Weiß** Uni Münster	Quantum Dot Optomechanics with Surface Acoustic Waves
12:40–12:55	C	**Mateusz Kuniej** Wrocław University of Science and Technology, Poland	Hybrid Acousto-Optical Spin Control in Quantum Dots
12:55–13:10	C	**Zhe Xian Koong** University of Cambridge, UK	Quantum control of an optically active semiconductor spin with cyclic transitions

13:10–13:30	**Discussion**		
13:30–14:45	**Lunch**		
WeC: Scaling, integration, and symmetry			**Chair:** Peter Michler
14:45–15:10	I	**Juan Loredo** Sparrow Quantum, Denmark	Deterministic photon-emitter chip technology
15:10–15:35	I	**Lukas Niekamp** University of Basel, Switzerland	GaAs quantum dots in an open microcavity
15:35–15:50	C	**Krzysztof Gawarecki** WUST, Poland	Radiative Auger transitions in self-assembled quantum dots: the role of symmetry breaking via atomic disorder
15:50–16:05	C	**Michael Zopf** Leibniz Universität Hannover, Germany	Optimizing the Scaling of Quantum Dot Technologies: Overcoming the Bottleneck
16:05–16:25	**Discussion**		
16:25–16:45	**Coffee**		
16:45–18:40	**Poster session**		

Thursday, May 8th

ThA: Fabrication and bonding			**Chair:** Grzegorz Sęk
10:15–10:40	T	**Sandra Stroj** FH Vorarlberg, Austria	Ablation with ultrashort laser pulses
10:40–10:55	C	**Vishnu Prakash Karunakaran** FH Vorarlberg, Austria & JKU Linz, Austria	Femtosecond Laser-Based Fabrication Workflow for Single-Crystal PMN-PT Piezoelectric Actuators
10:55–11:20	**Discussion**		
11:20–11:50	**Coffee**		
ThB: Spins, photons, and where they meet			**Chair:** Doris Reiter
11:50–12:15	T	**Dorian Gangloff** University of Cambridge	Nuclear Spins: From Spoiler to Spoils
12:15–12:40	C	**Christian Schimpf** University of Cambridge, UK	Optical and magnetic response by design in GaAs quantum dots
12:40–12:55	C	**Maja Wasiluk** Wrocław Tech, Poland	Spin Dephasing in Single InAs(P)/InP Quantum Dots Probed via Hanle Effect
12:55–13:30	**Discussion**		
13:30–14:45	**Lunch**		
ThC: Environmental impacts and their taming			**Chair:** Fei Ding
14:45–15:10	I	**Katarzyna Roszak** FZU, Czech Republic	Qubit-Environment entanglement in quantum dots
15:10–15:35	I	**Eva Schöll** JKU Linz, Austria	Environmental effects on the quality of emission properties of GaAs QDs
15:35–15:50	C	**Priyabrata Mudi** TU Berlin, Germany	Voltage-Controlled Noise Suppression of GaAs QDs in Deterministically Fabricated Circular Bragg Grating Resonators
15:50–16:05	**Discussion**		
16:05–16:35	**Coffee**		
17:30–19:30	**City tours**		
19:30	**Dinner**		

Friday, May 9th

FrA: Quantum emitters in practice			**Chair:** Arne Ludwig
09:30–09:55	I	**Fei Ding** Leibniz University Hannover, Germany	Field test of semiconductor quantum light sources
09:55–10:20	T	**Simone Luca Portalupi** IHFG-University of Stuttgart	Deployed experiments with GaAs quantum dots frequency converted to telecom wavelength
10:20–10:35	C	**Jingzhong Yang** LUH, Germany	Quantum key distribution with single photons from semiconductor quantum dots
10:35–10:50	C	**Tobias Maria Krieger** JKU Linz, Austria	Excitonic fine-structure control of GaAs quantum dots
10:50–11:10	**Discussion**		
11:10–11:40	**Coffee**		
FrB: Quantum dot diversity			**Chair:** Katarzyna Roszak
11:40–12:05	I	**Michał Zieliński** NCU, Toruń, Poland	Crystal-phase quantum dots: atomistic calculations and machine learning
12:05–12:30	I	**Anna Musiał** Wrocław University of Science and Technology, Poland	Antimony-based quantum dots fabricated by local droplet etching for single-photon sources at telecom wavelengths
12:30–12:55	**Discussion**		
12:55–13:10	**Student awards, closing**		
13:10–13:40	**Lunch**		

List of Abstracts – Talks

Wednesday, May 7th

Wafer scale GaAs quantum dot growth control for scalable single photon sources technology

E. Kersting[1], H.G. Babin[1], N. Spitzer[1], J.Y. Yan[2], T. Kruck[1], N. Bart[1], A. Wieck[1], F. Liu[2], A. Ludwig[1]

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A key component for photonic quantum devices is a high-fidelity single photon source. Semiconductor quantum dots (QDs) in photonic cavities offer a promising route to create such devices. However, noise processes can hamper solid-state emitters [1]. Major contributors to decoherence and low efficiency include random charge rearrangements in the semiconductor environment or the QD itself [2], caused by processes such as Meitner-Auger recombination [3] or photoionization [4]. Therefore, it is crucial to meticulously control the molecular beam epitaxy (MBE) machine's vacuum and effusion cells to grow wafers of the highest possible quality. Another important aspect is heterostructure design: embedding quantum emitters in a diode can stabilize the charge state and shield against fluctuations [5]. Even for ternary matrix material local droplet etched (LDE) QDs [6,7], we demonstrate that this approach can lead to blinking-free, transform-limited emission [8]. To make QDs a scalable technology, even more demanding requirements must be met:

1. The QD density must range from 0.1 to 10 QDs/μm^2 across the whole wafer, which is extremely challenging for strain-driven self-assembly [9,10].

2. The emission wavelength of a substantial portion of the QDs must be within the tuning range of the design wavelength.

Wafer rotation stop enables material gradient growth. Newly discovered implications of this well-known method, such as periodic modulation of QD density [10] and QD emission wavelength [11], will be presented. The gradient growth method is also the basis for identifying ideal growth parameters [11,12] for wafer-scale production of homogeneous QD density and QD wavelength material. We will present photoluminescence results of our wafer-scale attempts to homogenize these parameters for LDE-grown GaAs QDs [12,13].

References

[1] A.V. Kuhlmann et al., Nat Phys 9, 570 (2013).
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Theory of time-bin entangled photons

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Entanglement is a key resource for quantum communication applications. While polarization entanglement is well-established, time-bin entanglement has recently emerged as a promising alternative. In this approach, the time axis is partitioned into discrete bins, and correlation measurements between photons in different bins are used to reconstruct the density matrix.

From a theoretical perspective, describing time-bin entanglement poses challenges, as time quantization is non-trivial. Instead of quantizing time directly, we employ multi-time correlation functions to reconstruct the corresponding density matrix, closely following the experimental procedure.

In this tutorial, we introduce the theoretical framework for calculating multi-time correlation functions in the context of quantum state tomography. Using the pedagogical example of a single photon in a superposition state, we derive the density matrix step by step. The method generalizes directly to two-photon states and enables simulation of time-bin entangled density matrices [1].

We then discuss the generation of time-bin entanglement. The standard method using two identical pulses yields high-fidelity entanglement only at low excitation powers. As a more robust alternative, we present a scheme that exploits the dark exciton [2] to generate high-quality time-bin entangled photon pairs from quantum dots.

References

[1] T. K. Bracht et al., Phys. Rev. A 110, 063709 (2024)
[2] F. Kappe et al. https://arxiv.org/abs/2404.10708 (2024)

Passive Demultiplexed Two-photon State Generation from a Quantum Dot

Y. Karli[1,2], I. A. Arenas[1], C. Schimpf[2], A. J. Garcia Jr.[3], S. Manna[3,4], F. Kappe[1], R. Schwarz[1], G. Undeutsch[3], M. Aigner[3], M. Peter[3], S. F. Covre da Silva[3,5], A. Rastelli[3], G. Weihs[1], V. Remesh[1]

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High-purity multi-photon states are essential for photonic quantum computing. Among existing platforms, semiconductor quantum dots offer a promising route to scalable and deterministic multi-photon state generation. However, to fully realize their potential we require a suitable optical excitation method. Current approaches of multi-photon generation rely on active polarization-switching elements (e.g., electro-optic modulators, EOMs) to spatio-temporally demultiplex single photons. Yet, the achievable multi-photon rate is fundamentally limited by the switching speed of the EOM. Here, we introduce a fully passive demultiplexing technique that leverages a stimulated two-photon excitation process to achieve switching rates that are only limited by the quantum dot lifetime. We demonstrate this method by generating two-photon states from a single quantum dot without requiring any active switching elements. Our approach significantly reduces the cost of demultiplexing while shifting it to the excitation stage, enabling loss-free demultiplexing and effectively doubling the achievable multi-photon generation rate when combined with existing active demultiplexing techniques.

Theoretical insights into dynamically dressed states via nonlinear optical signals

J. M. Kaspari[1], **T. K. Bracht**[1], **K. Boos**[2], **S. K. Kim**[2], **F. Sbresny**[2], **K. Müller**[2], **D. E. Reiter**[1]

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Nonlinear optical signals in optically driven quantum systems can reveal coherences and thereby open up the possibility for manipulation of quantum states, which is of key interest both for fundamental quantum optics and quantum technological applications. While the limiting cases of ultrafast and continuous-wave excitation have been extensively studied, the time dynamics of finite pulses reveal intriguing phenomena.

In this talk, I will present the theory of dynamically dressed states and investigate the nonlinear optical probe signals of a two-level system excited with a laser pulse of finite duration. Beyond the well-known, prominent Mollow peaks, the probe spectra unveil several smaller peaks for certain time delays between probe and pump pulses. Similar features have been recently observed for resonance fluorescence emission signals of excitonic transitions in a semiconductor quantum dot driven by finite Gaussian pulses [1]. Our study explores these emergent features, attributing their presence to the interplay of Mollow triplet physics and perturbed free induction decay effects [2]. These insightful findings enhance the overall understanding of optical signals in quantum two-level systems.

References

[1] K. Boos et al., Phys. Rev. Lett 132, 053602 (2024).
[2] J. M. Kaspari et al., Phys. Rev. Res. 6, 023155 (2024).

Few-electron states in optically active GaAs quantum dots probed by nuclear spins

P. Millington-Hotze[1], **P. Klenovsky**[2,3], **H. E. Dyte**[1], **G. Gillard**[4], **S. Manna**[5], **S. F. Covre da Silva**[5], **A. Rastelli**[5], **E. A. Chekhovich**[6]

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The knowledge of the energy spectrum completely defines the dynamics of a quantum system for a given initial state. This makes spectroscopy a key characterization technique when studying or designing qubits and complex quantum systems. In semiconductor quantum dots, the electronic quantum states can be probed through charge transport spectroscopy, but the electric current itself disrupts the fragile quantum system, and the technique is practically limited to gate-defined quantum dots. Epitaxial quantum dots benefit from excellent optical properties, but are usually incompatible with charge transport, while alternative spectroscopy techniques provide only limited information. Here we demonstrate a spectroscopy technique which utilizes nuclear spins as a non-invasive probe. By using spin currents instead of the charge currents we achieve near-equilibrium probing. Experiments are conducted on low-strain GaAs/AlGaAs epitaxial dots, revealing energy spectra for charge configurations with up to seven electrons and the subtle properties of the multi-electron states. The rich variety of observations includes long-lived spin-qubit states in s and p shells, ground-state phase transitions, strong spin-orbit coupling regimes, and anomalously fast nuclear spin diffusion. Experiments are backed up by good agreement with the first-principles configuration-interaction numerical modelling. Our work uncovers few-electron states as a new operating regime for optically active quantum dots. Accurate control and probing of many-body states offers a test-bed system for fundamental physics studies, while prospective technological applications include electron spin qubits with extended coherence and scalable electrical control.

Quantum Dot Optomechanics with Surface Acoustic Waves

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Precise tuning and control of the emission energy of semiconductor quantum dots (QDs) is crucial for their application as single-photon sources in quantum technologies. The solid-state nature of QDs enables this control through deformation potential coupling. In this work, we achieve this tuning using the coherent phonon field of a surface acoustic wave (SAW). SAWs are mechanical waves that propagate along the surface of a crystal and can be electrically excited on piezoelectric substrates. The dynamic strain field of the SAW induces a harmonic modulation of the QD's transition energy, which can be observed in both spectral- and time-resolved photoluminescence measurements of individual QDs. To achieve single photons with high coherence and indistinguishability, we employ optically resonant excitation. In this regime, the dynamic modulation results in a comb-like resonance fluorescence spectrum, consisting of a central zero-phonon line and a series of phononic sidebands (PSBs) on either side, separated by the energy of a single SAW phonon. Furthermore, by simultaneously applying two mutually coherent SAWs to the QD, we can precisely control the emission intensity of the different spectral components via a wave-mixing process. [1,2] The presented parametric excitation scheme is not restricted to SAWs excited directly on III-V semiconductors. Hybrid devices comprising materials such as GaAs or $LiNbO_3$ can also be utilized, with $LiNbO_3$ offering an approximately 100 times stronger electromechanical coupling than GaAs, thereby potentially enhancing the modulation strength and tuning precision in these systems. [3]

References

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Hybrid Acousto-Optical Spin Control in Quantum Dots

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Multiple interfaces with light, microwaves, nuclear spins, and mechanical waves make optically active semiconductor quantum dots (QDs) excellent components of quantum hybrid systems [1]. Combining various quantum degrees of freedom to process, store, and transfer information may lead to the creation of next-generation devices. Common coupling between systems of different types is essential in such a case. Not all solid-state systems are optically active, but all of them can, in principle, be coupled to acoustic waves via material deformations. However, in QDs, phonons can only modulate the energy and virtually do not interact with the electron spin. To overcome this limitation, we propose an acousto-optical method that introduces acoustic control of spin states to this system. To drive spin rotations, we use a detuned optical coupling to a common trion state in the Voigt configuration and acoustic vibration that modulates the detuning. The optical field removes spin conservation and thus allows the nominally forbidden acoustic coupling of spin states. We model the states in a QD as a three-level system coupled to a continuous-wave laser field in the dipole and rotating wave approximations, with the charge exciton state energy modulated by a monochromatic coherent acoustic wave. Apart from directly finding the evolution of the system by solving the Lindblad master equation, we provide analytical insight within the effective two-level model, where the trion state is eliminated. With this model, we show that the angle of the qubit rotational axis can be controlled with the acoustic field parameters. Since full spin rotation cannot be achieved with a single acoustic pulse without significant trion state occupation, we combine two pulses with different phases, achieving complete spin control. Additionally, we evaluate the impact of the trion recombination on spin control, which is the only limitation in this scheme, identifying systems where fidelity exceeding 99.9Introducing spin-phonon interface to QDs opens a path for controllable spin-phonon entanglement and acoustic state transfer. Moreover, the simultaneous coupling of an electron spin to multiple fields creates the potential for QDs to become versatile transducers over different physical domains.

References

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Quantum control of an optically active semiconductor spin with cyclic transitions

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Solid-state spins are promising candidates as spin-photon interface for quantum technologies. Semiconductor quantum dots have shown excellent optical and spin coherence [1] and exhibit high collection efficiencies when coupled to photonic structures. Under a longitudinal magnetic field, the presence of cycling transitions allows for single-shot spin-state readout. Optical spin-control experiments are however done with an transverse magnetic field where a symmetric spin-Λ system facilitates quantum control of the electronic spin with high Rabi frequencies. This contradiction indicates incompatibility of both optical spin control and single-shot state readout under an applied transverse magnetic field configuration. To circumvent this, we use a stimulated Raman scheme to address a highly asymmetric spin$-\Lambda$ system from a negatively charged exciton under an applied longitudinal magnetic field, where we can precisely compensate for GHz-scale differential stark shift and perform nuclear spin cooling. This allows full quantum control of an electron spin qubit equipped with spin-selective optical transition with cyclicity of 407. Embedding such device in a photonic structure would then improve the collection efficiency further, allowing for high fidelity single-shot readout and spin control within the same device. This marks a critical step towards realizing efficient, long-lived quantum repeaters.

References

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

Deterministic photon-emitter chip technology

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The control of quantum states of light enables advancing multiple modern technologies. Semiconductor artificial atoms, such as quantum dots embedded in photonic structures, offer some of the most advances sources of quantum light. In this context, we describe Sparrow Quantum technology for producing high-performing sources of single-photons with features approaching the ideal.

GaAs quantum dots in an open microcavity

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In recent years, GaAs quantum dots were established as quantum emitters with exceptional photonic coherence [1] and hosts of coherent electronic spins [2]. The ability to control the spin in an all-optical manner as well as the intrinsically low strain allow for efficient cooling of the nuclear spin bath. This way, the electronic spin coherence time can be greatly enhanced [3]. Together with the high photon indistinguishability, this makes GaAs quantum dots a promising platform for deterministic spin-photon interfaces and hence future photonic quantum technologies. However, in order to obtain high photon extraction efficiencies required by technological applications, engineering of the quantum dot's photonic environment is needed. A successful concept in this regard is an open, tunable microcavity [4]. This approach allows for technologically relevant end-to-end efficiencies while being compatible with spin control and cooling of nuclear spins [5]. The integration of GaAs quantum dots into such a microcavity requires the design and growth of a semiconductor heterostructure and the fabrication of top mirrors. A GaAs quantum dot in an open microcavity will be an enabling device for both fundamental research as well as technological applications.

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Radiative Auger transitions in self-assembled quantum dots: the role of symmetry breaking via atomic disorder

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The optical spectra of semiconductor quantum dots are typically dominated by the emission lines corresponding to direct excitonic recombination. However, the interplay of Coulomb interaction and symmetry breaking leads to additional spectral features such as radiative Auger transitions. This process introduces red-shifted emission lines, offering a unique opportunity to probe single-particle excitation energies in the quantum dot spectrum that would otherwise remain inaccessible [1].

In our joint theoretical-experimental work [2], we present measurements of such radiative Auger lines for a range of InGaAs/GaAs self-assembled quantum dots. Within a realistic $sp^3d^5s^*$ tight-binding model combined with configuration-interaction approach, we calculate the emission from a negative trion. We get a very good agreement between the theory and the experimental data. We investigate the role of symmetry and show that correct ordering of the emission lines can be obtained assuming symmetry breaking by alloy disorder. We also provide in-depth analysis based on the group theory. The presented theoretical model and results give insight into the interplay between the symmetry breaking and the position and strength of the radiative Auger lines.

We show that the atomistic tight-binding model combined with the configuration-interaction approach accounts for the intensities of the Auger lines and the changes from quantum dot to quantum dot. We emphasize the role of symmetry breaking caused by alloy disorder, which turned out to be essential for the strength of the radiative Auger lines.

References

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Optimizing the Scaling of Quantum Dot Technologies: Overcoming the Bottleneck

M. Zopf[1,2], **C. Ma**[1], **J. Yang**[1], **Y. Zhang**[1], **M. Heller**[1], **F. Benthin**[1], **F. Ding**[1,2]

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GaAs quantum dots are pivotal in advancing quantum optical technologies due to their ability to produce high-quality single photons and entangled photon pairs. Significant progress has been made in creating devices with efficient, coherent single-photon emission, and in performing entanglement swapping and quantum key distribution experiments. However, the transition from demonstrations involving individual quantum dots to those utilizing multiple dots remains limited. This talk will delve into the factors contributing to this bottleneck and explore potential solutions. These include the design of innovative photonic structures with multiple tuning capabilities and efficient fiber coupling, precise determination of quantum dot positions within host crystals, and the standardization of experimental protocols and data management. Addressing these challenges is essential for realizing a scalable future for GaAs quantum dot technologies.

Thursday, May 8th

Ablation with ultrashort laser pulses

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Ultra-short pulse laser processing has become a highly precise and versatile technique for various applications. This tutorial presentation aims to provide a fundamental understanding of the underlying mechanisms of light-matter interaction in the femtosecond time scale, with a focus on the ablation process. The most important physical principles, such as nonlinear absorption, the coupling of energy into the material and material ablation, are discussed. In addition, simplified models are presented to describe the most important processing parameters, such as the material removal threshold or the ablation efficiency. These findings form the basis for the development of optimized processing strategies for modern applications.

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Femtosecond Laser-Based Fabrication Workflow for Single-Crystal PMN-PT Piezoelectric Actuators

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This work presents a comprehensive femtosecond (fs) laser-based fabrication workflow for the realization of complex piezoelectric actuators using single-crystal PMN-PT. The process enables precise local thinning of active regions to enhance strain transfer while preserving mechanical stability, followed by metallization and selective structuring of electrical contacts over non-planar surfaces via fs-laser ablation. The final device geometry is defined through ultraviolet fs-laser cutting, leveraging linear absorption at short wavelengths to improve edge quality and minimize damage - especially within laser-thinned regions. The workflow builds upon earlier demonstrations of fs-laser micromachining of PMN-PT [1] and advances strategies for high-precision laser ablation on crystalline substrates [2]. These results establish a scalable and precise fabrication platform for miniaturized PMN-PT actuators targeting applications in microsystems and quantum photonics [3,4].

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Nuclear Spins: From Spoiler to Spoils

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Control of nuclear spin ensembles in semiconductor quantum dots is a critical challenge for realizing scalable solid-state quantum technologies. This tutorial provides a comprehensive introduction to nuclear spin cooling—strategies aimed at reducing the entropy of the nuclear environment to enhance electron spin coherence, enable full quantum control of the electronic spin, and facilitate a long-lived quantum memory. We begin by reviewing the hyperfine interaction between confined electron or hole spins and the surrounding nuclear bath, highlighting its role in spin dephasing and back-action. The tutorial then surveys key nuclear spin cooling techniques, including dynamic nuclear polarization (DNP) and optical pumping schemes tailored to single-electron quantum dots.

Optical and magnetic response by design in GaAs quantum dots

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Quantum networking technologies use spin qubits and their interface to single photons as core components of a network node. This necessitates the ability to co-design the magnetic- and optical-dipole response of a quantum system - a capability that has been notably absent in solid-state platforms where spin-orbit coupling and the crystalline environment lead to inhomogeneity of electronic g-factors and optically active states. Here, we demonstrate the ability to design both the optical and magnetic response of a solid-state quantum emitter a priori. We show that GaAs quantum dots (QDs), obtained via local droplet etching epitaxy and already known as exceptionally coherent and efficient quantum light sources, also exhibit spin and optical properties that follow directly from assuming the highest possible system symmetry. Our measurements of electron and hole g-tensors - using a new sign-sensitive measurement protocol based on the hyperfine interaction - and of transition dipole moment orientations for charged excitons agree with our predictions from a multiband k.p simulation constrained only by a single atomic-force-microscopy reconstruction of QD morphology. This agreement is verified across multiple wavelength-specific growth runs at different facilities within the range of 730nm to 790nm for the exciton emission. Remarkably, our measurements and simulations track the in-plane electron g-factors through a zero-crossing from -0.1

to 0.3 and linear optical dipole moment orientations fully determined by an external magnetic field. The robustness and generality of these results establish a fundamentally new paradigm for solid-state spin-photon interfaces: one in which the properties of a spin qubit and its tunable optical interface can be designed - prior to growth - for a target magnetic and photonic environment, with direct applications to scalable and high-fidelity spin-photon entanglement.

Spin Dephasing in Single InAs(P)/InP Quantum Dots Probed via Hanle Effect

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Electron spins in quantum dots (QDs) are promising qubit candidates due to long relaxation times enabled by strong spatial confinement. However, dephasing induced by nuclear spin fluctuations remains a key obstacle, as it limits coherence time [1] and reduces entanglement fidelity [2]. While optical techniques allow efficient spin initialization and control, understanding dephasing mechanisms is essential for scalable quantum technologies.

We report Hanle effect measurements on individual InAs(P)/InP QDs emitting in the third telecommunication window. This is the first demonstration of this method applied to single QDs in this spectral range, which is highly relevant for fiber-based quantum communication. The Hanle effect enables probing spin dephasing in both ensembles and individual dots without the need for time-resolved measurements.

The QDs were grown by molecular beam epitaxy, with a ripening process resulting in a low spatial density ($\sim 2\times10^9$ cm^{-2}). A distributed Bragg reflector beneath the QDs increased photon extraction efficiency to 6.8% for planar samples and up to 13.3% for QDs in cylindrical mesas (numerical aperture NA = 0.4) [3]. These QDs exhibit single-photon emission purity, with a second-order correlation function $g^{(2)}(0) < 0.01$, making them candidates for quantum photonic devices [4].

Excitonic complexes were identified via power- and polarization-dependent photoluminescence in the Voigt configuration. We focused on a negatively charged trion (X^-) with a binding energy of 4.8 meV. Under quasi-resonant circularly polarized excitation, we observed a degree of circular polarization DOCP $= -36\%$ [5].

Using Hanle effect measurements and a previously reported electron g-factor ($g_e = 0.25$) [6], we estimated the electron spin dephasing time as $T_2^* = 1.6$ ns. This result indicates that dephasing is dominated by the interaction with the frozen fluctuation of the nuclear spin [7]. Despite the large nuclear spin of indium ($I = 9/2$) and its hyperfine constant ($A_{\mathrm{In}} = 56$ μeV) [8], the observed T_2^* values are comparable to those in GaAs QDs, likely due to the larger volume of telecom QDs [7, 9]. The fact that T_2^* is comparable to the radiative lifetime highlights the potential of these QDs for realizing efficient spin-photon interfaces, which are key building blocks for quantum repeaters and multiphoton entanglement protocols.

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Qubit-Environment entanglement in quantum dots

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An evolution between a system and its environment which leads to pure dephasing of the system may either be a result of entanglement building up between the system and the environment or not (the second option is only possible for initially mixed environmental states). I will present a straightforward way for the theoretical determination between the two scenarios and then present two schemes for experimental detection of such entanglement. One of the schemes which involves indirect detection of qubit-environment [1] will be exemplified on a spin qubit confined in a lateral quantum dot interacting with a nuclear spin environment via the hyperfine interaction. The other scheme which is more direct [2] will be exemplified on a charge qubit in a self assembled quantum dot interacting with a phonon reservoir. Both schemes require only operations and measurements performed on the qubit.

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Environmental effects on the quality of emission properties of GaAs QDs

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Many quantum technology applications require tailored quantum light sources that satisfy stringent criteria on the emission properties. Epitaxial semiconductor quantum dots operated at cryogenic temperatures (5 K) have emerged as promising sources of single photons with high purity, and near-unity indistinguishability. Additionally, the biexciton - exciton cascade allows the direct generation of highly entangled photon pairs, although the indistinguishability of cascaded photons is fundamentally limited by the lifetime ratio of the involved states [1]. We show that this ratio can be widely tuned via an applied electric field [2], and demonstrate a corresponding increase in photon indistinguishability through Hong-Ou-Mandel interference measurements, in agreement with theoretical predictions. Furthermore, we investigate the emission properties at elevated temperatures, where the quantum dots deviate from a clean two or three level behavior due to interactions with phonons. We investigate how phonon-induced pure dephasing degrade photon coherence, leading to broader emission spectra and reduced indistinguishability. These findings help the development of quantum light sources combining all key properties for applications in quantum technology tailored for higher-temperature operation.

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Voltage-Controlled Noise Suppression of GaAs QDs in Deterministically Fabricated Circular Bragg Grating Resonators

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The generation of indistinguishable single photons is a fundamental requirement for emerging quantum technologies, particularly in quantum repeater networks and distributed quantum computing, where ideal single-photon sources are essential. However, the presence of charge noise in epitaxial quantum dots gives rise to spectral diffusion and accelerates exciton dephasing, thereby limiting their viability in quantum photonic applications. In this work, we present a robust and scalable approach to suppressing charge noise-induced decoherence in droplet-etched GaAs quantum dots embedded within an n-i-p diode structure [1] and deterministically integrated into an electrically contacted circular Bragg grating (e-CBG) nanocavity. This electrically tunable cavity design [2] facilitates charge environment stabilization through the application of a bias, while ensuring a photon extraction efficiency of $(37 \pm 2)\%$. Hong-Ou-Mandel two-photon interference measurements on the QD-CBG device reveal a pronounced voltage dependence of both the exciton dephasing time and photon indistinguishability. Remarkably, under quasi-resonant excitation, coherence times T_2 are observed to approach the limit of Fourier-limited coherence times $T_2 = 2T_1$, without the necessity for additional post-processing techniques. The findings of this study are corroborated by theoretical models and voltage-dependent linewidth measurements, underscoring the efficacy of electrical control in tuning coherence properties. This study presents a pragmatic approach for achieving high-purity, indistinguishable photon emission from GaAs quantum emitters suffering from spectral diffusion. It also suggests a potentially viable path for integrating GaAs quantum dot sources with rubidium-based atomic memories in hybrid quantum networks.

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Friday, May 9th

Field test of semiconductor quantum light sources

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Semiconductor quantum dots (QDs) are among the most promising quantum light sources, with the potential to revolutionize quantum communication research. For instance, utilizing on-demand single photons and entangled photons in quantum key distribution (QKD) protocols can significantly enhance security and increase the maximum tolerable loss. However, several critical challenges must be addressed to bridge the gap between laboratory experiments and long-distance field tests using QDs. In this talk, I will first review our work over the past years on QD-based single-photon and entangled-photon sources. Following that, I will present our recent field tests of single photon transmissions over a 79 km link between Hannover and Braunschweig, with 25.49 dB loss — equivalent to 130 km in direct-connected optical fiber.

Deployed experiments with GaAs quantum dots frequency converted to telecom wavelength

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Strong research efforts are made to realize photonic quantum implementations outside a well-controlled lab environment. Key requirement is an efficient source of quantum light, better if on-demand. Semiconductor, epitaxial quantum dots can provide single and entangled photon pairs with high brightness, furthermore capable of triggered operation, key for upscaling the experimental complexity [1].

In this talk, we will discuss the role that GaAs quantum dots can play in quantum information and communication, particularly thanks to the excellent properties of the emitted photon. First, the use of highly-entangled photon pairs in an intra-city fiber network deployed within the city of Stuttgart will be highlighted. Quantum frequency conversion is employed to convert photons from NIR to telecommunication wavelength, while maintaining a high degree of entanglement. After one photon of the pair propagates for 36 km across the city, high entanglement fidelity is still observed [2].

Second, we will report on the recent results in implementing photonic quantum teleportation with remote emitters. In this experiment, two distinct QDs are employed, and two independent quantum frequency converters ensures operation and telecommunication wavelength, and help erasing the frequency mismatch of the two sources. After performing the Bell state measurement at telecom wavelength, a teleportation fidelity of 0.7211(33) was obtained, well above the classical limit [3].

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Quantum key distribution with single photons from semiconductor quantum dots

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Quantum key distribution (QKD) enables the transmission of information that is secure against general attacks by eavesdroppers. The use of on-demand quantum light sources in QKD protocols is expected to help improve security and maximum tolerable loss. Semiconductor quantum dots (QDs) are a promising building block for quantum communication applications because of the deterministic emission of single photons with high brightness and low multiphoton contribution. In a recent work we have reported on the first intercity QKD experiment using a bright deterministic single photon source. A BB84 protocol based on static polarisation encoding has been realised using the high-rate single photons in the telecommunication C-band emitted from a semiconductor QD embedded in a circular Bragg grating structure [1]. Here we present the high-speed modulation of the polarisation states of telecom C-band single photons. A sequence of 32-bit digital pseudo-random numbers is repeatedly encoded into the polarisation via the phase-modulator involved Sagnac-Loop interferometer. An ultra-low quantum bit error rate 1

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Excitonic fine-structure control of GaAs quantum dots

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Droplet-etched GaAs quantum dots (QDs) are promising sources of entangled photon pairs for quantum information and communication applications, owing to their deterministic emission of bright, indistinguishable, and polarization-entangled photon pairs [1]. These exceptional properties can be simultaneously leveraged through a photonic structure and strain engineering of the emitter. In our previous work, we demonstrated that a QD embedded in a tailored cavity can efficiently generate bright entangled photon pairs with high fidelity by eliminating the fine structure splitting (FSS) via multi-axial strain tuning [2]. However, tuning of the emission wavelength is still limited and fabricating such high-performance devices at scale remains challenging. Identifying an emitter that simultaneously meets all requirements—spatial alignment and mode matching with the cavity, as well as a sufficiently small FSS that can be reliably tuned to zero—is often statistically improbable.

In this work, we present a novel approach for improving strain transfer by bonding GaAs QDs in nanomembranes-on-reflector to a 12.5 µm thin molybdenum (Mo) foil. This Mo-bonded structure is integrated with a six-legged micro-machined piezoelectric actuator, enabling FSS tuning from 17 µeV to zero and a strain-induced energy shift of 1.1 µeV/V—more than ten times the efficiency of a nanomembrane-on-GaAs carrier sheet with 50 µm thickness (compare to [2]). This improvement is made possible by the superior mechanical stability of Mo compared to thinned GaAs, allowing for a reduced layer thickness. Additionally, the matched thermal expansion coefficient minimizes the spectral drift of QD emission at cryogenic temperatures. The use of Mo-bonded nanomembranes significantly increases the number of cavity-enhanced QDs that can function as near-ideal entangled photon sources, while also enabling larger wavelength tuning, essential for interfacing with quantum memories or other QDs.

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Crystal-phase quantum dots: atomistic calculations and machine learning

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Crystal phase quantum dots are formed during nanowire growth by the vertical stacking of distinct crystal phases within the same chemical compound, such as InP or GaAs. Using an atomistic many-body approach, I demonstrate that these structures can exhibit a peculiar and rare antibonding hole ground state [1]. Notably, even minor strain effects arising from the wurtzite–zinc-blende lattice mismatch, often neglected in modeling, as well as spontaneous polarization [2] originating at phase boundaries, can significantly modify the character of the lowest-energy hole states. These effects manifest in distinctive double-peak features in the excitonic optical spectra. Furthermore, we show that a rigorous, artifact-free modeling of crystal phase quantum dots requires the inclusion of all additional potentials on an equal footing with the electron–hole interaction. I discuss a robust theoretical framework for investigating these systems' electronic and optical properties, while also addressing challenges related to uncertainties in wurtzite bulk parameters. The importance of accurate excitonic calculations is underscored by the potential of crystal phase quantum dots for applications in nanowire-based photonics; however, further theoretical and experimental efforts are needed to achieve good qualitative agreement.

In the second part of my talk, I will present a strategy for estimating single-particle energies in double-nanowire quantum dots by combining an atomistic tight-binding approach with machine learning techniques [3]. Specifically, we employ a neural network enhanced by transfer learning, enabling the accurate prediction of ground state energies with root-mean-square deviations of approximately 1 meV, while relying on only a small subset of training data. This training set represents a fraction of the vast multidimensional parameter space defined by dot sizes and inter-dot separations. Beyond the systems explored in this study, the methodology offers promising opportunities for researchers tackling the inverse computational problem of inferring nanostructure morphology from optical spectra.

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Antimony-based quantum dots fabricated by local droplet etching for single-photon sources at telecom wavelengths

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In this contribution development of alternative material platform for quantum dot (QD) emission at telecom C band is reviewed. The idea is to combine growth mode of local nanohole droplet etching [1,2] beneficial for quantum emitter properties with Antimonides. First, transfer of the growth method will be described including influence of the material of the droplet and growth parameters (temperature and Sb flux) on the geometry and the density of the etched nanoholes [3]. The QDs formed by filling the nanohole in AlGaSb with (In)GaSb material feature type I band alignment in contrast to type II band alignment typical for Antimony-based structures for mid infrared range studied so far. This is a result of the fact that energy at different points of the Brillouin zone are characterized with different susceptibility to confinement, e.g., depending on the thickness of the quantum well either L point or Γ point constitutes the minimum energy in the conduction band leading to indirect-direct bandgap crossover [4].

GaSb filling of the nanoholes results in emission at around 1480 nm, inhomogeneous broadening of the QD ensemble below 10 meV with QD density as low as 2.5 x 107 /cm2. The single-photon emission with probability of the multiphoton emission of 16% under pulsed nonresonant excitation has been demonstrated. In the coincidences histogram strong carrier recapture is evidenced due to strong intervalley scattering which can be traced back to small energy difference between the energy minima for different k vectors [5]. To redshift the QD emission towards 1550 nm indium has to be added to the QD material which therefore becomes strained. So far the single photon emission has been shown for 1500 nm (multiphoton emission probability of 5% under LO phonon assisted excitation) [6] and single QD emission - for 1550 nm.

Experimental results are supported by 8 band k.p calculations combined with configuration interaction method for excitonic effects [7-9]. This allows to explore the regimes of parameters not yet explored in the experiment and revealed interesting interplay between light and heavy hole states in the QDs leading to spectrum of excitonic complexes challenging their common identification method.

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List of Posters

Self-consistent k.p model for nanowire crystal-phase quantum dots

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Quantum dots are leading candidates for solid-state qubits [1], offering exceptional optical coherence and efficient light-matter interaction [2], critical for quantum information processing and the quantum internet. While research has traditionally focused on isolated or paired quantum dots [3], crystal-phase engineering enables the integration of large quantum dot arrays within single nanowires, opening new avenues for scalable quantum technologies. Despite prior theoretical studies [4,5], a detailed understanding of their single-particle and excitonic properties remains limited. Here, we present a simulation framework combining self-consistent 8-band k·p theory with self-consistent field calculations to model excitonic complexes in crystal-phase quantum dots. This approach generalizes naturally to multi-dot systems and various material compositions, bridging optical properties with underlying structural features.

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Laboratory management software: Plexy : Python Library for EXperimental Physics

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Optical measurements of semiconductor quantum dots often involve complex protocols requiring the coordination of many different devices. Laboratory management software such as DynExp [1], MAHOS [2], NOMAD-CAMELS [3] and Qudi [4] assist in performing these tasks. It often provides a unique framework for extension and configuration as well as standalone graphical user interfaces (GUI) for device control. Here we present Python Library for EXperimental Physics (Plexy), which is a highly modular repository of Python modules. Among the main design goals are automatic metadata recording, distributed device coordination, modular and flexible but standardized code organization as well as independent and common GUIs. An analyzer GUI performs common analyses specific to photoluminescence spectroscopy and time-correlated single-photon counting of quantum dot single-photon sources. Attempting to "overcome 'not-invented-here'-ism" [5] we are joining NOMAD CAMELS in integrating several Python libraries of the Bluesky [6] project in our modules. Among these are Bluesky for experiment orchestration, Ophyd Async for abstracted hardware access and the Bluesky Queue Server with the ZeroMQ library for distributed device control. The current goals are independent GUIs and customized workflows to suit individual needs as well as common backends and standards for cooperation and mutual benefit. Furthermore we are beginning to use NeXus format [7] compliant HDF5 files for saving our data together with metadata in a common data format.

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Raman spectroscopy on MBE grown III-V semiconductor heterostructures

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We present micro-Raman spectroscopic measurements on molecular beam epitaxy (MBE) grown semiconductors heterostructures, and quantum dots. This technique offers unique insights into the vibrational modes, crystal structure, strain, alloying effects and defects of grown semiconductor structures, making it invaluable for the optimization of MBE processes. The Raman results for the relaxed material have been interpreted in the framework of the modified random element isodisplacement theory considering different vibrational modes of the lattice with changing compositional range. Optical-phonon deformation potentials have been successfully used to fit the different vibrational phonon frequencies in strained layers of semiconductors. Using comparable theoretical models, a substantial compositional dependency with phononic vibrations is found and established. Disordered activated vibrational modes are investigated for layers produced on various substrates. An analogous conclusion with the peak shift in photoluminescence spectra is reached by analyzing the Raman spectra of herostructures grown on InP-based substrates.

Optical Properties of GaSb-Based Quantum Emitters for Telecom C-Band

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Reaching the properties of quantum dots (QDs) closest to those of the ideal single photon emitter has become the goal of many research groups specializing in quantum communication and development of quantum key distribution (QKD) technology. Many different methods and technics of growth and tuning of quantum emitters were proposed and researched in past years. Only recently new growth mode – local droplet etching – has been proposed and proven beneficial not only for high purity of single photon emission, and relatively short lifetimes of excitons, but also minimal strain and high in-plane symmetry leading to low fine structure splitting required for generation of pairs of entangled photons as well as lowering spin decoherence [1]. Only recently development of this growth technique for material systems providing emission at telecom wavelengths has been attempted [2,3,4]. We proposed and successfully realized droplet etching growth for GaSb-based QDs with type I quantum confinement using Al droplet and AlGaSb barrier material [5,6]. This is highly interesting material system due to direct bandgap of GaSb at 0.73 eV [5], very high refractive index contrast of Antimonides (exceeding that of the most common AlGaAs/GaAs), low lattice mismatch necessary for complex photonic structures and devices and possibility of direct growth on silicon. They exhibit low QD density of 2.5.107/cm2 and high QD homogeneity with inhomogeneous broadening lower than 10 meV. So far, their single-photon emission has been demonstrated for wavelengths exceeding 1495 nm [2,7]. In this contribution we present experimentally determined optical properties of GaSb-based QDs with different In composition of the InGaSb QD material filling the nanohole resulting in different emission wavelengths. Indium composition required to reach telecom C-band is established and various figure of merits, like inhomogeneous broadening of the QD ensemble, single QD emission linewidth and intensity are determined. The electronic structure and optical properties are modelled using 8 band k.p approach combined with configuration interaction method for description of excitonic states.

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Many-body quantum register for a spin qubit

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Quantum networks require quantum nodes with coherent optical interfaces and several stationary qubits. In terms of optical properties, semiconductor quantum dots are highly compelling, but their adoption as quantum nodes has been impaired by the lack of auxiliary qubits. Here we demonstrate that the dense, always-present, nuclear spin ensemble surrounding a gallium arsenide quantum dot can be used as a functional quantum register. We prepared 13,000 host nuclear spins in a single many-body dark state that acts as a logical state of the register. A second logical state is defned as a single nuclear-magnon excitation, enabling controlled quantum-state transfer between an electron spin qubit in the quantum dot and the nuclear magnonic register. Using SWAP gates, we implemented a full write–store–retrieve-read-out protocol with 68.6(4)% raw overall fdelity and a storage time of 130(16) ¯s, which could be extended to 20 ms or beyond using dynamical decoupling techniques. Our work establishes how many-body physics can add functionality to quantum devices, in this case transforming quantum dots into multi-qubit quantum nodes with deterministic registers.

Designing geometry of zinc blende InP nanowires with InAsP QDs for efficient emission extraction in telecom spectral range

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Zinc-blende InP nanowire (NW) with InAsP quantum dot (QD) is a novel material system for implementation of a single photon source. Chemical Beam Epitaxy method is used to reproducibly grow defect-free NWs. It allows for good control over QD and NW parameters [1], including tuning the QD emission wavelength to telecom C-band and O-band, where propagation losses and dispersion in optical fibres are the lowest. Properly designed NW geometry results in single mode waveguiding effect, increasing directionality and extraction efficiency (EE) of QD emission [2]. These qualities address the issue of efficient fibre coupling and realising quantum communication protocols over large distances with low signal losses. In this contribution we present numerical simulations in commercial Ansys Lumerical software [3], using finite-difference time-domain method. The aim of this study is to guide the growth of NWs with optimized geometry and maximize EE within the numerical aperture (NA) of 0.4 and 0.65 used in experiment. The QD was simulated as an electric dipole placed on NW axis and polarised perpendicular to it. Extraction efficiency for a given NA was calculated based on the far-field emission pattern at different angles. Taking into account parameters space limited by growth technology, we found optimal NW length, diameter, taper angle and QD position along the NW. Maximal EE was achieved for a 3-segment NW with 1 ¯m long and 330 nm thick bottom part containing the dipole, a 620 nm long middle part with taper angle of around 1° for efficient light outcoupling and the 350 nm long tip, narrowing down to 50 nm, which comes from the presence of a gold droplet at the top, serving as a nucleation center during growth process. In order to further enhance EE of the structure, a mirror underneath the NW was added to the simulations, which resulted in doubling of the expected EE values. For experimentally achieved emission wavelength of 1500 nm we obtained theoretical EE equal to 46%, with Purcell factor of 1.46 for the 0.65 NA of detection optics. We considered practical implementation of the mirror in two ways: by PDMS transfer of the NWs onto a substrate with a gold layer and by growing the NWs directly on a distributed Bragg reflector (DBR). Both solutions showed similar EE results in the numerical simulations. Transfer matrix method was used to calculate the reflectance as a function of wavelength of DBRs in different possible material systems. We acknowledge financial support from Horizon Europe Framework Programme within PATHFINDER project no. 101185617

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An open microcavity interface for a QD multi-qubit register

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Semiconductor quantum dots (QDs) represent a leading quantum optical technology platform owing to their bright indistinguishable photon emission, electron-nuclear coupling, and highly scalable nature [1,2]. Recent fabrication techniques have heralded a new generation of "strain-free" GaAs QDs [3], promising superior electron spin coherence times [4]. In this context, QDs have been touted as an efficient source of photonic cluster states [5] and optically addressable quantum memories [6], both crucial for the realization of quantum repeaters and measurement-based quantum computing. A key outstanding challenge is the enhancement of photon collection efficiency. To this end, photonic microcavities have emerged as a means to increase photon emission rates and thus the efficiency of the QD spin-photon interface [7]. Open microcavities provide excellent tunability but are easily perturbed by cryostat mechanical noise. Here, we aim to utilize an open, tuneable photonic microcavity en route to the realization of an efficient source of photonic cluster states. We perform Finite Difference Time Domain (FDTD) simulations to explore the cavity parameter space for an optimum design. Furthermore, we show active frequency stabilization of the open microcavity within the cavity linewidth in a closed-cycle cryostat at 4K. The results lay the foundation for the demonstration of all-optical spin control and spin-photon entanglement of GaAs QDs in a locked, open microcavity, and consequently an efficient source of large-scale, multidimensional photonic cluster states.

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Observation of the Hanle Effect in Single InAs/InP Quantum Dots Emitting in the Telecom C-band

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Quantum dots (QDs) are zero-dimensional nanostructures extensively studied for their unique electronic and optical properties. Their fully discrete energy states give them atom-like characteristics, including spectrally narrow emission and single-photon generation. One of their key features is quantum spin coherence, achieved through strong spatial confinement. Long coherence times are essential for precise spin-state control, making QDs highly relevant for applications in quantum computing and cryptography. The initialization and readout of qubits require addressing and manipulating the individual spins of carriers. It may be realized by optical orientation. Circularly polarized light is converted into spin-polarized electron-hole pair, which recombines after a characteristic time. Measuring photoluminescence (PL) polarization provides information about the exciton spin configuration [1]. In this work, we study electron spin dephasing times in single InAs/InP QDs that emit around the 3rd telecommunication window. This spectral range is crucial for efficient optical fiber and free-space data transmission applications.

Our sample contains Stranski-Krastanow InAs on InP QDs, grown using ripening process-assisted molecular beam epitaxy [2,3]. These highly symmetrical QDs emit within the telecommunication C-band. Low density between $5 \cdot 10^8$ and $2 \cdot 10^9$ per cm^2 enables the study of individual QDs. They are grown on top of a Bragg mirror with reflectivity of 99%, boosting extraction efficiency to 6.8% for planar structure, and 13.3% for quantum dots in cylindrical, micrometre size mesas [4]. Determined single carrier g-factor values are $g_e \approx -5$ and $g_h \approx +6$ for out-of-plane direction and similar for hole and electron of ≈ 0.25 in-plane, measured in the magnetic field in Faraday and Voigt configurations, respectively [5].

To characterise electron spin lifetimes in the investigated structures, we conducted circular polarization-resolved, magnetic-dependent micro-PL study. Magnetic field was applied in Voigt configuration, and excitation realised in a quasi-resonant scheme. For the emission line associated with trion, we observed negative circular polarization with a degree of circular polarization (DOCP) reaching 40% [6]. The Hanle effect, which measures the DOCP change due to an applied external magnetic field, was investigated. The Lorentzian-shaped dependence was consistent with previous studies on single QDs [1], and based on the fitting, the dephasing time of the single spin of the resident electron confined in a QD is estimated to be 1.6 ns.

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Femtosecond Laser-Based Fabrication Workflow for Single-Crystal PMN-PT Piezoelectric Actuators

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This work presents a comprehensive femtosecond (fs) laser-based fabrication workflow for the realization of complex piezoelectric actuators using single-crystal PMN-PT. The process enables precise local thinning of active regions to enhance strain transfer while preserving mechanical stability, followed by metallization and selective structuring of electrical contacts over non-planar surfaces via fs-laser ablation. The final device geometry is defined through ultraviolet fs-laser cutting, leveraging linear absorption at short wavelengths to improve edge quality and minimize damage - especially within laser-thinned regions. The workflow builds upon earlier demonstrations of fs-laser micromachining of PMN-PT [1] and advances strategies for high-precision laser ablation on crystalline substrates [2]. These results establish a scalable and precise fabrication platform for miniaturized PMN-PT actuators targeting applications in microsystems and quantum photonics [3,4].

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The fluctuations of Overhauser field for the light-hole qubit in Ge/GeSn electrically-defined QD

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We investigate the impact of hyperfine interaction on hole states in gate-defined quantum dots created in Ge/GeSn quantum well. In such a system, tensile strain leads to the emergence of the light-hole ground state doublet [1].

Using an atomistic $sp^3d^5s^*$ tight-binding model that includes strain and spin-orbit coupling [2,3], we simulate the influence of quantum well thickness, Sn concentration in the barriers, and in-plane confinement strength on the hole energy levels. We model the strain distribution using the Martin's Valence Force Field (VFF) method [4]. We analyze hyperfine interaction by computing the fluctuations of the Overhauser field acting on the lowest Zeeman doublet [5]. To obtain the hyperfine coupling parameters, we calculated atomic wave functions using density functional theory (DFT) together with a hybrid functional for bulk Ge and Sn. Following the definition of all-electron wavefunctions in the projector-augmented-wave (PAW) formalism, we reconstructed the wave functions on radial grids near the atomic cores.These calculations provide us with the necessary parameters, such as the value of the radial wavefunction at the nucleus and the integrals over the orbital contributions.

We present the Overhauser field fluctuations as functions of the confinement potential, quantum well width, and Sn content in the barrier layers. Our results show that the Overhauser field strongly depends on the barrier composition, which can be attributed to a changing confinement depth (hence the wave function participation number), and to a difference between the nuclear magnetic moments for Sn and Ge.

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The effect of interactions in an optically active gate-defined quantum dot

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Numerous types of quantum dots (QDs) are used everyday in various fields of quantum technologies and quantum information. Gate-defined QDs, created by applying electrodes over a quantum well, allow for a level of control over their properties archived by adjusting potentials applied to said electrodes. Typically, however gate-defined QDs can confine only confine one type of carrier simultaneously and therefore they are unable to couple with light directly. Self-assembled QDs, on the other hand, can be optically active since they can confine both electrons and holes at the same time. These QDs, although easier to manufacture, tend to have harder to control properties, as they are characterized by randomness in their arrangement and defining features (size, shape, and details of chemical composition). Given that, creating a QD that would combine the advantages of both kinds of dots i.e., easily adjustable properties and controlled coupling between QDs with optical activity would be desirable.

Here, we propose to use the simplest possible geometry of circular electrodes whose combined potential would confine both holes and electrons. By preforming numerical simulations, we show that using this geometry it is theoretically possible to create an optically active gate-defined QD.

Our calculations are carried out by numerically solving the Schrödinger equation in cylindrical coordinates. Direct discretization of the problem leads to carrier wave functions exhibiting nonphysical behavior near the origin and to avoid this problem, we implement the improved discretization [1]. Then we calculate the overlap integral of carrier wave functions. With a nonzero result showing a theoretical possibility of both carriers occupying the same region of space, which is a necessary condition for optical transitions to occur. After achieving that result, we carry out an optimization process to maximize it. To expand our calculations further, we include the electron-hole interaction in the model. From which the overlap of the carrier wave functions is increased significantly due to the attraction of the carriers. To achieve result that are more numerically reliable, we we use a numerical implementation of the $k \cdot p$. This allows us to obtain a more detailed simulation of the proposed QD, including exciton states calculated in the configuration interaction approach and their optical properties showing nonzero optical activity promising for applications.

Our results can be an introductory step in creating optically active gate-defined QDs. If a

QD of this kind was added to a linear array or a matrix of standard gate-defined QDs it could serve as an interface with light for such a device. This additional component could open the door for long-distance quantum communication between gate-defined QD matrices.

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Spin Engineering in GaAs Quantum Dots

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With the long term aim of creating a node for a quantum network, one key priority is a stable and reliable quantum memory. In quantum dot platforms this will require precise control of both the electron spin and surrounding nuclear ensemble. In this review poster we briefly discuss some new developments towards this goal as well as our future aims:

- active cooling of the nuclear spin ensemble [1]
- single magnon injection, storing electron states in a nuclear memory [2]
- collective phenomena and many-body states we hope to engineer
- a potential method for spin pumping using higher energy transitions

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Hybrid platform designed with numerical simulations to host phononic and photonic modes

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Hybrid quantum technologies focus on the simultaneous integration of different quantum degrees of freedom in one structure. This can be realized by combining phononic and photonic elements, such as surface acoustic waves (SAWs) and GaAs quantum dots (QDs), on one chip. One promising structure consists of QDs grown in an epitaxial (In,Al,Ga)As heterostructure acting as high quality photon source, which is heterogeneously integrated on $LiNbO_3$ for efficient SAW generation. For optimal hybridization, a targeted co-design of the phononic and photonic properties is necessary. This enables strong optomechanical coupling between the SAWs and QDs ([1], [2], [3], [4]) and facilitates the out-coupling of generated single-photons, allowing for the observation of phononic modulation of single-photon states. To achieve this goal, we perform numerical studies to evaluate the phononic properties of circular Bragg gratings (CBRs) with embedded QDs, where the central disk hosts both phononic and photonic modes [5], [6].

CBRs offer excellent photon extraction efficiencies (PEE) because they fulfill the second-order Bragg condition [7]. Our simulations are based on a typical structure, which comprises a (In,Ga)As QD membrane (150 nm) processed to contain the CBR, a gold mirror (100 nm) with a SiO_2 spacer (360 nm) beneath the QDs to enhance photon extraction, and a piezoelectric $LiNbO_3$ substrate for efficient excitation of SAWs. We assess the confinement of photonic and phononic modes in the central disk in numerical simulations. Since we can tune the frequency of our SAW easily by design, we ensure good optical performance at the target wavelength of 920 nm first [8]. After that, we use finite element simulations (FEM) to determine the mechanical eigenmodes of the system. We find strongly localized modes matched to SAW operation frequencies ranging from 2.45-2.7 GHz.

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Qubit-environment entanglement in time-dependent pure dephasing for transmon qubits

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We generalized the methods for quantification of system-environment entanglement that were previously developed for interactions that lead to pure decoherence (PD) of the system for time-independent Hamiltonians to time-dependent Hamiltonians. We have shown that the if-and-only-if criteria of separability [1], the entanglement measure [2], and the methods of detecting entanglement through operations and measurements performed only on the system without access to the environment [3] generalize in a straightforward manner to the case of time-dependent Hamiltonians. Thus the theoretical study of this type of entanglement is straightforward, while the time-dependence can enable experimental detection of entanglement for a wider class of PD interactions. The methods were used to study the evolution of system-environment entanglement of a transmon qubit interacting with microwave cavity photons [4] for an interaction switching between an entangling and a non-entangling one. This allows us to study nontrivial dependencies between the buildup of classical and quantum correlations, as the buildup of entanglement does not directly follow the switching of the interaction [5].

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Growth and characterization of atypical InGaAs/GaAs quantum dots optimized for room temperature emission in the 935-955 nm range for laser-based water vapor detection

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In spectroscopic gas analyzers, to exploit multi-line signal of gases, one has to obtain wide spectral tunability of the used light source. It requires a gain medium with bright and spectrally broad emission. A matrix of tunable vertical-cavity surface-emitting lasers (VCSELs), with an active region made of epitaxial quantum dots (QDs), might satisfy the abovementioned conditions better than conventional quantum wells with a narrowband gain spectrum. We have performed optimization of metalorganic chemical vapor deposition-grown InGaAs/GaAs QDs, for use as an active region of such a VCSEL, operating in the range of 935-955 nm at room temperature, since it matches the characteristic strong absorption lines of water vapor, detection of which is crucial in many industrial applications. The spectral range of interest is hardly reachable by as-grown Stranski-Krastanow InGaAs/GaAs QDs. Therefore, our work focused on a multistep optimization of low-strain (low In content) QD structures embedded in GaAs barriers, and stacked into multilayers to maximize the gain of an operational device. Modifications in the composition of QDs and barriers were used to tailor the spectral range of emission and radiative efficiency. In addition, post-growth rapid thermal annealing was employed to further blue shift the emission and enhance its intensity via defect curing. We used cross-sectional transmission electron microscopy imaging, combined with energy-dispersive X-ray spectroscopy, to probe the dots morphology and the composition profiles. Those constituted the input parameters for electronic structure modeling in the eight-band k·p formalism implemented in nextnano++ software. We compared our calculations with photoreflectance and photoluminescence (PL) spectra, and achieved good agreement. We also investigated time-correlated PL to characterize the PL decay mechanisms and to probe changes in the oscillator strength of the ground state transition. Thanks to high QDs density, bright and spectrally broad emission (above 50 nm) has been obtained in the targeted range at room temperature, which is a milestone requirement on the way to develop a low-cost VCSEL-based spectroscopic sensing system for industrial applications.

Impact of various noise types on the indistinguishability of single photons

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Over recent decades, the field of quantum communication technologies has gained substantial research interest, particularly concerning the production and transmission of indistinguishable single photons and entangled photon pairs. Quantum networks typically rely on telecommunication wavelengths around 1310 nm and 1550 nm, where optical fiber and earth-satellite communication systems exhibit minimal losses and dispersion [1]. Although these wavelengths are well-suited for quantum operations and quantum dot (QD)-based photon sources are available [1], challenges persist in reliably generating high-quality, indistinguishable photons for optical fiber transmission. One of the main reasons for these challenges is the presence of various decoherence processes in the environment of the emitter that disrupt photon generation, highlighting the necessity of thoroughly studying the impact of such noise on the single photon generation process. Here, we present a simulation of the Hong-Ou-Mandel (HOM) experiment [2], which utilizes two photons emitted by a quantum dot (QD) to assess their degree of indistinguishability. Our study focuses on analyzing the influence of various noise types — specifically, colored noise — on the experimental outcomes. In practical implementations, such noise manifests through the second-order correlation function $g^{(2)}(\tau)$, which reflects photon counting statistics at detectors placed along the separate photon paths after the beam splitter [3]. To examine these effects, we compute $g^{(2)}(\tau)$ in the presence of white and various colored noise types, assessing how they perturb the autocorrelation function of an otherwise ideal single-photon source. By comparing our theoretical results with experimental observations, it is possible to identify the dominant sources of degradation within the system, thereby enabling their mitigation. Additionally, this comparative approach may offer a method for detecting and classifying the nature of the noise affecting the system.

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Towards Dynamical Decoupling in a Quantum Dot via Nuclear Magnetic Resonance

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This poster outlines progress in exploring NMR in GaAs quantum dots for dynamical decoupling of nuclear magnons, highlighting the motivation behind this work and an outlook to future work.

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Useful Information

Talks

We aim to foster the exchange of ideas, so we have planned to maximize time for discussions.
Invited talks are 20 minutes, plus a few minutes for discussion.
Contributed talks are 12 minutes, with additional time for discussion.
Projector connectivity: VGA, HDMI, Mini DisplayPort (Apple).
If possible, please upload your presentations to the computer provided by the organizers to avoid delays.

Posters

The poster space will be located in the conference hall, adjacent to the social space.
We invite presenting authors to display their posters on the first day of the conference in the morning. We kindly ask participants to remove their posters at the end of the conference on Friday.
Poster format: up to A0, vertical.

Food and coffee

Lunches and coffee breaks will be provided for all participants during the three days of the workshop.
Lunch and coffee breaks will be organized in the space adjacent to the conference hall.
The conference dinner will take place on **Wednesday at 19:30 in Piwnica Świdnicka**.

Social program

For Thursday, we have planned guided city tours. You can choose between:

- **Wrocław in the footsteps of medieval convicts**, a guided walk retracing the steps of a 15th-century convict. Learn the city's legends and explore its most beautiful Romanesque and Gothic monuments, including entrances to the Old Town Hall, the Cathedral, and more!

- **Wrocław differently – "Venice of the North"**, a scenic walk along the Odra River and Wrocław's most iconic landmarks. This tour reveals the charm of the city's historic islands in the Old Town, often called the "Venice of the North" for its many bridges and footbridges connecting the river's channels. Both tours will start at 17:30 from the Cathedral of St. John the Baptist and will conclude after around 2 hours near Piwnica Świdnicka, where the dinner will take place.

Other

A cloakroom is available at the entrance to the venue.
The members of the local research groups will be happy to help you if you encounter any problems

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