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4th International GaAs QD workshop

10 - 12 June 2026

Dornbirn, Austria

Book of abstracts

Hosted by the
Vorarlberg University of Applied Sciences
Hochschulstraße 1, 6850 Dornbirn

Welcome to the 4th International GaAs QD Workshop

It is our great pleasure to welcome researchers, students, and industrial partners from around the world to Dornbirn, Austria, for three days dedicated to the latest developments in GaAs quantum dot research and related quantum technologies.

Hosted by FHV – Vorarlberg University of Applied Sciences, this fourth edition continues a successful workshop series previously held in Oxford, Traunkirchen / JKU Linz, and Wrocław. The workshop brings together leading experts, early-career researchers, and students to discuss current developments, challenges, and future directions in GaAs quantum dot science and technology.

Nestled between the Alps and Lake Constance, Dornbirn provides an inspiring setting for scientific exchange, networking, and collaboration.

We thank all speakers, participants, sponsors, and supporting institutions for contributing to the success of this workshop.

The Organising Committee

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Previous editions

1st International GaAs QD Workshop
22 – 23 May 2023, Oxford, UK

The first edition established the foundation for the international GaAs QD workshop series and initiated collaborations across the GaAs quantum dot community.

2nd International GaAs QD Workshop
17 – 19 April 2024, Traunkirchen, AT

The second edition expanded the scientific scope and strengthened interdisciplinary exchange between theoretical and experimental groups.

3rd International GaAs QD Workshop
7 – 9 May 2025, Wrocław, PL

The third edition highlighted recent progress in coherent spin control, quantum optics, and applications of GaAs quantum dots in quantum technologies.

About the workshop 2026

The 4th International GaAs Quantum Dot Workshop focuses on recent advances in GaAs quantum dots and their applications in emerging quantum technologies.

The workshop provides a platform for presenting cutting-edge research and encouraging discussions between experimentalists and theorists across a broad range of disciplines related to semiconductor quantum systems.

The scientific program includes invited talks, contributed presentations, poster sessions, networking opportunities, and social activities.

Scientific Topics

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

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Talks

To encourage the exchange of ideas, we have scheduled time for discussion.
Invited talks: 35 minutes (30 minutes + discussion)
Contributed talks: 20 minutes (15 minutes + discussion)
Available projector connections: VGA, HDMI, Mini DisplayPort (Apple).
To avoid delays, we kindly ask speakers to upload their presentations to the conference computer provided by the organizers.

Posters

The poster area is in the foyer.
Please set up posters on the first morning of the conference. The panels are numbered so please find your poster presentation number in the program.
Posters should be removed by the end of the conference on Friday.
Format: up to DINA0, portrait orientation.

Food & Coffee

Lunches and coffee breaks will be provided to all participants on each of the three conference days.

Meals and refreshments will be served in the foyer at the end of the corridor to the autidorium, except for Friday's lunch, which will be covered by vouchers included in the badge and redeemable at the FHV Mensa.

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Important emergency numbers

European emergency number 112
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Sessions: A - Aula

Coffee breaks, lunch, poster area: F - Foyer

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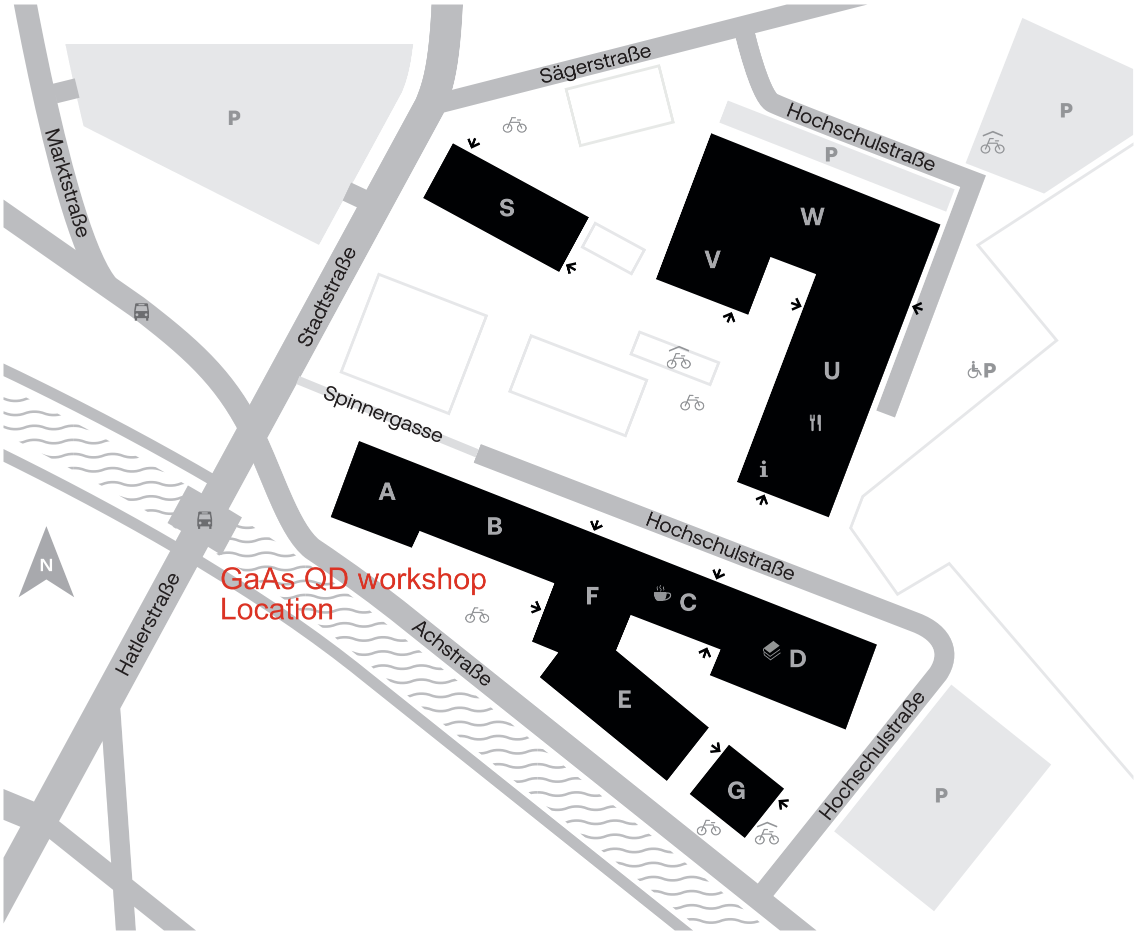

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W	Labore | Hörsäle

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🚲	Fahrradstellplatz
🚌	Bushaltestelle
P	Gebührenpflichtige Parkplätze
♿**P**	Behindertenparkplätze

Social program

Conference Dinner on Thursday, 11

The conference dinner will take place on Thursday evening on the historical ship Hohentwiel on the Lake of Constance. For the transfer to the marina, a bus will depart at the FHV.

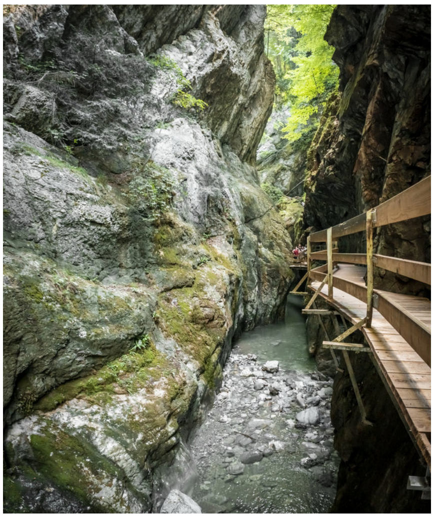
Bus departure: 17:30 at the conference site (Bus waits between Campus cafe C and U)
Estimated time of return: 22:30

Tour to the Rappenloch Gorge on Friday, 12

Join us on Friday afternoon for a group hike to the stunning Rappenloch Gorge! It is located close to the venue and can be conveniently reached by local bus. Weather permitting, this will be a great opportunity to enjoy nature together. Participants are advised to wear sturdy walking shoes.

14:40 at meeting point Foyer F to take the local bus together

Bus 177 departure: 14:52 from Sägerbrücke (7 min to Gütle)
Estimated walking time: 1,5 hours
Bus back every 30 min



Program at a glance

The workshop program consists of invited keynote lectures, contributed oral presentations, a poster session, networking opportunities, and a conference dinner.

Time	Wednesday, 10th June 2026
08:30-09:15	Registration
09:15-09:30	Opening
	Session 1: QD Growth and Modeling I
09:30-10:05	**Christian Heyn**
10:05-10:40	**Michał Gawełczyk**
10:40-11:00	Tom Fandrich
11:00-11:30	Coffee break
	Session 2: Quantum Optics I
11:30-12:05	**Peter Michler**
12:05-12:25	Moritz Langer
12:25-12:45	Mattia Beccaceci
12:45-13:05	Paul Hagen
13:05-14:30	Lunch
	Session 3: Entanglement
14:30-15:05	**Rinaldo Trotta**
15:05-15:40	**Eva Schöll**
15:40-16:00	Lukas Niekamp
16:00-16:20	Aleksander Rodek
16:20-16:40	Sai Abhishikth Dhurjati
16:40-18:30	Poster session

Time	Thursday, 11th June 2026
	Session 4: Spin and Charge Physics
10:00-10:35	**Mark Hogg**
10:35-11:10	**Zhe Xian Koong**
11:10-11:30	Lara Couronné
11:30-11:50	Shikai Liu
11:50-13:00	Lunch
	Session 5: QD Growth and Modeling II
13:00-13:35	**Teemu Hakkarainen**
13:35-13:55	Dirk Reuter
13:55-14:15	Rubén Santana Alonso
14:15-14:35	Petr Klenovsky
14:35-14:55	Eric Murphy
14:55-15:30	Coffee break
	Session 6: Applications
15:30-16:05	**Tina Müller**
16:05-16:25	Ievgen Brytavskyi
16:25-16:45	Vishnu Prakash Karunakaran
17:30-22:30	Conference dinner

Time	Friday, 12th June 2026
	Session 7: Quantum Optics II
08:30-09:05	**Alexey Tiranov**
09:05-09:25	Caspar Hopfmann
09:25-09:45	Samuel Sheldon
09:45-10:05	Juan Nicolas Claro Rodriguez
10:05-10:25	Koray Kaymazlar
10:25-11:00	Coffee break
	Session 8: Theory
11:00-11:35	**Ed Barnes**
11:35-11:55	Krzysztof Gawarecki
11:55-12:15	Jan Kaspari
12:15-12:30	Awards and Closing
12:30	Lunch
14:40-17:00	Social program Tour to the Rappenloch gorge (1,5 h walk)

Invited talks

List of Invited Speakers

- Ed Barnes, Virginia Tech
- Michał Gawełczyk, Wrocław University of Science and Technology
- Teemu Hakkarainen, Tampere University
- Christian Heyn, University of Hamburg
- Mark Hogg, University of Basel
- Zhe Xian Koong, University of Cambridge
- Peter Michler, University of Stuttgart
- Tina Müller, Karlsruhe Institute of Technology
- Eva Schöll, JKU Linz
- Alexey Tiranov, Sparrow Quantum
- Rinaldo Trotta, Sapienza University of Rome

Program
Wednesday, June 10, 2026

08:30-09:15	Registration
09:15-09:30	Opening
	Session 1: QD Growth and Modeling I Chair: Armando Rastelli
09:30-10:05	Christian Heyn Self-assembled local droplet etching during MBE for versatile and field-tuneable quantum structures
10:05-10:40	Michał Gawełczyk Using sound to control quantum dot charge and spin states
10:40-11:00	Tom Fandrich Revisiting Quantum well thickness fluctuation Quantum Dots as a source of single photons
11:00-11:30	Coffee break
	Session 2: Quantum Optics I Chair: Doris Reiter
11:30-12:05	Peter Michler State preparation, control and decoherence
12:05-12:25	Moritz Langer Bright quantum dot light sources using monolithic microlenses on gold back-reflectors
12:25-12:45	Mattia Beccaceci Cavity enhanced phenomena in GaAs quantum dots in CBRs
12:45-13:05	Paul Hagen Exciting the Biexciton using Floquet-Engineered Two-Photon Excitation
13:05-14:30	Lunch
	Session 3: Entanglement Chair: Peter Michler
14:30-15:05	Rinaldo Trotta Entanglement distribution via photon pairs generated by remote quantum dots
15:05-15:40	Eva Schöll A bright, blinking-free and fast source of wavelength-tunable entangled photons and indistinguishable single photons
15:40-16:00	Lukas Niekamp The-phonon sideband of resonantly driven GaAs quantum dots
16:00-16:20	Aleksander Rodek Exciton and biexciton preparation via coherent swing-up excitation in a GaAs quantum dot embedded in a micropillar cavity
16:20-16:40	Sai Abhishikth Dhurjati Atomic force lithography positioned circular Bragg cavities for high performance quantum dot based quantum light sources
16:40-18:30	Poster session Refreshments, including drinks and snacks, will be provided during the poster session

Abstracts

Session 1: QD Growth and Modeling I

Self-assembled local droplet etching during MBE for versatile and field-tuneable quantum structures

Christian Heyn

Center for Hybrid Nanostructures (CHyN), University of Hamburg,
Luruper Chaussee 149, 22761 Hamburg, Germany

This review addresses various types of quantum structures that are created by self-assembled local droplet etching (LDE) during molecular beam epitaxy (MBE). LDE can drill spatially well separated nanoholes of precisely controlled size into semiconductor surfaces and, thus, represents a top-down structuring which fundamentally extends the usual bottom-up MBE growth [1,2,3]. LDE nanoholes can be filled with a material different from the substrate for the creation of, e.g., ballistic point-contacts for phonons (Fig.1a) [4], well separated quantum dots (QDs) (Fig.1b) [3,5], quantum rings (QRs, Fig.1c) [3], vertically stacked QD molecules (Fig1d) [6], and hybrids of a QD and a plasmonic nano antenna (Fig.1e). In particular strain-free LDE GaAs QDs in AlGaAs have attracted significant interest for applications in quantum information technology [7]. The shape of the bottom part of LDE QDs is given by the cone-like shape of the initial nanoholes and the top by a cone-like indentation formed by capillary. Due to this unique shape, they are called cone-shell QDs (CSQDs), where the charge-carrier wave-functions (WFs) can be shifted by external electric fields F over the surface of a cone (Fig.1f). Single-dot photoluminescence (PL) and simulations indicate that a vertical F transforms the hole WF from a dot into a quantum ring (Fig.1f) [3] and establish a transition from a strong into an asymmetric strong–weak confinement [3]. Furthermore, simulations predict that CSQDs in combined vertical electric and magnetic fields might be used as a storage for photo-excited charge carriers [3]. A lateral F allows to tune a CSQD into an in-plane dipole, where for instance the exciton fine-structure splitting can be rotated by the field direction.

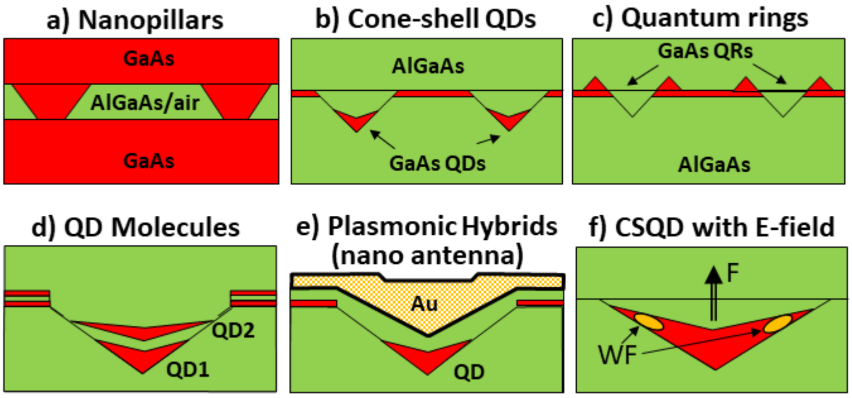


Fig. 1: Cross-sectional schematics of various quantum structures formed by local droplet etching

References
[1] Z.M. Wang, B.L. Liang, K.A. Sablon, and G.J. Salamo, Appl. Phys. Lett. 90, 113120 (2007).
[2] N. Somaschi et al., Nat. Photonics 10, 340 (2016).
[3] Ch. Heyn in "Physics of Quantum Rings" 3rd edition, ed. by V. Fomin (2025).
[4] Th. Bartsch, M. Schmidt, Ch. Heyn, and W. Hansen. Phys. Rev. Lett. 108, 075901 (2012).
[5] Ch. Heyn et. al., Appl. Phys. Lett. 94, 183113 (2009).
[6] Ch. Heyn et. al., Phys. Rev. B, 96, 085408 (2017).
[7] L. Zhai, G.N. Nguyen, C. Spinnler, J. Ritzmann, M.C. Löbl, A.D. Wieck, A. Ludwig, A. Javadi, and R. J. Warburton, Nature Nanotechnol. 17, 829 (2022).

Using sound to control quantum dot charge and spin states

Michał Gawełczyk

Institute of Theoretical Physics, Wrocław University of Science and Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Semiconductor quantum dots (QDs) combine optically addressable charge excitations with long-lived, coherent spin qubits, and offer a controllable interface between them [1]. Recent progress on QD homogeneity further extends spin coherence times. Additionally, it provides a uniform ensemble of nuclear spins with a controllable interface to the QD spin [2], which can act as a quantum memory [3]. However, what QDs lack are direct phonon-mediated charge and spin transitions despite strong energy modulation by elastic waves. This limitation hinders their integration into hybrid quantum systems based on acoustic (phononic) interconnects, which offer a promising strategy for coherently linking solid-state quantum systems with complementary functionalities.

We explore acoustic modulation for QDs in phononic media [4], and propose a family of acousto-optical schemes that overcome this limitation and enable coherent control of both QD charge and spin degrees of freedom. For charge-state preparation, we develop acousto-optical parametric control [5] of the "swing-up" type [6]. We leverage the parametric character of the control and show that it also allows for higher-harmonic driving that separates the control field frequency from the much larger state splitting [7]. For spin states, we use a detuned optical coupling to a trion state to break spin conservation, which enables acoustic spin control [8]. To overcome gate infidelity caused by relatively long operation times in the presence of quasistatic noise in QDs, we propose error-mitigating control sequences, making the spin-control scheme applicable to current QDs with cooled nuclear environments.

Because the same interaction structures arise for quantized acoustic modes in the coherent-state limit, these methods can enable generating QD-phonon entanglement, state transfer, and generation of nonclassical multi-phonon states in phononic resonators.

References
[1] C. Schimpf, et al., *PRX Quantum* **6**, 040309 (2025).
[2] N. Shofer, et al., *Phys. Rev. X* **15**, 021004 (2025).
[3] M. H. Appel, et al., *Nat. Phys.* **21**, 368 (2025).
[4] J. Rosiński et al., arXiv:2601.14162.
[5] M. Kuniej, et al., *npj Quantum Inf.* **11**, 161 (2025).
[6] T. K. Bracht et al, *PRX Quantum* **2**, 040354 (2021).
[7] M. Kuniej, et al., arXiv:2603.09849.
[8] M. Kuniej, et al., *Phys. Rev. Lett.* **136**, 046904 (2026).

Revisiting Quantum well thickness fluctuation Quantum Dots as a source of single photons

Tom Fandrich, Frederik Benthin, Yiteng Zhang, Benjamin Bohn, Maximilian Heller, Johan Hilbig, Tom Rakow, Arijit Chakraborty, Doaa Abdelbarey, Eddy P. Rugeramigabo, Michael Zopf, Fei Ding

Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover
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Semiconductor-based quantum dots (QDs) are promising candidates for quantum network applications due to their ability to generate single, entangled, and indistinguishable photons on demand. Modern epitaxial III-V quantum emitters based on local droplet etching with nanohole infilling or Stranski-Krastanov growth exhibit excellent properties from the near-infrared to the telecom bands. An alternative from the early days of QD research involved QDs formed by thickness fluctuations in quantum well (QW) heterostructures. These QW thickness fluctuation (QWTF) QDs can naturally display strong light–matter interaction due to giant oscillator strengths, yet have not been the focus of recent research as quantum emitters for single-photon applications. In this work, we investigate the optical properties of naturally formed QWTF QDs in GaAs QWs emitting in the near infrared range. Our results demonstrate that their distinctive properties justify revisiting QWTF QDs with today's standard for single-photon sources competing against state-of-the-art epitaxial approaches.

Abstracts

Session 2: Quantum Optics I

State preparation, control and decoherence

P. Michler

Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

The electronic excitations of quantum dots (QDs) are coupled to vibrational modes, i.e phonons of the host material and can also experience interaction with electric and magnetic fields caused by fluctuating charges and magnetic moments in their solid-state environment. These effects lead to dephasing, spectral diffusion and therefore to linewidth broadening, which can also seriously limit their usability as quantum light sources in quantum photonic applications [1]. However, a detailed physical understanding of all these effects allows to predominantly avoid the thereby connected drawbacks. It is important to note that QD single photon sources have demonstrated close to ideal single-photon emission at cryogenic temperatures, exploiting photonic structures and optimized resonant optical excitation schemes.

In this tutorial, we will discuss some aspects of quantum state preparation in QDs and their decoherence due to different interactions with the environment. Furthermore, we will present recent results on our research on GaAs based quantum-dot light sources in deployed fibers.

[1] Peter Michler and Simone Luca Portalupi, Semiconductor Quantum Light Sources, *De Gruyter, (2024)*

Bright quantum dot light sources using monolithic microlenses on gold back-reflectors

M. Langer[1,2], S.A. Dhurjati[1], Y.G. Zena[1], A. Rahimi[1], M. Pal[1], L. Raith[1], S. Nestler[1], R. Bassoli[2], F.H.P. Fitzek[3], O.G. Schmidt[4], C. Hopfmann[2]

1)Institute for Emerging Electronic Technologies, IFW Dresden, Helmholtzstrase 20, 01069 Dresden, Germany

2)Quantum Communication Networks research group, Deutsche Telekom Chair of Communication Networks, Technische Universitat Dresden, Dresden, Germany

3)Deutsche Telekom Chair of Communication Networks, Technische Universitat Dresden, Dresden, Germany

4)Research Center for Materials, Architectures and Integration of Nanomembranes (MAIN), Chemnitz University of Technology,Chemnitz, Germany

GaAs quantum dots (QDs) embedded in monolithic AlGaAs microlenses represent a highly promising platform for the realization of compact, directly fiber-coupled entangled photon sources. A detailed understanding of the fabrication process, in conjunction with the microlens shape factor, is therefore of critical importance. Here, we present a theoretical framework together with a scalable fabrication strategy for monolithic AlGaAs microlens arrays on gold-coated GaAs substrates incorporating GaAs QDs. The approach comprises pattern definition via thermally reflown cylindrical photoresist templates with diameters in the range of 2-5 µm, which are subsequently transferred into AlGaAs thin films deposited on gold mirror layers by means of an optimized three-dimensional reactive ion etching process. This process yields large-area (2 mm × 4 mm), high-density (~ 40×10^3 mm^{-2}) microlens arrays with highly uniform morphology. The maximum QD photoluminescence intensities are observed for lenses with a diameter of 2.7 µm and a height of 1.35 µm. Finite-difference time-domain simulations of the corresponding lens geometries identify further optimization pathways, including the incorporation of anti-reflection coatings. The simulations indicate that free-space and fiber-coupled photon-extraction efficiencies can attain values of up to 62% and 37%, respectively. A statistical fabrication model, validated by photoluminescence spectroscopy, predicts intensity enhancement factors of up to 200 in approximately 1 out of 200 lenses, in good agreement with the theoretical expectations. Overall, this methodology demonstrates the potential of compact and highly efficient single-photon sources for future large-scale quantum network architectures.

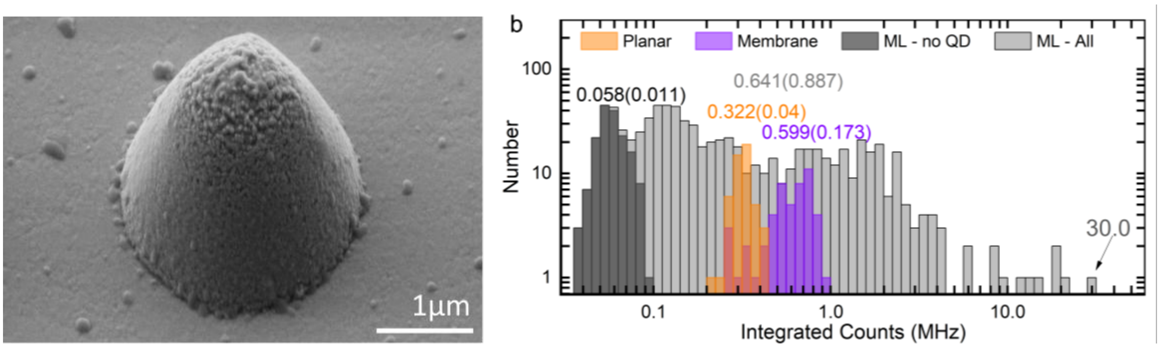

Figure 1: Monolithic AlGaAs microlens with embedded GaAs QDs. Comparison of integrated raw-detector count-rate of QD emission in the range 775-785nm for QD in as-grown sample, membrane on gold-mirror sample and microlens on gold-mirror sample.

Cavity enhanced phenomena in GaAs quantum dots in CBRs

M. Beccaceci[1], A. Laneve[1], M. B. Rota[1], T. M. Krieger[2], G. Ronco[1], Thomas Oberleitner[2], Q. Buchinger[3], Y. Reum[3], S. Manna[2], S. Stroj[4], M. Moczała-Dusanowska[3], S. F. Covre da Silva[2], F. Basso Basset[1], S. Höfling[3], T. Huber-Loyola[3], A. Rastelli[2] and R. Trotta[1]

1. Department of Physics, Sapienza University of Rome, 00185 Rome, Italy
2. Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, 4040 Linz, Austria
3. Technische Physik, University of Würzburg, 97074 Würzburg, Germany
4. Forschungszentrum Mikrotechnik, FH Vorarlberg, 6850 Dornbirn, Austria

The possibility to generate single and entangled photons have paved the way to the next quantum revolution. Among all different sources, semiconductor quantum dots (QDs) are emerging as one of the main building blocks of the newborn field of quantum networks. Their peculiar electronic structure can be exploited for the generation of polarization entangled photons via two-photon resonant excitation of the biexciton-exciton (XX-X) cascade. While massive efforts are being devoted to enhance the optical properties of quantum emitters through the integration in optical cavities [**1**], these very latter allowed to put into light effects that were never experienced before. When the lifetimes of the excited states approach the temporal duration of the excitation pulse, we experience the effects of the laser induced AC Stark shift on the excitonic levels. In particular, we study the detrimental effect of the energy shift on the entanglement degree of the emitted photon pairs [**2**,**3**], which introduces a trade-off between count rates and entanglement degree, setting constraints on the operation rate of deterministic sources. Furthermore, we investigate the interplay between photon polarization and emission wavevector [**4**]. We observe how the polarization entanglement of the photon pairs from a XX-X cascade strongly depends on the emission wavevector, observing a drop in quantum correlation for increasing collection angles due to the increasing polarization degree of the emitted photons. This finding provides a fundamental guideline for engineering optical cavities that maintain high entanglement while maximizing collection efficiency.

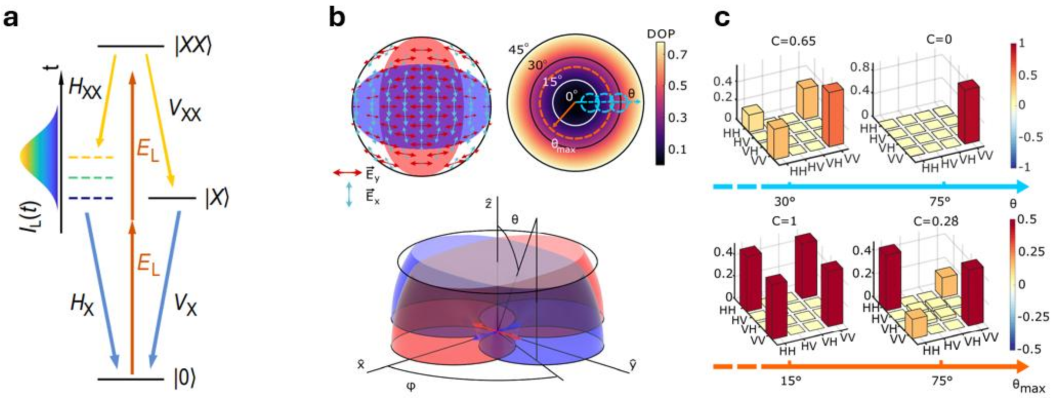

Fig. 1: a Energy diagram of the XX-X cascade under TPE and AC Stark effect. **b** Sketch of the far-field intensity and polarization distribution from two orthogonal dipoles. **c** Simulated density matrices for increasing emission (blue arrow) and integration (orange arrow) angles.

References
[**1**] M. B. Rota, T. M. Krieger, Q. Buchinger, M. Beccaceci, *et al.,* eLight 4, 13 (2024)
[**2**] F. Basso Basset, M. B. Rota, M. Beccaceci, *et al.,* Phys. Rev. Lett. **131**, 166901 (2023)

Exciting the Biexciton using Floquet-Engineered Two-Photon Excitation

P. C. A. Hagen[1], J. Y. Yan[2], M. Cygorek[3], D. E. Reiter[3], F. Liu[2] and V. M. Axt[1]

[1]*Theoretische Physik III, University Bayreuth, Germany*
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[3]*Condensed Matter Theory, TU Dortmund, Germany*

Two-photon excitation (TPE) is a cornerstone in the quantum-dot (QD) community when exciting biexcitons. In TPE, two degenerate photons are absorbed by the QD simultaneously, which excites it into the biexciton state [1].

We show that this excitation still occurs when both photons are detuned symmetrically, so the sum of their energies matches the ground state-to-biexciton transition. The level scheme for this excitation is shown in Fig. 1. This scheme becomes most efficient when the detuning δ significantly exceeds the biexciton binding energy E_B. We refer to this scheme as Floquet-engineered two-photon excitation (FTPE).

FTPE presents concrete advantages over regular TPE. In particular, it is more robust towards laser-power variations, allows more efficient laser filtering and produces near-unity fidelity of the subsequently emitted photons. The excitation fidelity has also experimentally been determined to be larger than regular TPE [2].

The proposed scheme is fundamentally different from conventional schemes, and can not be described in the same ways as SUPER or STIRAP, which also make use of two lasers exciting two transitions. We show how it can be understood using Floquet theory and that it is sufficient to use stroboscopic models for its investigation.

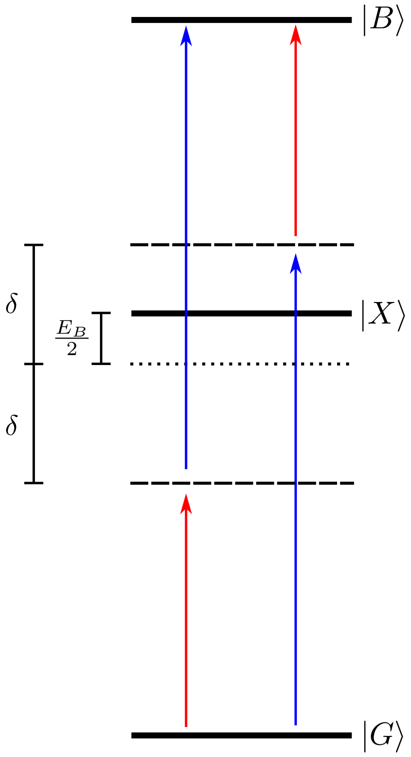

Fig. 1: Energy levels of the three-level system, where E_B is the binding energy of the biexciton. This scheme becomes regular TPE for $\delta = 0$.

References

[1] S. Stufler, P. Machnikowski, P. Ester, M. Bichler, V. M. Axt, T. Kuhn, A. Zrenner, *Phys. Rev. B* **73** (2006) 125304

[2] J. Y. Yan, P. C. A. Hagen, H. G. Babin, A. D. Wieck, A. Ludwig, C. Y. Jin, V. M. Axt, D. W. Wang, M. Cygorek, F. Liu, arXiv: 2504.02753v2.

Abstracts

Session 3: Entanglement

Entanglement distribution via photon pairs generated by remote quantum dots

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Entanglement swapping is a protocol that details how to create entanglement between previously uncorrelated particles. It represents a key building block for the realization of global quantum networks and, for practical applications, should ideally rely on deterministic entanglement sources. Despite significant recent progress, however, the implementation of entanglement swapping protocols using deterministic quantum emitters remains a major open challenge.

In this talk, I will show that photons generated on-demand by remote GaAs quantum dots [1] can be used to implement an entanglement swapping protocol with a fidelity that exceeds the classical limit by more than ten standard deviations [2]. I will also present our first steps toward the realization of a quantum-dot-based quantum network for secure communication across the University campus in the center of Rome [3, 4]. The talk will conclude with a discussion of the remaining challenges and future perspectives.

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A bright, blinking-free and fast source of wavelength-tunable entangled photons and indistinguishable single photons

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Quantum communication places stringent requirements on quantum light sources, including high brightness, low noise, and excellent photon coherence. Semiconductor quantum dots (QDs), particularly GaAs QDs, already satisfy many of these criteria; however, their performance is often limited by modest extraction efficiency and charge noise from an unstable electric charge environment. While photonic resonators can significantly enhance brightness [1,2], they often come with additional charge noise because of etched surfaces. In turn, it has been shown that charge noise can be effectively suppressed using diode structures [3, 4].

Here, we present our recent device that combines both approaches: a GaAs quantum dot deterministically coupled to a circular Bragg resonator and simultaneously integrated into a diode structure (Fig. 1a) [5]. This architecture results in an extraction efficiency of up to 54%, strongly suppressed blinking, and short radiative lifetimes corresponding to a Purcell enhancement of approximately 8. Crucially, the device enables the emission of polarization-entangled photon pairs with fidelities exceeding 92% to the $\Phi+$ state over a wide exciton tuning range of 1.7 nm (Fig. 1b). In addition, the capability of controlling the charge state of the QD, allows us to perform resonance fluorescence on the negative trion X^-, which shows high-purity single-photon emission and highly indistinguishable photons, with a raw Hong–Ou–Mandel visibility of V=0.93. Finally, we explore novel excitation schemes aimed at overcoming remaining limitations, such as the Stark-effect-induced degradation of entanglement fidelity [6].

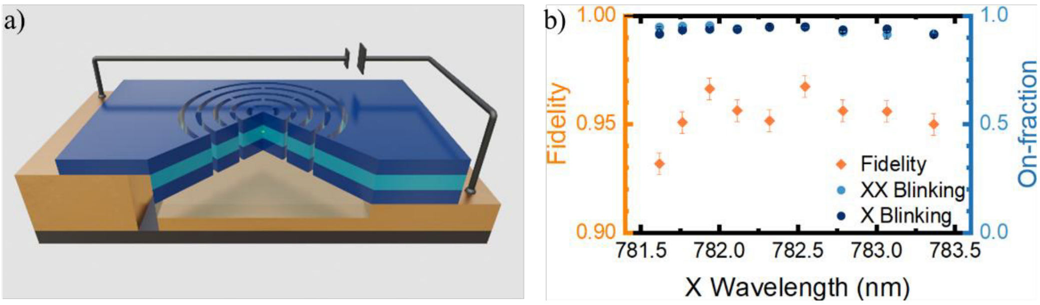

Fig. 1: a) Schematic of the electrically contacted circular Bragg resonator, b) Entanglement fidelity and blinking as a function of exciton wavelength

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The phonon-sideband of resonantly driven GaAs quantum dots

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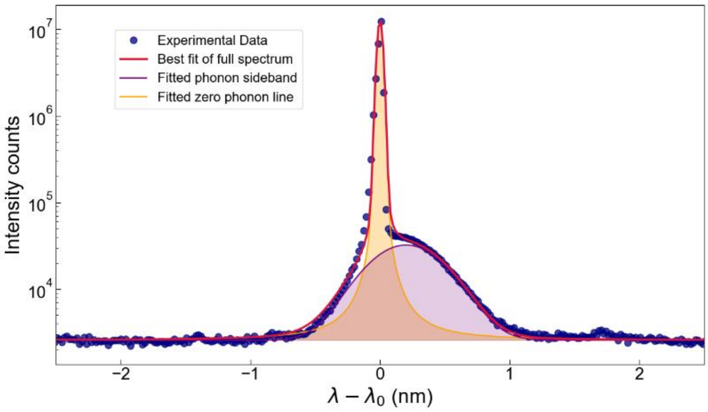
In recent years, GaAs quantum dots have been established as sources of coherent photons [1, 2] and hosts of coherent spins [3, 4]. Therefore, they are a promising platform for photonic quantum technologies, such as quantum networking or cluster state generation. For these applications, a high indistinguishability of photons emitted by the quantum dot is crucial. The indistinguishability is typically limited by excitations of the solid-state matrix such as charge noise and phonons. Charge noise can be greatly reduced by using ultrapure materials for quantum dot growth and embedding the quantum dots into a diode structure [1]. The coupling to phonons, on the other hand, cannot be controlled easily and leads to emission of photons into a phonon-sideband. This process degrades the indistinguishability of emitted photons, as demonstrated on InAs quantum dots [5]. In order to develop GaAs quantum dots into a mature quantum technology platform, a detailed understanding of the exciton-phonon interaction is thus required.

Here, we present measurements of the phonon-sideband of resonantly driven GaAs quantum dots. From fits to an analytical expression of the full emission spectrum [5], we determine the exciton-phonon coupling strength, cutoff-frequency and Franck-Condon factor and find correlations between these parameters and the center wavelength of the zero-phonon line. In particular, the fraction of photons emitted into the zero-phonon line reaches values up to 97%, even without integration into photonic nanostructures. This advantageous phononic property confirms the promise of GaAs quantum dots for future technological applications.



Full emission spectrum of a resonantly driven GaAs quantum dot consisting of a zero-phonon line (orange) and a phonon-sideband (purple).

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Exciton and biexciton preparation via coherent swing-up excitation in a GaAs quantum dot embedded in a micropillar cavity

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Coherent control of quantum emitters is essential for scalable quantum photonic technologies. The recently proposed swing-up of quantum emitter (SUPER) scheme [1-2] allows efficient and coherent preparation of single photons via off-resonant, red-detuned laser pulses, simplifying laser suppression and enhancing photon collection. We present a systematic study of SUPER excitation applied to a single GaAs quantum dot in a low-Q micropillar cavity. We perform a comparison of the key figures of merit against the well-established two-photon excitation (TPE). Despite requiring higher excitation powers, SUPER achieves near-unity population inversion of the exciton state (~95%) and high single-photon purity ($g^{(2)} = 0.03$) comparable to that under TPE, while also exhibiting a shortened decay time (~200 ps) reducing the time jitter in the exciton population. A polarization-resolved analysis reveals that when both excitation and collection are aligned with one of the exciton dipoles, SUPER results in polarized single-photon emission, exceeding the resonant TPE saturation by a factor of 1.45. Under optimized excitation conditions, we also observe biexciton preparation via a distinct SUPER resonance, confirmed by the appearance of the biexciton emission line, constituting the first experimental demonstration of biexciton preparation using SUPER. These findings are in good agreement with a proposed four-level theoretical model including the biexciton state and establish the SUPER scheme as a versatile tool for state-selective exciton and biexciton control [3].

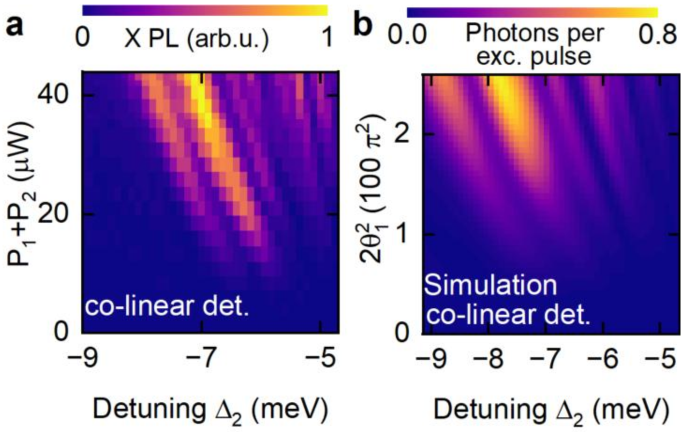

Fig. 2:
Experimental **a** and simulated **b** excitation power scans of the X emission intensity under SUPER scheme for different detuning energy of the second excitaiton pulse for co-linear configuration of detection polarization. Excitation parameters: $\Delta_1 = -3.7$ meV, $P_1 = P_2$

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Atomic force lithography positioned circular Bragg cavities for high performance quantum dot based quantum light sources

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Semiconductor quantum dots (QDs) grown by molecular beam epitaxy are excellent quantum emitters due to their discrete energy levels and ability to generate single photons and entangled photon pairs on demand [1, 2]. However, their inherently random spatial distribution presents a significant challenge for deterministic coupling to optical microcavities, where precise alignment between the emitter and the cavity mode is required to maximize photon extraction efficiency and preserve polarization symmetry [3, 4]. In this work, we demonstrate a room-temperature atomic force microscopy (AFM)-assisted nano-oxidation lithography technique enabling QD positioning with a radial displacement of $51(28)$ nm. Free-standing asymmetric circular Bragg gratings incorporating AFM-positioned GaAs QDs exhibit a 245-fold photoluminescence enhancement and fine-structure splitting (FSS) comparable to bulk QDs. Polarization-resolved spectroscopy and finite-difference time-domain simulations show robust emission for displacements up to 50 nm, with Stokes parameter $|S| < 0.05$. The devices display stable FSS and polarization imbalance below 5 %, confirming precise, reproducible alignment and strong potential for high-fidelity quantum photonic devices. This scalable approach enables deterministic integration of high-performance QDs with photonic cavities, advancing practical quantum light sources for quantum information technologies.

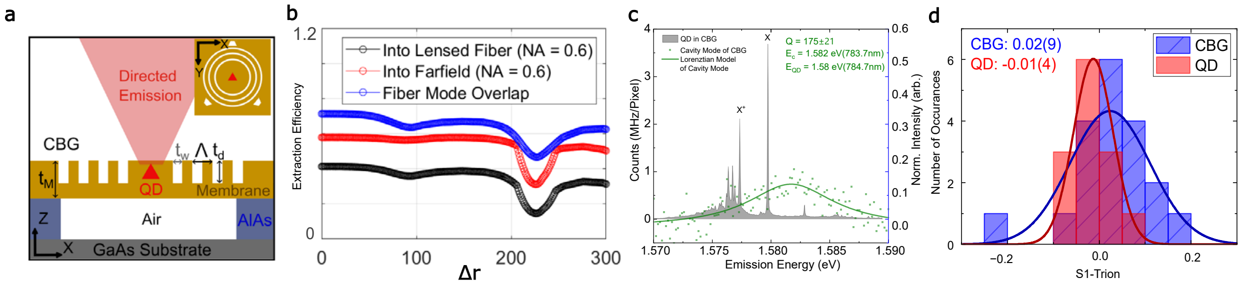

Fig. 1: (a) Schematic overview of a QD-containing free-standing circular Bragg grating cavity. (b) FDTD simulations of lateral displacement versus extraction efficiency. (c) μ-PL spectrum of a QD-containing CBG. (d) Distribution of the Stokes vector of trion emission for CBGs and planar QDs.

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Abstracts

Poster Session

Engineering the Indistinguishability of Single Photons Emitted from GaAs Quantum Dots using Swing-Up Excitation

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The growing field of photonics-based quantum technologies relies on the generation of single photons with near-unity indistinguishability. To achieve this, a number of single-photon sources and photonic micro-structures have been developed in recent years. Self-assembled GaAs quantum dots (QDs) provide a reliable platform offering deterministic single photon emission, along with high brightness, and relatively low infrastructure overheads [1,2]. Emission can be achieved by generating exciton states within the QD, which then recombine according to optical selection rules. As a solid-state device, the behaviour of the electronic states is necessarily dependent on the QD environment. During exciton preparation, a phonon wavepacket (polaron) can be emitted, which leads to a linewidth broadening of the subsequently emitted photon [3,4].

The swing-up of emitter (SUPER) scheme has emerged in recent years as a useful and interesting excitation scheme, as it circumvents traditional laser filtering requirements, using two far red-detuned laser pulses [5]. The rotation of the Bloch vector into the excited state is achieved by the beats between the two pulses. These beats are typically of the same energy (of a few meV) as the longitudinal acoustic phonons which most strongly couple to a typical self-assembled GaAs QD, which necessarily jeopardises the indistinguishability which can be achieved. We investigate the indistinguishability of the emission from GaAs QDs, generated using SUPER scheme excitation. Our experimental results provide a unique insight into the underlying physics, and are another step towards the practical implementation of the scheme for quantum communication protocols.

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Towards electron-spin single-shot readout of cavity-coupled GaAs/AlGaAs quantum dot

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Quantum dots (QDs) coupled to open-microcavities are the best single-photon source to-date, enabling source efficiencies of ~70% [1], above the threshold for linear optical quantum computation with near indistinguishability and transform-limited linewidth. Recent methods [2, 3] to polarise the local nuclear-spin ensemble of lattice-matched droplet etched GaAs/AlGaAs QDs have enabled nearly two-orders-of-magnitude improvement in the electron-spin coherence under dynamical decoupling [4] and coherent swap operation between the electron and nuclear-spin register [5], thereby constituting a long-lived quantum memory. By coupling such a system with the photonic advantages of a tuneable open-microcavity, an efficient light-matter interface can be realised for quantum information processing applications such as cluster state generation [6] and distributed quantum computation [7]. An essential capability for these applications is high-fidelity, single-shot readout of electron-spin state. This requires the mapping of the spin state onto a macroscopic interpretable classical signal, such as photon counts, with a sufficient signal-to-noise ratio, within the relaxation time of the qubit, to determine the spin-state in a single measurement. However, measurement back-action and lossy channels in typical experimental settings, limit capabilities to an ensemble-averaged readout. We present our progress towards achieving single-shot readout by using a tuneable open-microcavity to enhance the system efficiency and operating in the Faraday configuration where spin-control and high spin-conserving cyclicity have been demonstrated [8].

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Nuclear State Engineering in a Many-Body Central Spin System

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GaAs quantum dots exhibit rich fundamental spin physics due to their dense nuclear ensembles, which couple to a spin qubit. With sufficiently high fidelity control and state preparation, this many-body environment will act as a central spin system, with many exciting applications such as quantum memories [1], collective entanglement [2], or creation of non-equilibrium states [3]. In this poster, we show our current level of control over the nuclei, characterised by long phase coherence times (T_2^*=355ns), and demonstrate the ability to individually address and polarise each isotopic ensemble. We identify some of the current factors limiting to degree of control we can achieve. We then conclude with a short-term outlook on future directions for this new many-body spin system.

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Photonic cluster state Generation from a Telecom-Emitting Quantum Dot

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Photonics is widely regarded as a leading platform for quantum computing and quantum communication [1]. Unlike many other platforms, which typically implement quantum computation using the circuit model, photonics is particularly well suited to the measurement-based paradigm [2]. In this approach, qubits are prepared in highly entangled graph states, and quantum computation is performed through sequences of adaptive projective measurements.

A central resource for measurement-based quantum computing is the linear cluster state, consisting of a chain of qubits entangled with their nearest neighbours. Deterministic generation of such states has been demonstrated using semiconductor quantum dots following the protocol of Lindner and Rudolph [3], in which a confined spin mediates entanglement between sequentially emitted photons [4-6]. While these experiments represent major advances, they were realized in the near-infrared wavelength range, which is suboptimal for many practical applications. In particular, fibre-based quantum communication is most efficient in the telecom C-band around 1550 nm, where attenuation in silica fibres is minimal.

In this poster, we will present our recent progress on generation of a cluster state directly in the telecom C-band. This is achieved through repetitive excitation of a hole spin confined in an indium-arsenide quantum dot subjected to an external magnetic field. We characterize the cluster state by measuring its quantum process map. While measuring the process map, the spin-photon entanglement between a single photon and the spin is also measured and here, we observe spin–photon polarization entanglement with a negativity of $N=0.27\pm0.02$.

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Electrical Control of GaAs Quantum Dots in Monolithic Photonic Integrated Circuits

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GaAs quantum dots (QDs) obtained via droplet etching epitaxy are a high-quality source of single and highly indistinguishable photons. Their optical properties, such as a narrow wavelength distribution, short decay times, linewidths close to the Fourier limit, and the resulting indistinguishable photons, make them appealing for several quantum technologies [1]. To achieve increased scalability, a direct integration of QDs into photonic integrated circuits (PICs) potentially enables a compact packaging of optical elements on chip scale. It has already been demonstrated that GaAs QDs integrated into monolithically fabricated waveguides (WGs) maintain their high-quality emission properties within PICs [2]. Nevertheless, bunching and inhomogenous broadening are observed. The latter results in non-Fourier-limited linewidths and therefore reduces the indistinguishability of the emitted photons. This issue can be addressed by embedding the GaAs QDs in a p-i-n diode to stabilize the charge environment.

We present our first experimental results of electrically controlled GaAs QDs in PICs. This includes the investigation of the WG attenuation, the wavelength distribution of the QD emission, and characterization of the optical properties. Additionally, several wavelength-tuning mechanisms are discussed and investigated in more detail. First, the Stark-shift achieved by the applied electric field can be used for spectral tuning of the QD emission. Furthermore, strain-tuning mechanisms represent a promising additional tuning knob by employing miniaturized single-crystal PMN-PT piezoelectric actuators [3]. Together, these approaches enable a high degree of spectral and electrical control of GaAs QDs in PICs.

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Temperature dependent photon indistinguishability from GaAs quantum dots

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Two-photon interference represents a fundamental phenomenon in the field of quantum optics and applied quantum photonic technologies. In order to successfully implement experiments and protocols, such as a photonic quantum repeater, near unity photon indistinguishability is essential. Pulsed resonance fluorescence from charge-controlled GaAs quantum dots (QDs) cooled down to cryogenic temperatures has been shown to generate highly indistinguishable photons, even for remote emitters [1]. However, at elevated temperatures, the significance of interactions between the excitonic state in a QD and phonons, as well as closely spaced hole states, increases. This, in turn, has a detrimental effect on the photon indistinguishability [2,3].

We measure the temperature-dependent two-photon interference of the negative trion in a GaAs QD through Hong-Ou-Mandel (HOM) experiments. The consecutively emitted photons are highly indistinguishable at 4.5 K ($V_{HOM} = 0.966(6)$), and become fully distinguishable at 50 K ($V_{HOM} = 0.048(37)$). Simulations taking into account pure dephasing and interactions with higher excited states, are in good agreement with the data. Especially the energetically closely spaced hole states show a significant impact on the degradation of photon indistinguishability.

Furthermore, the measured HOM visibilities are at the theoretical limit obtained from the measured linewidth, indicating no time dependence in the absence of charge noise.

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Wavevector-resolved optimization of photonic cavities for bright entangled photon pairs from charge-controlled quantum dots

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Epitaxially grown semiconductor quantum dots (QDs) exhibit characteristics well-suited for deterministic single and entangled photon generation. To overcome the obstacle of low light extraction efficiency, integration into photonic structures like circular Bragg gratings (CBGs) proved to be a viable method, also allowing for a high Purcell factor [1,2]. Furthermore, the entanglement fidelity of emitted photon pairs can be improved by erasing the fine-structure-splitting of cavity-enhanced QDs via strain-tuning [3]. As resonantly pumped QDs in intrinsic semiconductors suffer from a limited brightness due to a fluctuating charge-state and charge environment, the integration of QDs in a diode structure is required [4]. In the case of CBGs, the implementation of a diode structure can be realized via a labyrinth geometry for the resonator [5].

Although the emission of single photons from an electrically contacted QD embedded in a CBG has been demonstrated [6], the extraction efficiency is still limited and requires a revised device design. Furthermore, when entangled photon emission is addressed, it has recently been shown that CBGs influence entanglement by altering the wavevector dependence of the photon polarization compared to QDs out-of-cavity [7]. In agreement with numerical simulation, the entanglement fidelity of photons emitted by QDs embedded in CBG designs realized so far degrades, when the photons are collected with high numerical aperture objectives and transmitted in free space or glass fibers. Other established designs such as low-Q micropillars offer similar emission characteristics [8] and may exhibit improved polarization-dependence.

Here we present ongoing work in the investigation of different photonic cavities while considering both a high extraction efficiency and high zenithal angles. We try to develop a new design, incorporating enhanced brightness by combining different cavity approaches with a diode structure, while including the effects on photon entanglement from emission polarization. This requires an optimization method combining extraction efficiency, Purcell factor and farfield-degree-of-polarization as figure of merit. A first implementation of this method reveals trade-offs between the emission characteristics dependent on cavity type.

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Deployed BBM92 quantum key distribution using frequency-converted entangled photons emitted by a quantum dot

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Quantum cryptography employs quantum light, very often single photons, to provide security guarantees unreachable by classical schemes. The non-classical behaviour of the photons set the security level for individual cryptographic tasks. Single-photon sources based on epitaxial quantum dots (QDs) represent a highly promising candidate for quantum cryptographic implementations, as they can, in principle, emit photons on-demand with low multiphoton probability [1]. Sources with high brightness and low time jitter are key for high-speed quantum communication, while a low multiphoton component reduces the risk of information leakage to eavesdroppers. These properties can be achieved pumping a QD under two-photon excitation (TPE). Additionally, TPE can lead to the generation of entangled photon pairs, allowing for implementations of entanglement-based cryptographic schemes.

We implemented an entanglement-based BBM92 quantum key distribution (QKD) protocol along 700 m across the campus of the University of Stuttgart (see Fig. 1), whilst utilizing the existing deployed fibre network. As source for the entangled-photon pair, served an epitaxially grown droplet-etched GaAs quantum dot (QD) embedded in a dielectric antenna structure. In two-photon excitation (via a pulsed laser that emits 10 ps pulses at 779 nm with a 380 MHz repetition rate) the QD emits an entangled-photon pair at a wavelength of ~780 nm. To prevent extreme losses in silica fibres, we shifted the wavelength to the telecom C-band using bidirectional, polarization-conserving quantum frequency conversion. Stable QKD operation was reached for over 10 hours, leading to a raw key rate exceeding 200 Hz with a quantum bit error rate under 4.5 %. Including error correction and privacy amplification, we achieved a secure key rate of 100 Hz.

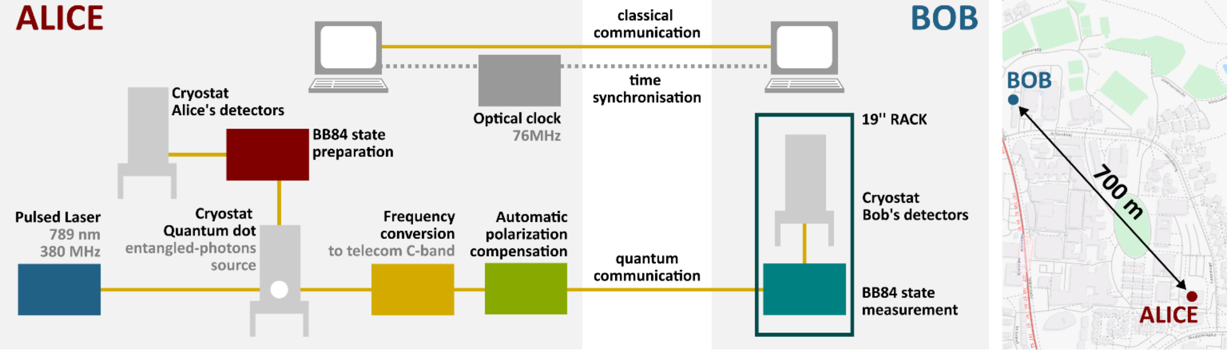

Figure 1: Block diagram of the experimental setup for implementing a quantum-dot-based BBM92 QKD protocol on the University of Stuttgart Campus Vaihingen fibre network.

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Enhanced Electron Spin-Coherence in a GaAs Quantum Dot

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Semiconductor quantum dots are promising candidates for photonic quantum technologies such as cluster state generation or distant spin-spin entanglement. In these systems spin decoherence is mainly caused by magnetic noise from the host nuclei. Droplet-etched GaAs quantum dots are particularly of interest due to their low strain environment compared to established InGaAs quantum dot systems. The homogeneous nuclear ensemble in GaAs quantum dots is affirmed by successful electron spin decoupling from the host nuclei with $T_2^{CPMG} > 100$ µs [1].
Through Ramsey interferometry the electron coherence time T_2^* is determined, which simultaneously probes the nuclei's temperature. We implement an all-optical nuclear-spin cooling scheme [2,3,4] to increases electron spin-coherence time in a GaAs QD from 3.9 ns to 78 ns after Rabi cooling and up to $T_2^* = 608$ ns after feedback cooling [4] (see Figure 1). The optical pulse protocols, and therefore the cooling efficiency, can be further optimized by adapting the pulse shape itself to the frequency distribution of the nuclear spin environment. The electron coherence is maintained for much longer times than pulse sequences for photonic quantum logic gates as well as the radiative decay time which paves the way for a coherent spin-photon interface.

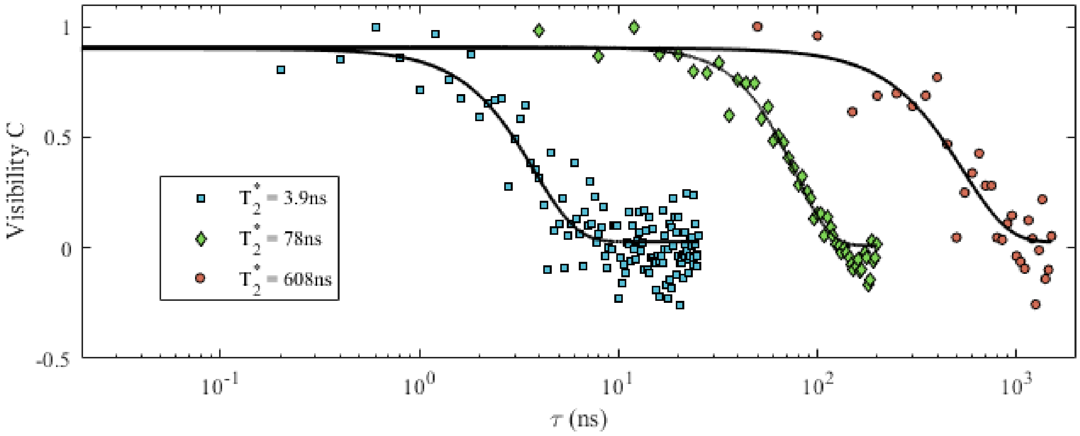

Fig. 1: Ramsey visibility before cooling (blue), after Rabi cooling (green), and after feedback cooling (red). [4]

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P 10

TOWRADS NUCLEAR SPIN COOLING FOR THE GENERATION OF LONG PHOTON CLUSTER STATES BY A III-V SEMICONDUCTOR QUANTUM DOT

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C2N & Quandela

Self-assembled III–V semiconductor quantum dots are among the most promising platforms for photonic quantum technologies, enabling both quantum computing and quantum memory applications. When integrated into photonic devices such as micropillar cavities, they act as efficient single-photon sources. By charging a dot with a single electron or hole, the spin ½ of this carrier provides an additional quantum degree of freedom. Through spin-orbit coupling, the spin can be entangled with the polarization of an emitted photon, allowing the generation of photon cluster states, a crucial resource for optical quantum computing [1]. However, the spin coherence time in III–V quantum dots is limited to a few nanoseconds, mainly due to hyperfine interactions with the surrounding nuclear-spin bath, which limits the creation of long multi-entangled photon states [2][3]. Recent work has shown that optical techniques exploiting nuclear Zeeman splitting in strong magnetic fields can reduce nuclear-spin entropy and prolong coherence by over two orders of magnitude [4][5][6]. This project aims to implement such nuclear-spin cooling on the micropillar quantum dots developed in the lab and to extend it to low magnetic fields (<100 mT) to ensure compatibility with photon cluster-state generation.

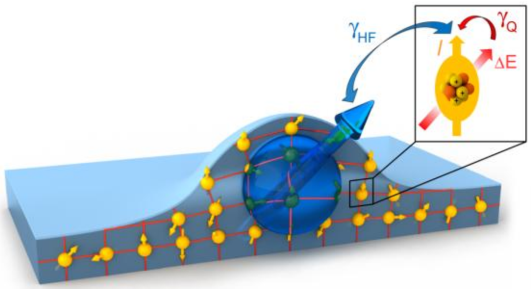

Fig. 1: Hyperfine and quadrupolar interactions between electron and nuclear spins. [2]

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Towards the on-demand readout of a long-lived nuclear spin quantum register

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Controllable and efficient quantum nodes, functioning as quantum memories or deterministic sources of multi-dimensional cluster states, are essential for scalable quantum networks. Recently, it has been shown that a quantum register of ~10^5 nuclear spins can be collectively excited by a central electron spin [1] to deterministically store multiple qubits for up to 130(16) µs [2]. However, this storage time is still well below the minimum required millisecond timescale for practical quantum networks. Furthermore, single-shot readout with simultaneous optical spin control remains challenging, despite recent progress [3]. Here, we design and fabricate gold coplanar waveguides (CPW) on a GaAs quantum dot heterostructure for direct control of both the nuclear- and the electron-spins. Nuclear-spin-resonance (NMR) with pulses in the MHz regime allows for dynamical decoupling of the nuclear spin ensemble to increase the storage time to the homogeneous limit of 10s of milliseconds [4]. By incorporating CPW resonator cavities, we can enhance the magnetic field delivered to the quantum dot in the GHz regime for electron spin resonance (ESR). Direct microwave control removes the need for the off-resonant two-color optical Raman processes for ESR used in previous methods and can increase the fidelity of controlled SWAP gates [5], which opens the possibility for efficient electron spin control with simultaneous single-shot readout [6]. Our work shows that the previously mutually exclusive elements of optical control and efficient read-out of an electron spin in quantum dots can potentially be married for a promising multi-qubit quantum node in quantum networks.

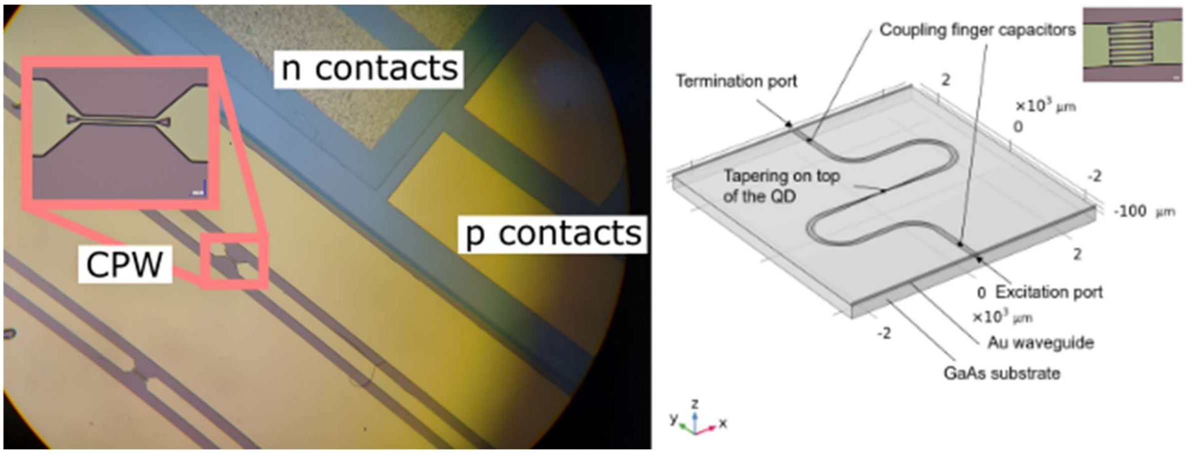

Fig. 1: (Left) Microscope image of waveguide deposited on quantum dot structure. The inset shows a zoomed in image of tapered active area in gold coplanar waveguide. (Right) Design of tapered waveguide with coupling finger capacitors for resonator cavities. The inset in the top right corner shows a microscope image of coupling finger capacitors after lithography.

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Lateral Electric Field Tuning of Quantum Dots

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Quantum dots are among the most promising material systems for single photon sources in quantum communication and computation. However, they exhibit a stochastic distribution of emission wavelengths and fine-structure splitting, necessitating post-growth tuning that must be compatible with their fabrication and photonic environment. In this study, we use planar electrodes in parallel and quadrupolar configurations at varying distances to investigate the influence of electric fields on the emission wavelength and fine-structure splitting of different types of quantum dots: perowskite based colloidal dots, DENI-quantum dots and surface fluctuation quantum dots.

The optical properties and Overhauser field fluctuations in GaAs/AlGaAs QDs: the atomistic and k·p approach

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The modeling of spin and spectral properties of semiconductors quantum dots was a subject of many theoretical studies. The methods used in such calculations can be divided into two classes: The first one contains multiband k·p models based on the continuous media approximation. The second one involves various atomistic approaches. The k·p methods are closely related to experimental quantities (such as the band gap and the effective masses) and are computationally efficient. However, they loss information on the underlying atomic lattice, which limits the accuracy for the cases, when subtle atomic effects are important.

In this contribution, we systematically compare the results of the eight-band k·p [1,2] (in the envelope function approximation) and the $sp^3d^5s^*$ tight-binding [3] model for the spin and optical properties of GaAs/AlGaAs quantum dots. Starting from the electron and hole single-particle states, we account for the Coulomb interaction via configuration interaction approach. Then we calculate the exciton lifetimes using both models.

We model the hyperfine interaction, by calculating of the Overhauser field in fluctuations. Because the $sp^3d^5s^*$ tight-binding model is inherently atomistic and includes the atomic d-shell, it provides a reliable benchmark for validating the k·p implementation of the hyperfine coupling [4], which necessarily relies on additional assumptions and simplifications.

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Higher-harmonic acoustic driving of quantum-dot optical transitions beyond Rabi-frequency resonance

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Acoustic control and coupling of various quantum systems via phonons can enable miniaturized quantum technology devices for on-chip integration. Optically active quantum dots (QDs) are essential for such platforms, yet the lack of direct acoustic transitions between charge states prevents their easy integration into such systems. The recently proposed hybrid acousto-optical swing-up scheme introduces such high-fidelity transitions, but originally has been proposed for phonons in the (nearly) THz frequency range, limiting practical implementations [1]. Thus, a low-frequency acoustic control of QD charge states remains missing.

Here, we show how to overcome this limitation by exploiting higher-harmonic-assisted processes arising from strain-induced modulation of the optical transition energy. This parametric modulation of the optically dressed splitting produces multi-phonon-like resonances when a harmonic of the mechanical modulation matches the generalized Rabi frequency.

We predict faithful state preparation with an acoustic frequency that is only a fraction of this splitting, thereby bridging control at accessible acoustic frequencies with the THz optical energy scales. In doing so, we establish control principles that separate optical energy delivery from coherent acoustic control. As a proof of concept, we simulate the control of 0.34-THz-split optically dressed states (~1 eV bare splitting) with a feasible 42 GHz acoustic drive.

To evaluate the evolution of the system and estimate the effects of thermal phonons, we perform numerical simulations within a non-Markovian framework. We predict high state-preparation fidelity, comparable to one-phonon and all-optical schemes [2]. Additionally, we provide an effective model that explains the observed evolution.

Potential applications of this approach may extend beyond QD charge state preparation. Since the same interaction structure arises for a quantized acoustic field, our results provide a foundation for multi-phonon processes in QDs coupled to phononic resonators, including photon-phonon entanglement, state transfer, and the optical preparation of nonclassical phonon states in quantized acoustic modes, all essential for future on-chip quantum technologies.

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Towards Dual-band GHz-clocked Single-photon QKD

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In quantum cryptography, fundamental laws of physics are exploited to enhance the security of cryptographic primitives such as quantum key distribution (QKD). Recent advances showed that quantum dot (QD) based single-photon sources (SPS) enable a performance-advantage compared to weak coherent pulses (WCP), both in implementations of QKD [1] and cryptographic primitives beyond QKD [2]. The clock rates of QD-based QKD implementations, however, are typically limited to values of about 80 MHz or below [3], while WCP based implementations use clock-rates in the GHz-regime [4].

Here, we report recent advances towards implementations of single-photon QKD operating at GHz clock speeds. Employing state-of-the-art cavity-enhanced QD single-photon sources emitting at 921 nm [5] and 1550 nm [6], respectively, we achieve system clock rates of 1.28 GHz and 2.50 GHz in the respective spectral range. Random polarization-state encoding for implementing the BB84 protocol is realized by a customized fiber-based electro-optic modulator (EOM) in single-pass configuration in combination with a fast arbitrary waveform generator (AWG) using the laser trigger as common clock for the QKD setup. We show that our current setup allows for sufficiently-low quantum bit error ratios below 6% in both wavelength bands. Finally, first preliminary results for the achieved raw key rates are presented.

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Spin dynamics in GaSb/AlGaSb quantum dots and wells

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(In)GaSb/AlGaSb quantum dots (QDs) are a promising telecom analogue of GaAs-based quantum-photonic emitters, with the added prospect of monolithic integration on silicon [1]. The nanostructures are formed by local droplet etching, where a thin (In)GaSb quantum well (QW) fills the etched nanoholes and naturally defines a coupled QW-QD system. Since non-resonantly excited carriers relax through the QW before capture in the dots, and previous studies have suggested the QW-QD transfer to be slow [2] and limited by a thermally activated barrier [3], understanding the QW dynamics is essential for interpreting the QD magneto-optical response.

Here, we combine temperature-dependent PL, ensemble and single-dot magneto-PL, QW time-resolved PL at 4 K and in fields up to 9 T, and 8-band k·p simulations to study the spectral and spin properties of this system. The QD spectra show a well-defined ground state and a structured excited-state manifold, whose orbital magnetic-field evolution is well reproduced by theory. While single-dot μPL reveals strong negative effective g-factors for individual lines (with values reaching up to -9.9), the substantial Zeeman splittings are obscured in ensemble PL by excitonic effects and by the quasi-continuum of mixed valence-band states associated with the large, nearly strain-free QDs. In parallel, polarization-, energy-, and time-resolved QW magneto-TRPL is quantitatively described by a disorder-localization model (Fig. 1), yielding an exciton g-factor of about -2.4 and spin-flip times of 0.2-0.3 ns. These results identify the QW as a central element governing carrier capture and magneto-optical response, providing a consistent framework for interpreting ensemble QD spectroscopy and for optimizing silicon-compatible telecom quantum emitters.

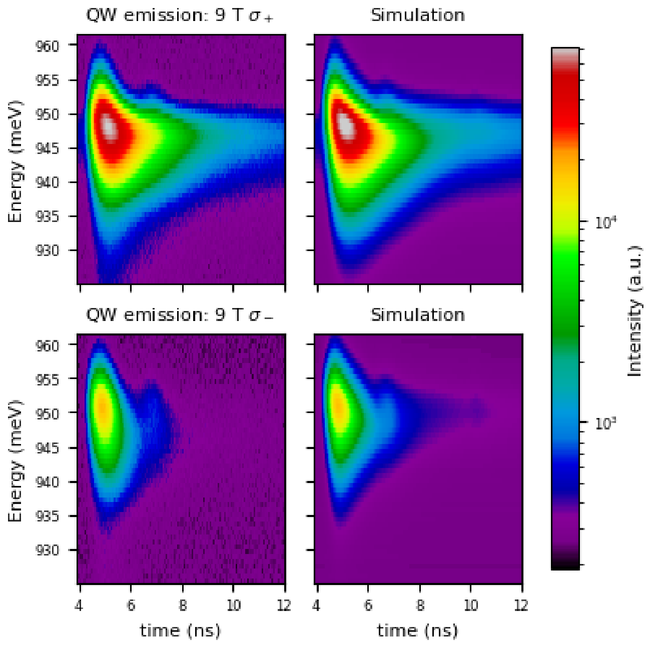

Fig. 1: Polarization- and energy-resolved QW TRPL at B=9T (left) and corresponding simulations (right).

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Fano profile in the resonance fluorescence spectrum of a quantum dot coupled to phonons

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We present a theory of resonance fluorescence (RF) of a quantum dot (QD) in the regime of weak optical excitation [1]. The QD is coupled to the phonon modes of the surrounding bulk semiconductor, described by a super-Ohmic spectral density. We show that the RF spectrum of this system consists of a central elastic line, a broad phonon sideband known from other linear and non-linear spectra of such systems, as well as a narrow inelastic contribution, which is characteristic of scattering spectra and stems from noise-induced transient dynamics. At moderate phonon couplings or low temperatures, the interplay between the broad sideband and the inelastic feature leads to a Fano-like profile near the resonant energy with the Fano parameter determined by laser detuning. In the weak-coupling limit (where only single-phonon processes are included), the spectrum becomes an exact Fano shape, and resonant light scattering is entirely suppressed. The amplitude of this spectral feature grows linearly with temperature, while its width depends solely on the spontaneous emission rate of the emitter. We relate the quantum character of the reservoir to the non-commutativity of noise observables and show that the Fano resonance persists in the classical (commutative) limit. We also discuss how the redistribution of optical coupling efficiency between the central line and the sidebands affects the total scattering rate under various excitation conditions. We include also the effects of inhomogeneous line broadening due to background charge noise and show that the particular spectral feature persists even in the presence of such fluctuations, although the characteristic Fano profile is expected to be observable in full only in QDs with Fourier-limited line widths.

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Photonic fusion of deterministically generated entangled states

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Self-assembled semiconductor quantum dots embedded in nanophotonic crystal waveguides provide a cutting-edge platform for photonic quantum technologies. Their integration in low-noise heterostructures has enabled deterministic single-photon sources with high brightness and excellent indistinguishability, forming essential building blocks for scalable photonic quantum computing. [1] In this work, we create entanglement between the electron spin of a quantum dot and multiple emitted photons, encoded in time-bin states. [2] By combining these small, spin-based, entangled photon resource states with linear optical fusion, we propose scalable protocols to build larger photonic cluster states [Fig1(a)], serving as robust resources for fusion-based quantum computing architectures. Recently, proof-of-concept realization of temporal fusion [Fig1(c)] has shown the ability of fusing photons emitted at different times from the same quantum dot emitter. [3] Building on these results, we present a scheme to extend our previous experiments toward the creation and optical fusion of small resource states. To enable this, we employ nuclear spin cooling and dynamical decoupling techniques to enhance the spin coherence properties of our quantum dots. These improvements are expected to increase the fidelity and scalability of photonic fusion protocols, paving the way toward photonic resource generation for quantum networking and computation.

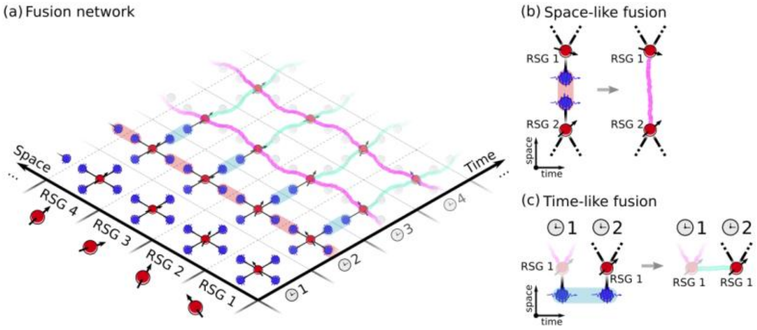

Fig. 1: Previous demonstration of creating cluster states with time-like fusion taken from [3]. (a) Possible scheme for creating a 2D cluster state with a network of fusion operations. The red dots represent single electron spins in self-assembled semiconductor quantum dots, while the blue dots are the photons emitted. RSG refers to resource state generators, and the clock symbols refer to different clock-cycles in the experiment. (b) For space-like fusion, two photons emitted from different quantum dots are jointly measured to achieve entanglement between the electron spins of their spatially separated emitters (magenta line). (c) Time-like fusion between two photons emitted by the same quantum dot at different clock cycles creates entanglement between the same electron spin, only at different times (cyan line).

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Electrical Control of Excitonic States in Droplet-Etched GaAs Quantum Dots via Stark and Charge Tuning

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Semiconductor quantum dots (QDs) are premier candidates for deterministic single-photon sources in quantum communication and quantum computing. However, the stochastic nature of self-assembled growth leads to broad emission wavelength distributions, complicating their use in wavelength-specific applications. In this work, we address this challenge by embedding droplet-etched nanohole-infilled GaAs QDs within a p-i-n diode structure grown via molecular beam epitaxy. By applying an external bias at cryogenic temperatures (4 K), we utilize the junction's built-in electric field to achieve precise electro-optical control. We demonstrate discrete transitions between charge states—characteristic of the Coulomb blockade regime—alongside continuous spectral tuning of the emission energy via the Stark effect. The impact of contact fabrication on the emission properties of GaAs quantum dots is investigated. We aim to optimize the process of forming ohmic contacts to n- and p-doped GaAs, placing special emphasis on the selection of materials and the reduction of contact resistance.These results highlight a robust pathway for mitigating charge noise and achieving the spectral precision necessary for integrated quantum technologies.

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Polarisation entangled photons enhanced by nuclear spin cooling in QDs

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After years of research the QD-intrinsic properties inhibiting perfect polarization-entanglement from emitted photon pairs are well understood. A constant fine structure splitting (FSS) [1], governed by QD asymmetry, induces which-path-information, while a slowly fluctuating nuclear-spin environment couples to excitons via an effective Overhauser field [2]. Few material systems, like local-droplet-etched GaAs QDs, were able to mostly overcome these limitations by years of refining QD-symmetry and lowering the radiative lifetime but suffer from the technologically challenging emission wavelength of ~780 nm. Other promising material systems, like InAs QDs, can emit natively in the Telecom-C band but suffer much more from FSS and Overhauser fluctuations, owed to the strain-driven growth and In's high nuclear spin. Time filtering [3], strain-tuning [1] and the integration of optical cavities with Purcel enhancement [4] can push the entanglement fidelity to a certain degree but are often inefficient, challenging to implement and new sources of noise.

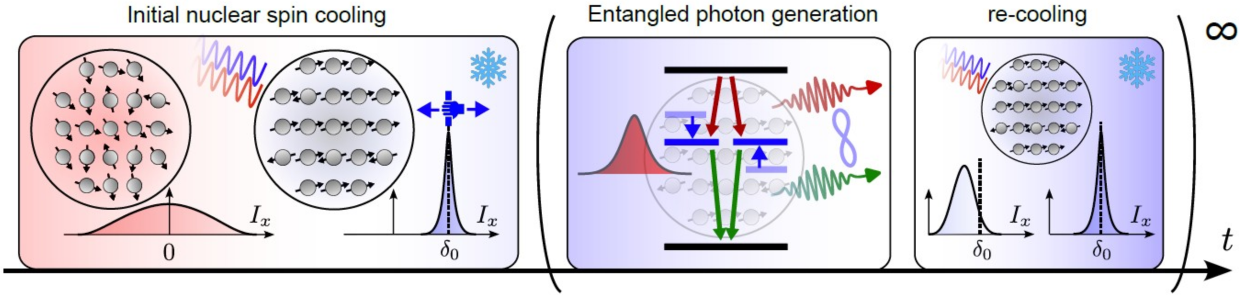

Fig. 1: Loop for generating polarization-entangled photons from a cooled nuclear environment

Here, we propose a novel technique which does not rely on the suppression of the effects of FSS and Overhauser fluctuations but eliminates both factors altogether, during operation and all-optically. Our method relies on the laser-induced engineering of the nuclear-spin-polarization into a narrow distribution with a well-defined mean value, such that the FSS is cancelled via the electron-nuclear hyperfine interaction, while the Overhauser fluctuations are simultaneously suppressed. In contrast to external magnetic fields alone [5], this method can cancel moderate FSS for any g-factor configuration. We believe that our method allows several QD systems to reach near-unity entanglement without complex device-integration or time-filtering.

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Growth of lattice-matched InGaAs/InAlAs QDs via LDE as C-band single photon emitter

Rabbia Tahir [1], Pawel Wyborski [2], Artur Tuktamyshev [3] , Stefano Vichi [3], Richard Noetzel [3], Battulga Munkhbat [2] and Stefano Sanguinetti [3]

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Strain-free semiconductor quantum dots (QDs) have attracted a significant interest for telecom quantum photonics. In this study, $In_{0.7}Ga_{0.3}As$ QDs emitting in telecom C-band, were fabricated on GaAs(111) substrate via local droplet etching on thin $In_{0.7}Al_{0.3}As$ metamorphic buffer layer (MMBL). The (111)A orientation enables efficient strain relaxation by using thin MMBL while preserving natural C_{3v} symmetry to produce highly symmetric QDs [1]. AFM analysis confirmed triangular pyramidal nanoholes (fig.1a), which were subsequently filled with $In_{0.7}Ga_{0.3}As$ to form telecom-emitting QDs. The QD geometry and electronic structure were optimized using k·p and envelope-function calculations.

Photoluminescence measurements demonstrated emission in the range of 1388 to 1553 nm (fig.1b), in consistent with theoretical simulations. The fabricated QDs exhibited single-photon emission with a measured $g^{(2)}(0)$ value of 0.141±0.027. In addition, time-resolved photoluminescence measurements revealed excitonic lifetimes in the range of 1.3–1.9 ns, demonstrating the potential of strain-free InGaAs/InAlAs QDs as telecom C-band single-photon emitters in quantum telecommunication applications.

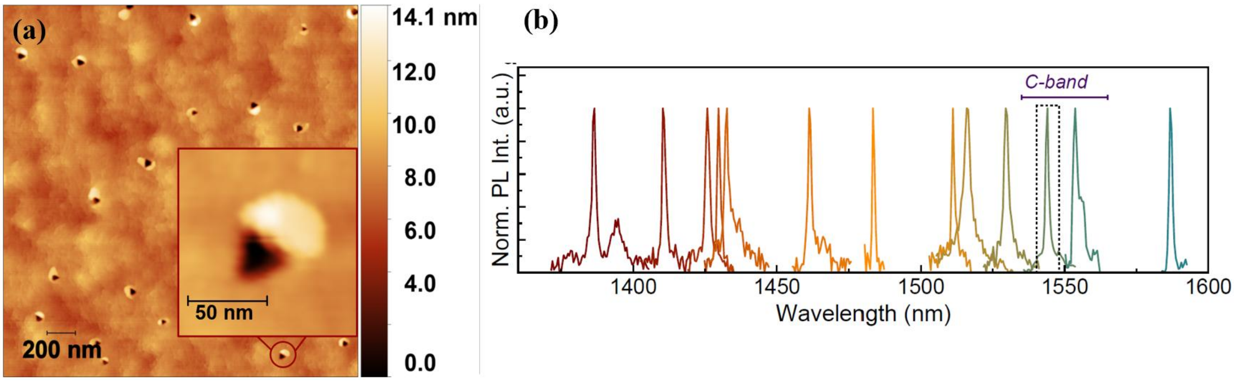

Fig. 1: Figure 1 (a) AFM image of nanoholes with 1024×1024 resolution at 2.5×2.5 μm^2 scale with Inset of nanohole having C_{3v} symmetry (b) μ-PL measurements of the fabricated QDs exhibiting the emission in C-band

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Scalable Quantum Interference from Indistinguishable Quantum Dots

Sheena Shaji[1], Suraj Goel[1], Julian Wiercinski[1], Frederik Brooke Barnes[1], Moritz Cygorek[2], Antoine Borel[1], Natalia Herrera Valencia[1], Erik M. Gauger[1], Mehul Malik[1], and Brian D. Gerardot[1],
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Quantum interference of indistinguishable photons is the foundation of photonic quantum technologies, yet scaling from a few to many identical quantum light sources remains a major challenge. In solid-state platforms, spatial and spectral inhomogeneity and resource-intensive architectures impede scaling. As a result, interference between remote, independent quantum emitters has been thus far limited to pairs. Here we introduce a wavefront-shaping approach that enables scalable interference from multiple indistinguishable quantum dots on the same chip[1]. Using programmable spatial light modulators, we independently excite, collect, and route emission from spatially distinct, yet spectrally degenerate dots. Scaling from two to five indistinguishable emitters, we verify interference through cooperative-emission phenomena and Hong–Ou–Mandel two-photon interference, thereby establishing a route towards large-scale, programmable quantum photonic architectures[2-3].

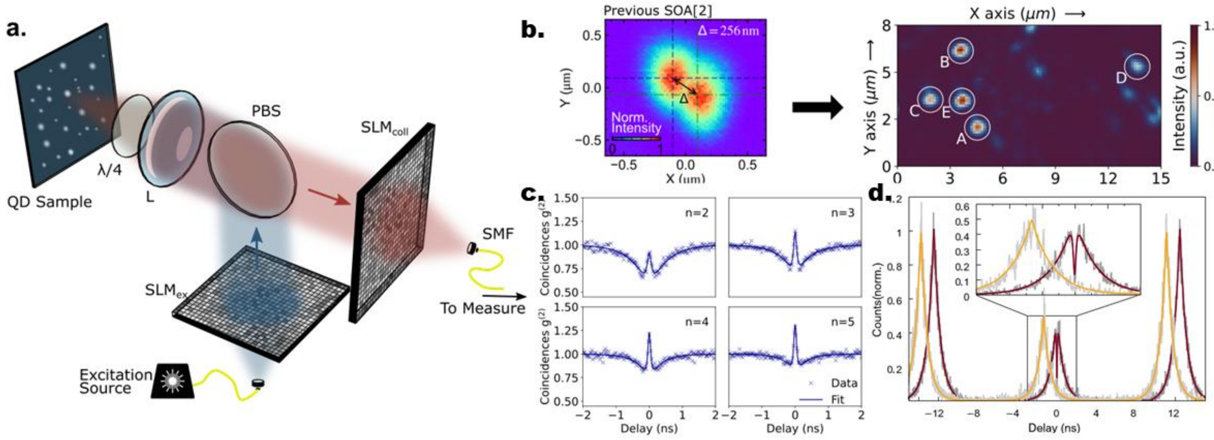

Fig. 1: (a) A pair of spatial light modulators SLMs are used to simultaneously excite multiple quantum dots (QDs) on a sample, and collect the corresponding emission into a multi-core fiber~(MCF), leading to a Hanbury-Brown Twiss measurement~(HBT) or Hong-Ou Mandel~(HOM) measurement. (b) Spatial map of quantum dots on the sample : Previous state-of-the-art[4] compared to the characterised map of five independent quantum dots (labelled A-E) in the current experiment shows a 40 times increase in QD separation. (c) HBT measurement results for 2,3,4 and 5 indistinguishable emitters, (d) HOM results for the two indistinguishable (red) and indistinguishable (blue) quantum dots. The zero-delay dip for the indistinguishable case is a characteristic of HOM-type interference.

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Waveguide driving of a chiral spin with tunable cyclic transitions

Shikai Liu[1], Joan Alba[1], Ming Lai Chan[1,2], Balint Sarkozi[1], Arne Ludwig[3], Peter Lodahl[1,2], and Anders S. Sørensen[1]

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Chiral light-matter interfaces are essential for enabling direction-dependent photon–emitter interactions[1,2], deterministic entanglement generation[3], and many body bound state dynamics[4]. Here, we experimentally investigate the chiral coupling of a negatively charged quantum dot, a four-level spin system, embedded in a standard W1 photonic-crystal waveguide. We observe spin-dependent directional emission reaching above 75% and extract a chiral phase of ~0.27π between the outer circular transitions in the Faraday geometry. By transitioning to the Voigt geometry, we characterize the upper bound of the waveguide-modified intrinsic cyclicity to be ~6. More significantly, we discover that continuously mixing the Voigt and Faraday magnetic field geometries provides a mechanism to fully tune the cyclic transition strengths. This effect allows us to suppress specific decay channels, achieving a modified cyclicity exceeding ~4000, two orders of magnitude larger than current waveguide-based spins in the Voigt configuration. Finally, we show a proof-of-concept that this local chiral point can enable waveguide remote spin control. By coupling a bichromatic Raman laser through the waveguide transmission, we successfully drive spin-flip Raman transitions mediated purely by the local circular waveguide mode, eliminating the need for polarization optimization required in external driving directly on top of the QD through the loss channel. Our results show the possibility of exploiting magnetic field mixing as a new degree of freedom for engineering cyclic transitions in standard nanophotonic interfaces.

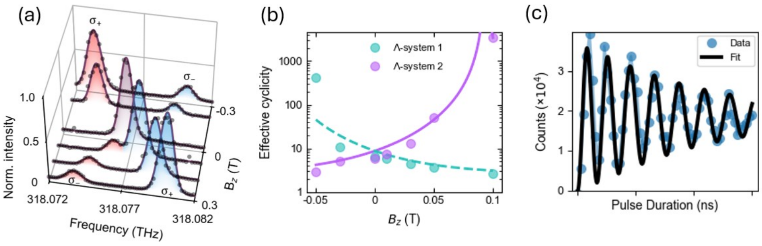

Fig. 1: (a). Spin-dependent directionality via cavity-assisted spectroscopy as a function of the applied Faraday magnetic field Bz (b) Effective cyclicity from two different λ systems by mixing Voigt with Faraday. (c) Rabi oscillation scan as a function of duration via waveguide spin driving.

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Characterizing Coherence in Resonant Transmission through a Waveguide-Coupled Quantum Dot

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A single two-level emitter coupled to a one-dimensional optical mode can transform a weak coherent field through photon-number-dependent scattering. Accessing the resulting two-photon amplitudes in the Heitler regime remains challenging because they are usually embedded in antibunched resonance fluorescence and revealed only after filtering, displacement, or interferometric post-processing. Here, we demonstrate direct two-photon phase superresolution and coherence from continuous-wave resonant transmission through a waveguide-coupled quantum dot. A single phase-controlled Mach-Zehnder interferometer maps both the first-order and second-order interference of the transmitted field. In the coincidence signal, we observe phase oscillations at twice the interferometer phase at the zero-delay centre peak, revealing a NOON-state-like two-photon response induced by the single-photon nonlinearity. Away from zero delay, the side peaks and coincidence background show a one-fold phase dependence. The phase- and time-resolved interferometer thus provides a diagnostic of resonant transmission and a spectroscopy tool for extracting the coupling efficiency, dephasing, and spectral diffusion of a quantum emitter.

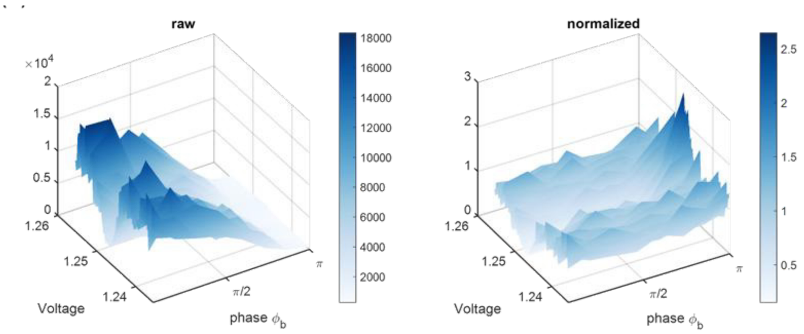

Fig. 1: Raw and normalized intensity data as a function of the quantum-dot bias voltage and the phase induced by the Mach-Zehnder interferometer. The left panel shows the raw collected intensity, while the right panel shows the corresponding normalized intensity.

Program

Thursday, June 11, 2026

Session 4: Spin and Charge Physics

Chair: Dorian Gangloff

10:00-10:35	Mark Hogg Fast optical control of a coherent hole spin in a microcavity
10:35-11:10	Zhe Xian Koong Coherent Control of Quantum-Dot Spins with Cyclic Optical Transitions
11:10-11:30	Lara Couronné Optimizing the generation of spin-based multi-photonic entangled states
11:30-11:50	Shikai Liu Waveguide driving of a chiral spin with tunable cyclic transitions
11:50-13:00	Lunch

Session 5: QD Growth and Modeling II

Chair: Michał Gawełczyk

13:00-13:35	Teemu Hakkarainen GaSb-based Quantum Dots for Telecom Wavelengths
13:35-13:55	Dirk Reuter Statistical Analysis of the Spatial Distribution of InAl Droplet-Etched Nanoholes in $In_{0.52}Al_{0.48}As$ Layers
13:55-14:15	Rubén Santana Alonso Electronic Coupling Mechanisms in [111] Oriented GaAs Quantum Dot Molecules: A Theoretical Study.
14:15-14:35	Petr Klenovsky Dipole vs Beyond-Dipole Radiative Rates in GaAs/AlGaAs Quantum Dots: Exciton, Trions and Biexciton
14:35-14:55	Eric Murphy Optical Signatures of Interdot Coupling in Stacked Site-Controlled GaAs Quantum Dots
14:55-15:30	Coffee break

Session 6: Applications

Chair: Sandra Stroj

15:30-16:05	Tina Müller Entanglement from Telecom-Wavelength Quantum Dots
16:05-16:25	Ievgen Brytavskyi Fabrication challenges and solutions on the way to a multifunctional quantum light source based on a GaAs QD in electrically contacted CBR
16:25-16:45	Vishnu Prakash Karunakaran Electrically Induced Strain Mapping in GaAs Layers Integrated on Piezoelectric Actuators

	Conference dinner 17:30 Bus departure 18:00 Boarding

Abstracts

Session 4: Spin and Charge Physics

Fast optical control of a coherent hole spin in a microcavity

Mark R. Hogg[1], Nadia O. Antoniadis[1], Malwina A. Marczak[1], Giang N. Nguyen[1], Timon L. Baltisberger[1], Alisa Javadi[1], Rüdiger Schott[2], Sascha R. Valentin[2], Andreas D. Wieck[2], Arne Ludwig[2] and Richard J. Warburton[1]

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Spin-photon interfaces are a key ingredient for quantum technologies, enabling quantum information to be mapped between stationary spins and photons travelling at the speed of light. Spin-photon interfaces are also promising as a deterministic source of entangled photonic graph-states [1], which serve as resource states for measurement-based quantum computation and one-way quantum repeaters. The ideal spin-photon interface combines both a highly coherent spin and coherent, efficient photon emission. Self-assembled semiconductor quantum dots (QDs) are demonstrated excellent on-demand sources of indistinguishable single-photons, and impressive progress has been made in mitigating the impact of magnetic noise from the host nuclear spins on electron-spin decoherence [2]. Although the ingredients for a leading spin-photon interface (high-fidelity spin control, long coherence times, high-efficiency photon extraction) have been demonstrated in individual quantum dot experiments, combining all these components at a state-of-the-art level is an important outstanding challenge.

Here, we demonstrate a system that combines the best of all worlds: we achieve fast and high-fidelity coherent control of an InGaAs QD hole-spin with coherence metrics significantly exceeding the state-of-the-art for this system ($T_2^* = 530$ ns, $T_2 = 40\mu$s), all on a QD embedded in a tunable open microcavity with a high end-to-end single photon source efficiency. We use a microwave-modulated control scheme [3], making coherent rotations around an arbitrary Bloch sphere axis trivial and allowing all-optical cooling of the host nuclei to extend the hole spin coherence. We achieve a maximum π-pulse fidelity of 98.7%, and ultra-fast Rabi frequencies above 1 GHz. Upon cooling the nuclear spin ensemble, we observe the injection of collective nuclear spin excitations (nuclear magnons [4]) activated by the hole spin. Our work demonstrates the potential for semiconductor QDs as fast, efficient, and coherent spin-photon interfaces.

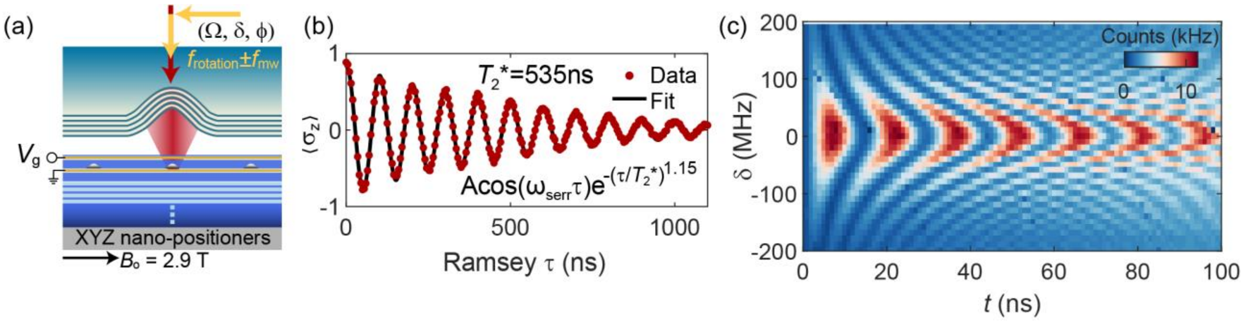

Fig. 1: (a) Tunable open microcavity, consisting of a gated InGaAs quantum dot sample integrated with a highly reflective bottom mirror and a free-standing top mirror. (b) Ramsey interferometry after quantum sensing-based nuclear bath cooling, achieving $T_2^* = 535 \pm 20$ ns. (c) High-quality Rabi chevron after nuclear bath cooling.

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Coherent Control of Quantum-Dot Spins with Cyclic Optical Transitions

Zhe Xian Koong[1], Urs Haeusler[1], Jan M. Kaspari[2], Christian Schimpf[1], Benyam Dejen[1], Ahmed M. Hassanen[1, 3], Daniel Graham[1], Ailton J. Garcia Jr.4, Melina Peter[4], Edmund Clarke[5], Maxime Hugues[6], Armando Rastelli[4], Doris E. Reiter[2], Michał Gawełczyk[7], Mete Atature[1], and Dorian A. Gangloff[1]

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Solid-state spins are promising as interfaces from stationary qubits to single photons for quantum communication technologies. Semiconductor quantum dots have excellent optical coherence, exhibit near-unity collection efficiencies when coupled to photonic structures, and possess long-lived spins for quantum memory. However, the incompatibility of performing optical spin control and single-shot readout simultaneously has been a challenge faced by almost all solid-state emitters. To overcome this, we leverage light-hole mixing to realize a highly asymmetric lambda system in a negatively charged heavy-hole exciton in Faraday configuration [1]. By compensating GHz-scale differential Stark shifts, induced by unequal coupling to Raman control fields, and by performing nuclear-spin cooling, we achieve quantum control of an electron-spin qubit with a π-pulse contrast of 97.4% while preserving spin-selective optical transitions with a cyclicity of 409. We demonstrate this scheme for both GaAs and InGaAs quantum dots and show that it is compatible with the operation of a nuclear quantum memory. Our approach thus enables repeated emission of indistinguishable photons together with qubit control, as required for single-shot readout, photonic cluster-state generation [2], and quantum repeater technologies [3].

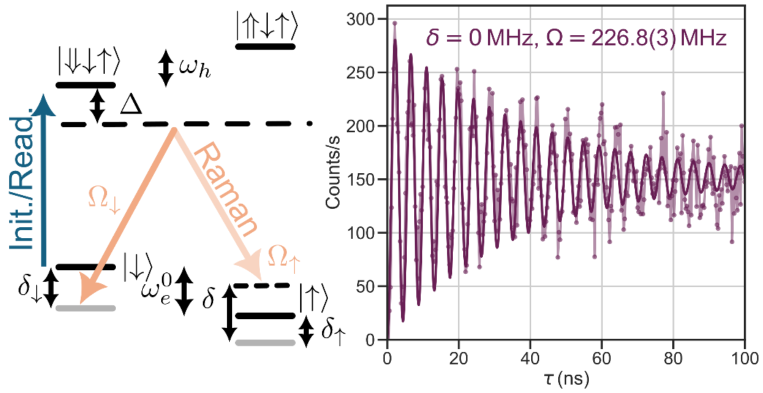

Fig. 1: (Left) Energy level of the schematic of a negatively charged exciton in the presence of an out-of-plane magnetic field (Faraday configuration), showing the Stark shifts due to the strong, detuned Raman laser pair. (Right) Measurement of the Rabi oscillations of the electron spin at 226.8 (3) MHz in a GaAs QD.

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Optimizing the generation of spin-based multi-photonic entangled states

L. Couronné[1,2], H. Huet[1], E. Annoni[1], S. Boissier[1], A. Lemaître[2], M. Morassi[2], A. Pishchagin[1], P. Steindl[2], O. Krebs[2], V. Villafane[1], D. Fioretto[2], S. Wein[1], P. Senellart[2]

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One of the most promising approaches to scalable and universal photonic quantum computation is measurement-based quantum computing, which uses multi-photon entangled states as resource states. To generate such states, we employ state-of-the-art single-photon sources with brightnesses of up to 60%. These sources are InGaAs quantum dots embedded in micropillar cavities, which emit single photons with high indistinguishability when triggered by short optical pulses.

In addition, the quantum dot enables the deterministic confinement of an extra charge carrier with a spin. Through optical selection rules, the spin state of the carrier is uniquely mapped onto the polarization of the emitted photon. By operating the spin in a weak external magnetic field, under which the spin precesses, we initialize the spin in a superposition state, leading to the generation of spin-photon entanglement. Repeating this process enables the implementation of the Lindner-Rudolph scheme [1], allowing for the generation of multiphoton entangled states that are, theoretically unbounded in size, as demonstrated by several groups [2, 3, 4].

More recently, this scheme has been extended by introducing short optical pulses that act as spin phase controls; enabling the generation of more complex entangled states, including so-called "caterpillar states" through full control of the spin [5].

In this talk, we present work carried out in our group on the implementation of this scheme, achieving the entanglement of up to ten photons. We focus in particular on the role of techniques such as spin-echo and temporal filtering in improving the performance of state generation. This work represents a fundamental milestone toward small-scale demonstrations of fault-tolerant quantum computing.

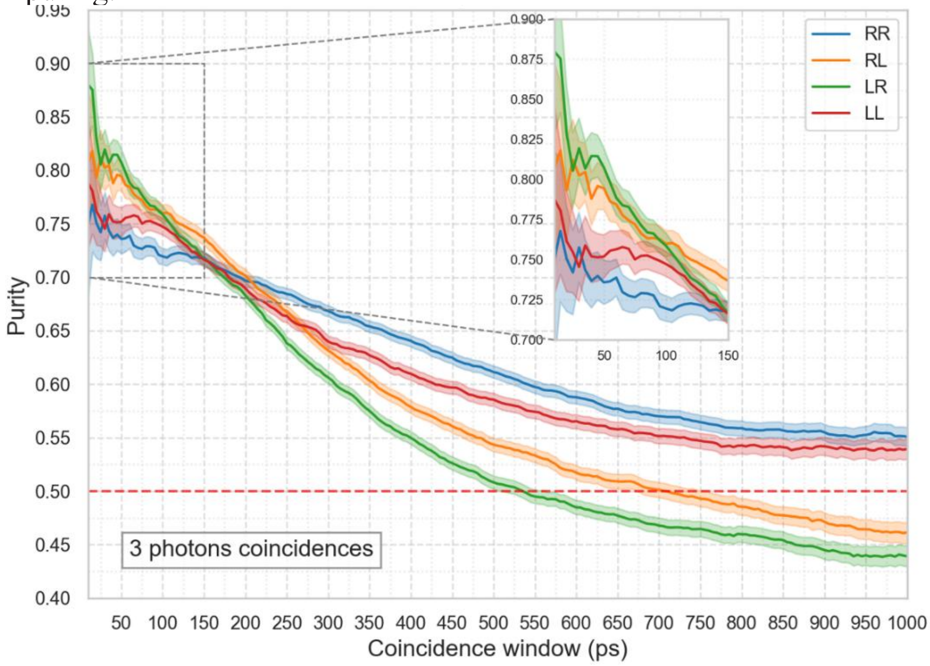

Fig. 1: Evolution of the purity of a 3-photons cluster state as a function of time filtering. Plotted purity value is purity of 2nd photon depending on polarization of 1st and 3rd photons (which can each be R or L, hence RR, LL, RL and LR possibilities)

Waveguide driving of a chiral spin with tunable cyclic transitions

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Chiral light-matter interfaces are essential for enabling direction-dependent photon–emitter interactions[1,2], deterministic entanglement generation[3], and many body bound state dynamics[4]. Here, we experimentally investigate the chiral coupling of a negatively charged quantum dot, a four-level spin system, embedded in a standard W1 photonic-crystal waveguide. We observe spin-dependent directional emission reaching above 75% and extract a chiral phase of ~0.27π between the outer circular transitions in the Faraday geometry. By transitioning to the Voigt geometry, we characterize the upper bound of the waveguide-modified intrinsic cyclicity to be ~6. More significantly, we discover that continuously mixing the Voigt and Faraday magnetic field geometries provides a mechanism to fully tune the cyclic transition strengths. This effect allows us to suppress specific decay channels, achieving a modified cyclicity exceeding ~4000, two orders of magnitude larger than current waveguide-based spins in the Voigt configuration. Finally, we show a proof-of-concept that this local chiral point can enable waveguide remote spin control. By coupling a bichromatic Raman laser through the waveguide transmission, we successfully drive spin-flip Raman transitions mediated purely by the local circular waveguide mode, eliminating the need for polarization optimization required in external driving directly on top of the QD through the loss channel. Our results show the possibility of exploiting magnetic field mixing as a new degree of freedom for engineering cyclic transitions in standard nanophotonic interfaces.

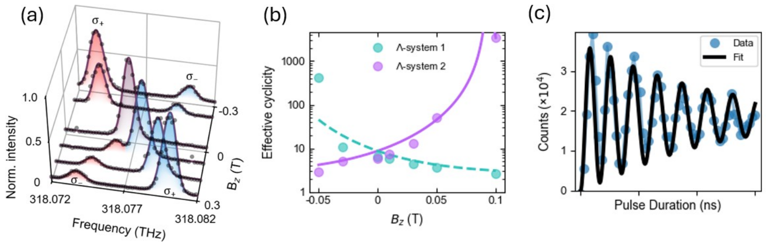

Fig. 1: (a). Spin-dependent directionality via cavity-assisted spectroscopy as a function of the applied Faraday magnetic field Bz (b) Effective cyclicity from two different λ systems by mixing Voigt with Faraday. (c) Rabi oscillation scan as a function of duration via waveguide spin driving.

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Abstracts

Session 5: QD Growth and Modeling II

GaSb-based quantum dot emitters for telecom wavelengths

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Solid-state single and entangled photon emitters linked coherently over long distances with optical fibers enable a new generation of quantum-based communications networks. Currently, epitaxial semiconductor quantum dots (QDs) pave the way as a scalable approach for fabricating deterministic non-classical light sources that can be integrated with other photonic or electronic components in miniaturized form. Here, we present a new quantum material system based on GaSb-based QDs formed by filling droplet-etched nanoholes [1,2], a technique which has been previously used for the state-of-the-art single- and entangled-photon sources in the GaAs-based materials emitting at wavelengths shorter than 800 nm [3-6].

This presentation covers the development steps and the current state-of-the-art of (In)GaSb QDs grown by filling droplet-etched nanoholes in AlGaSb. It is demonstrated that, while the GaSb QDs exhibit high homogeneity and small fine structure splitting similarly to their GaAs counterparts, they also enable single-photon emission in the 3rd telecom window [7] with prospects for extending towards 2µm. Furthermore, by employing quasi-resonant excitation or LO-phonon-assisted excitation of a single QD, it is possible to it is possible to achieve spectrally clean emission from a single exciton line and high-quality single-photon emission [8]. These properties make GaSb-based QDs ideal candidates for quantum photonic applications requiring compatibility with Si-photonics and fiber-based telecom

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Statistical Analysis of the Spatial Distribution of InAl Droplet-Etched Nanoholes in $In_{0.52}Al_{0.48}As$ Layers

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Strain-free, droplet-etched quantum dots are widely considered the gold standard for the generation of entangled photon pairs, especially in the GaAs/$Al_xGa_{1-x}As$ system. Recently, emission in the optical C-band has been achieved using droplet-etched $In_xGa_{1-x}As$ quantum dots in an $In_{0.52}Al_{0.48}As$ matrix lattice-matched to InP [1]. In this contribution, we present a study of the spatial distribution of the nanoholes etched by InAl droplets in $In_{0.52}Al_{0.48}As$, employing molecular beam epitaxy [2]. By analyzing atomic force microscopy images, we identified two temperature regimes, which exhibit significantly different droplet aggregation behavior. As can be seen in Fig. 1, the droplet density shows an exponential decrease with increasing temperature in the low-temperature regime (300–390 °C), which is characterized by an activation energy of 0.34 eV, whereas for the high-temperature regime (435–505 °C), the exponential decrease persists but with a much larger activation energy of 2.20 eV. The increased activation energy is accompanied by a strong elongation of the denuded zone around the nanoholes in the distribution of the nearest neighbors along the [011] direction, whereas the distribution is almost isotropic in the low-temperature regime. In both temperature regimes, we observe a narrowing of the capture-zone size distribution with increasing temperature; however, the distribution broadens with the transition to the high-temperature regime before narrowing again with further increasing temperature. By employing nucleation theory, we find that the critical nucleus size does not appear to be significantly different between the two temperature regimes. However, Ostwald ripening is probably relevant, so nucleation theory does not describe our experiments completely. We propose a change in the surface reconstruction, with a more anisotropic arrangement in the high-temperature regime, as the underlying reason for the significantly different behavior in the two regimes.

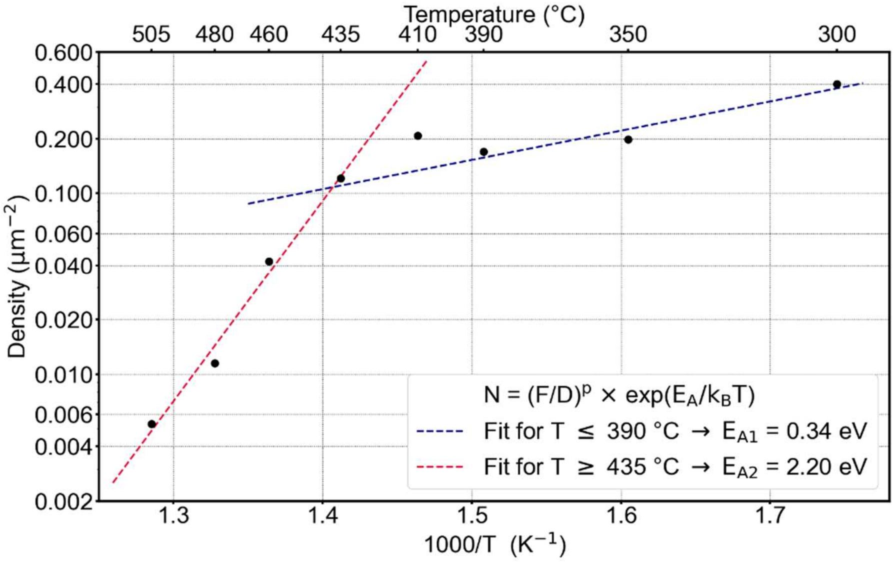

Fig. 1: Average hole density as function of temperature. The InAl flux was 0.7 ML/s for all samples.

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Electronic Coupling Mechanisms in [111]-Oriented GaAs Quantum Dot Molecules: A Theoretical Study.

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Multidimensional photonic cluster states (MDPCS) have emerged as a promising route to scalable quantum computing, offering a powerful substrate for measurement-based quantum processing [1]. Yet producing these highly entangled states on demand and at scale remains a major challenge.

Semiconductor quantum dots (QDs) and quantum dot molecules (QDMs) have been explored as platforms for generating linear photonic cluster states (LPCS) and MDPCS. LPCS have already been demonstrated using single QDs [2], while MDPCS have primarily been pursued through probabilistic fusion protocols [3]. To circumvent the limitations of probabilistic schemes, proposals based on QD molecules (QDMs) have been introduced [4]. These approaches, however, require precise control over the structures' geometry and composition to tailor their electronic and optical properties to the specifications outlined in the literature. Conventional QD and QDM systems, such as Stranski–Krastanov (SK) QDs, offer limited deterministic control [5], thus posing challenges for scalable MDPCS generation.

In contrast, site-controlled [111]-oriented GaAs QDs provide a promising alternative, offering high reproducibility in dot dimensions and alloy composition [6]. This level of control brings the deterministic fabrication of QDMs, suitable for MDPCS generation, within reach. Experimental studies further show that [111]-oriented structures exhibit electronic and optical properties markedly different from their [001]-oriented counterparts. Owing to these in part symmetry-driven differences, insights derived from [001]-oriented QDs cannot be directly transferred to [111]-oriented systems, whether for single dots or coupled molecules.

In this work, we investigate the electronic and optical properties of site-controlled [111]-oriented GaAs QDs and QDMs. Our theoretical results are benchmarked and compared against experimental data. We use an 8-band **k.p** model combined with a configuration interaction scheme to analyse multi-exciton states in site-controlled [111]-oriented GaAs QDs and QDMs. Size, geometry, and alloy composition strongly shape the electronic structure, and we find robust light-hole (LH) excitonic states in both single dots and molecules, in contrast to SK systems. For QDMs, we map how geometry and spacer-layer thickness impact the level structure, with a view to meet requirements for MDPCS generation. We find that LH-mediated coupling persists even at large inter-dot separations, highlighting hole states as strong candidates for deterministic MDPCS generation in site-controlled [111]-oriented GaAs QDMs.

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Dipole vs Beyond-Dipole Radiative Rates in GaAs/AlGaAs Quantum Dots: Exciton, Trions and Biexciton

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We compute the electronic and emission properties of Coulomb-correlated multi-particle states (X^0, $X^\pm$, XX) in weakly confining GaAs/AlGaAs quantum dots using an 8-band **k·p** model coupled to continuum elasticity and configuration interaction (CI). We evaluate polarization-resolved oscillator strengths and radiative rates both in the dipole approximation (DA) and in a quasi-electrostatic beyond-dipole (BDA) [1] longitudinal formulation implemented via a Poisson reformulation exactly equivalent to the dyadic Green-tensor kernel. For the dots studied, BDA yields lifetimes in quantitative agreement with experiment, e.g., $\tau^X = 0.279$ ns vs 0.267 ns (exp.) and $\tau^{XX} = 0.101$ ns vs 0.115 ns (exp.) (Fig.1) [2]. The framework also reproduces electric-field tuning of the multi-particle electronic structure and emission including the indistinguishability inferred from $P = \tau^X/(\tau^X+\tau^{XX})$ [3] and we assess sensitivity to CI-basis size and to electron-electron and hole-hole exchange [4].

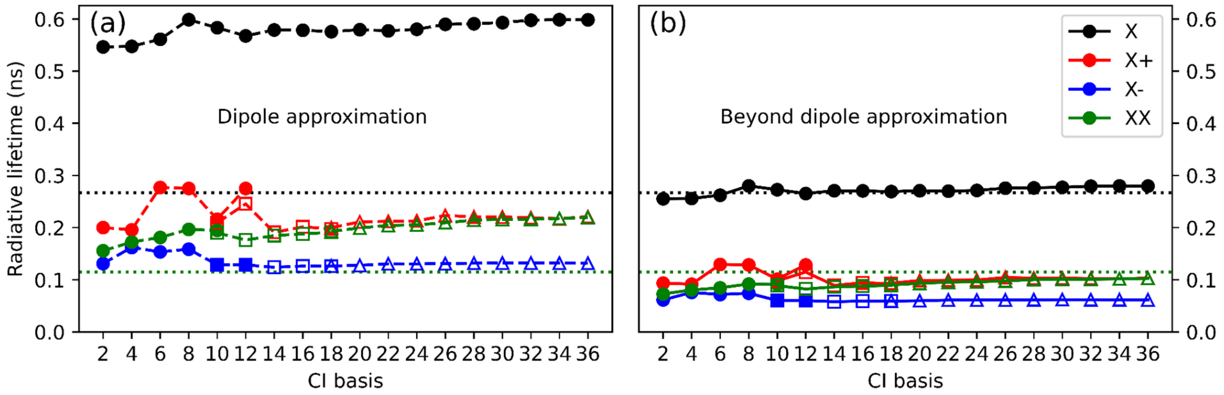

Fig. 1: The evolution of the radiative lifetime of ground states of X, X+, X−, and XX as a function of the CI basis size when the overlap integrals are evaluated considering (a) DA and (b) BDA. The black (green) dotted horizontal line mark the measured values of exciton (biexciton) lifetime from Ref. [2].

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Optical Signatures of Interdot Coupling in Stacked Site-Controlled GaAs Quantum Dots

Eric Murphy, Fabian Noel, Sarath C.R. Sanivarapu, Rubén Alonso, Neil O'Connor, Luca Colavecchi, Stefan Schulz, Emanuele Pelucchi, Gediminas Juška

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We present resonant and above-band photoluminescence (PL) studies of a series of stacked site-controlled GaAs quantum dots (QDs) with a varied interdot barrier thickness. By tailoring the thickness of the barrier between dots, such that only the excited states are coupled with individually addressable ground transitions, we aim to implement the protocol for the generation of a 2D photonic cluster state [1].

The dots are confined by effective $Al_{0.14}Ga_{0.86}As$ barriers and grown in an inverted pyramidal recess on (111)B oriented substrates [2]. An 8-band $k{\cdot}p$ model combined with a configuration interaction scheme, tailored to site-controlled [111]-oriented GaAs QDs, shows a fundamentally interesting and practically attractive QD coupling pathway via excited light-hole-like excitonic states unique to this QD system.

The effect of a spacer thickness in a range of h=15-30 nm (the effective h is estimated to be reduced by ~3x) was studied. Highly separated dots show two overlapping but distinct sets of spectral features (Fig. 1), corresponding in absolute energy and energetic structure to those observed in single dots. Building on a well-established single QD energetic structure model, using polarisation resolved PL, correlation measurements and PLE-like experiments, we study the energetic structure of stacked and potentially coupled QDs.

The onset of coupling is expected to be accompanied by changes in the well-known energetic structure, as we show in this work. For example, for thin interdot spacers, the dots couple, and the emission spectra become increasingly complex. We identify known peaks of coupled dots using polarisation resolved PL (including fine-structure splitting inheritance), with particular emphasis on excitonic features to compare to simulations. Resonantly targeting the excited exciton state of one dot, we see bright ground exciton emission from both dots (Fig. 2), showing already strong coupling as electron and hole states are shared between the two dots. A detailed and extended study of such optical signatures is described in this work.

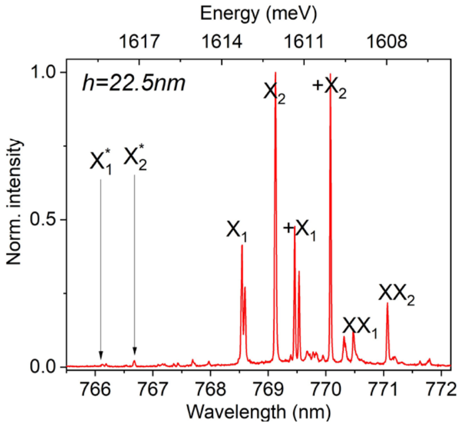

Fig. 1: Emission spectrum of uncoupled stacked QDs, showing two distinct dot spectra.

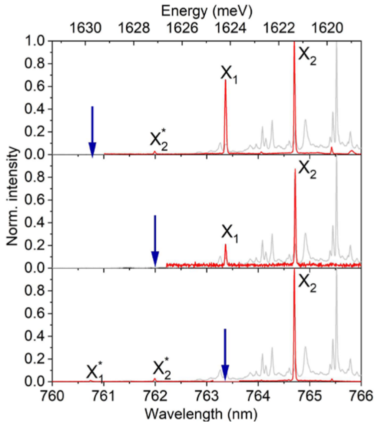

Fig. 2: Resonant excitation study of fully coupled QDs.

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Abstracts

Session 6: Applications

Entanglement from telecom-wavelength quantum dots

Tina Müller

Quantum networking schemes such as blind quantum computing, clock synchronisation, and entanglement distribution between any points on the globe, are currently in development, primarily using photons at telecom wavelengths for long-distance transmission of quantum information. Solid-state based spin-photon interfaces are a practical and integrable resource for such schemes with impressive recent progress towards first applications.

In this talk I will discuss recent progress towards multiqubit entanglement with quantum dots emitting at telecom wavelength, starting with the transfer of established methods for manipulation and control of a solid-state spin to control the spin in an InAs/InP QD. With these tools, we can demonstrate entanglement between the electron spin and the frequency of a photon at telecom wavelengths. Further, the established spin-photon interface can be used to produce non-classical correlations between multiple qubits, i. e. the electron spin and two consecutively emitted photons. Finally, I will discuss possible improvements to extend the number of entangled qubits.

Fabrication challenges and solutions on the way to a multifunctional quantum light source based on a GaAs QD in electrically contacted CBR

Ievgen Brytavskyi[1], Tobias Krieger[1], Thomas Oberleitner[1], Tobias Steindl[1], Markus Wiener[1], Eva Schöll[1], Christian Weidinger[1], Maximilian Aigner[1], Gabriel Undeutsch[1], Ailton Garcia Jr. [1], Naser Tajik[1], Melina Peter[1], Tobias Huber-Loyola[2], Armando Rastelli[1]

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One of the promising platforms for efficient quantum light sources is a quantum-dot (QD) emitter embedded in a doped semiconductor membrane and coupled to deterministically positioned photonic cavity structures [1–4]. MBE-grown GaAs quantum dots offer high-fidelity, on-demand generation of single and entangled photons due to their in-plane symmetry, low fine-structure splitting, and excellent optical quality. A diode structure enables electrical control over the QD charge environment (blinking-free emission), approaching Fourier-limited emission (high indistinguishability), and wavelength tuning via the Stark effect. Circular Bragg resonators (CBRs) around QDs provide the way for efficient lateral photon collection (increased brightness) and selective Purcell enhancement (shortened excitonic lifetimes that help mitigate charge noise and dephasing). Integration of both functionalities in a single diode-CBR device is challenging and requires optimization of both the sample structure and the fabrication workflow.

We present the practical realization of this design, highlight the optoelectronic properties of the device, discuss the key parameters (doping concentrations, layer structure, CBR geometry) and focus on details of the resolved fabrication challenges, including the formation of ohmic electrical contacts, issues related to contact annealing, stability of membrane bonding to the carrier substrate, optimization of the QD coordinate collection procedure and marker grid design, and adjustments to electron-beam lithography and plasma etching for improved reproducibility.

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Electrically Induced Strain Mapping in GaAs Layers Integrated on Piezoelectric Actuators

V.P. Karunakaran[1,2], I. Brytavskyi[2], T. M. Krieger[2], S. Stroj[1], M. Domke[1], A. Rastelli[2],
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Integration of a GaAs layer with piezoelectric actuators provides a scalable approach to electrically control the strain in semiconductor devices. In this work, we investigate the strain transfer, and strain mapping of a GaAs layer integrated onto a PMN-PT piezoelectric actuator. A low-temperature bonding approach is used to couple the GaAs layer to the actuator while maintaining structural integrity and optical quality. Electrical actuation of the PMN-PT actuator induces controlled deformation on actuator legs, enabling efficient transfer of strain into the GaAs layer. The resulting strain fields are characterized using Raman spectroscopy and photoluminescence mapping, this allows correlation between applied electric fields and local strain-induced band-structure modifications in GaAs.

This study evaluates strain transfer efficiency and reversibility under electrical control. Detailed characterization is used to test the quality of the bonding and to analyse the strain distribution across the GaAs layer based on applied voltage. Independent control of the actuator legs enables tuneable and anisotropic strain profiles, providing insight into localized strain modulation and its effects on the GaAs layer. The demonstrated strain-engineered GaAs layer has implications for tuneable photonic devices, strain-controlled waveguides, and spectral tuning of semiconductor quantum dots for quantum photonic applications.

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Program

Friday, June 12, 2026

Session 7: Quantum Optics II
Chair: Rinaldo Trotta

08:30-09:05	Alexey Tiranov Deterministic photon-emitter interfaces for photonic quantum technology
09:05-09:25	Caspar Hopfmann A compact, deployable and industry-compatible entangled photon pair source based on GaAs quantum dots in monolithic microlenses
09:25-09:45	Samuel Sheldon Generating redundantly encoded resource states for quantum computing
09:45-10:05	Juan Nicolas Claro Rodriguez Benchmarking the Spatial Integration of Photonic Structures with Optically Localized Semiconductor Quantum Dots
10:05-10:25	Koray Kaymazlar Single-photon Advantage in Quantum Cryptography beyond QKD
10:25-11:00	Coffee break

Session 8: Theory
Chair: Mark Hogg

11:00-11:35	Ed Barnes Electron-nuclear entanglement dynamics and photonic resource state generation from quantum dots
11:35-11:55	Krzysztof Gawarecki Microscopic origins of nuclear inhomogeneity in quantum dots
11:55-12:15	Jan Kaspari Revisiting the Two-Photon Resonance in Faraday Spin Control
12:15-12:30	Awards and Closing
12:30	Lunch

14:40-17:00	Social program Tour to the Rappenloch gorge (1,5 h walk) 14:40 at meeting point Foyer F to take the local bus together Bus 177 departure: 14:52 from Sägerbrücke (7 min to Gütle) Bus back every 30 min

Abstracts

Session 7: Quantum Optics II

Deterministic photon-emitter interfaces for photonic quantum technology

A. Tiranov [1]
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In this presentation, I will highlight recent progress at Sparrow Quantum in the development of advanced solid-state single-photon sources. These devices achieve a combination of high brightness, near-unity indistinguishability, and deterministic emission - key properties for scaling quantum information processing systems. Our approach relies on deterministic photon–emitter interfaces based on InGaAs quantum dots integrated into planar photonic nanostructures, forming an essential platform for scalable photonic quantum technologies [1,2].

I will also discuss our latest results on deterministic spin–photon interfaces, which enable the generation of spin–multiphoton entangled states. This emitter-based strategy supports the on-demand production of photonic cluster states for measurement-based quantum computing and is well suited to fusion-based architectures for fault-tolerant photonic computation [3].

Finally, I will outline the hardware requirements needed for resource-state generation and fusion-based networking, along with precise resource estimates for encoding a logical qubit. Together, these results establish a realistic and experimentally grounded route toward fault-tolerant photonic quantum computing based on emitter platforms.

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A compact, deployable and industry-compatible entangled photon pair source based on GaAs quantum dots in monolithic microlenses

Y. G. Zena[1], M. Langer[1,2], A. Dhurjati[1], P. Ruchka[3], R. Bassoli[1,2], F. H. P. Fitzek[2], H. Giessen[3], and C. Hopfmann[2]
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[2] *Deutsche Telekom Chair of Communication Networks, Technische Universität Dresden, Germany*
[3] *4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany*

Entangled photon pair sources are a key enabling technology for quantum communication and networking, yet their deployment beyond laboratory environments is hindered by system-level complexity, limited operational stability, and insufficient industry compatibility. Here we demonstrate a rack-based, mobile quantum light source architecture based on a GaAs quantum dot emitter that directly addresses these challenges through modular system integration and automated operation. This source is based on monolithic quantum dot microlenses on gold back reflectors manufactured using a specialized Gray lithography on AlGaAs nanomembranes [1]. In order to attain efficient ultra-compact sources in situ coupling to single mode fibers using 3D-printed micro-objectives are utilized [2]. The resulting source generates polarization-entangled photon pairs with an entanglement negativity n of up to $2n = 0.98 \pm 0.01$, confirming near-maximal entanglement quality. In continuous, hands-off operation over a six-hour time window, we observe an average single-photon emission rate of (671 ± 76) kHz, while maintaining an entanglement fidelity exceeding 95%. These results are enabled by the integration of optical excitation, collection, cryogenic operation, and control electronics within a standardized rack footprint, together with automated stabilization and monitoring infrastructure. By demonstrating simultaneously high entanglement quality, sustained brightness, and long-term operational stability in an industry-aligned system architecture, this work advances semiconductor quantum dot sources toward deployable entangled photon sources for applied quantum photonics.

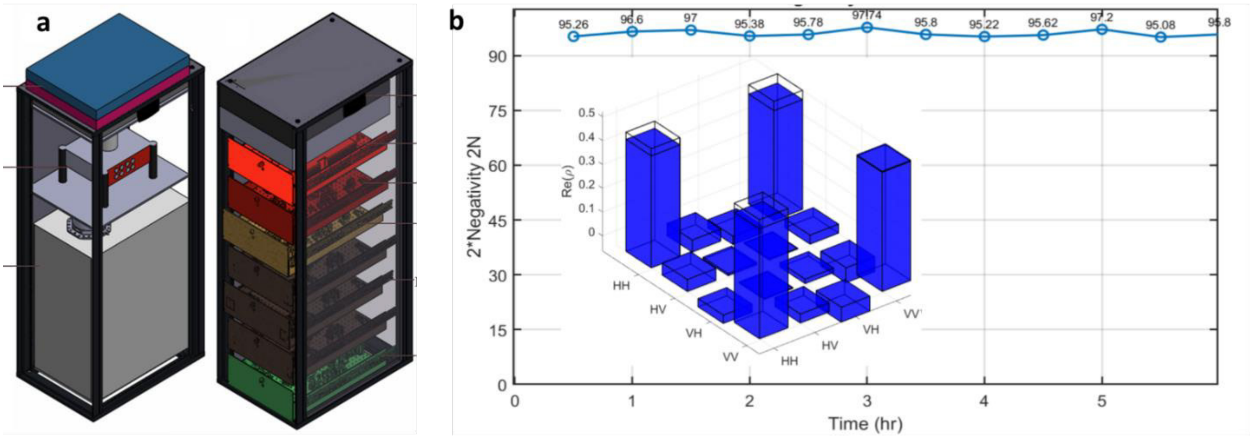

Fig. 1: a) Schematic illustration of the compact, deployable entangled photon pair source based on 19-inch rack systems. b) Hand-off entanglement negativity of the source over a six-hour period. Inset: Exemplary real part of the two-photon density matrix (2n ~ 0.98).

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Generating redundantly encoded resource states for photonic quantum computing

S. J. Sheldon[1] and P. Kok[1,2]

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Measurement-based quantum computing relies on the generation of large entangled cluster states that act as a universal resource on which logical circuits can be imprinted and executed through local measurements [1,2]. A number of strategies for constructing sufficiently large photonic cluster states propose fusing many smaller resource states generated by a series of quantum emitters. However, the fusion process is inherently probabilistic with a 50% success probability in standard guise [3]. Recently a time-delayed repeat-until-success strategy has been proposed using redundantly encoded resource states to increase the probability of successful entanglement generation via photonic fusion to near unity in the limit of low loss [4]. We present a protocol outlining the physical operations required to generate these redundantly encoded resource states when employing solid-state quantum emitters generating entangled time-bin encoded photonic qubits as the resource state generators considering how the order of operations changes the structure of the generated state. We also study the impact of operational errors resulting from the dynamical behaviour of such quantum emitters on both the generated states and on the outcomes of type-II photonic fusion measurements.

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Benchmarking the Spatial Integration of Photonic Structures with Optically Localized Semiconductor Quantum Dots.

Nicolas Claro-Rodriguez[1*], Oscar Camacho-Ibarra[1], Santiago Bermudez-Feijoo[1], Patricia Kallert[1], Leonie Schubert[1], Maranatha Andalis[1], Atzin David Ruiz-Pérez[1], Normen Auler[1], Marc Satison[1,2], Dirk Reuter[1], and Klaus D. Jöns[1]
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Semiconductor quantum dots (QDs) are a promising platform for next-generation devices requiring deterministic sources of single photons, entangled photon pairs, and more complex quantum states. Integrating these emitters into photonic structures (PSs) such as cavities, waveguides, or plasmonic devices, requires knowledge of their positions with nanometer-scale precision [1]. Since QDs are randomly distributed within the sample, various techniques have been developed to localize these emitters accurately.

In this work, we present a localization method based on wide-field microscopy and introduce a systematic approach to quantify the final positioning precision of photonic structures relative to individual emitters. Our method builds upon previous implementations based on distortion corrections [2,3] and incorporates an additional correction derived from the known positions of artificial reference emitters using Zernike polynomials [4], allowing us to model localization errors arising from optical aberrations.

While image analysis provides an estimate of the localization error, it does not fully account for inaccuracies introduced during the lithography process. To isolate this contribution, we fabricate samples requiring two consecutive lithography steps—one for markers and artificial reference emitters, and a second for the photonic structures—and characterize their relative displacement using high-resolution scanning electron microscopy (SEM).

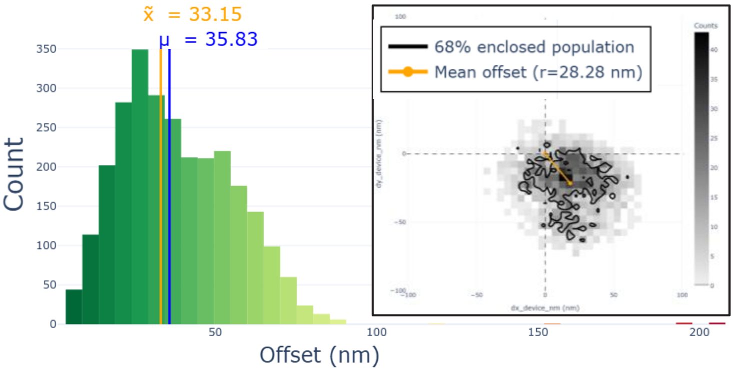

Figure 1: Expected positioning accuracy of photonic structures respect to quantum emitters.

This evaluation framework enables systematic benchmarking of the localization algorithm under different conditions. Using this approach, we measure positioning accuracies of 14±7 nm at room temperature and 28±20 nm under cryogenic conditions. Furthermore, polarization measurements of QDs integrated into photonic structures provide independent experimental support for the positioning accuracy obtained with our approach.

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Single-photon Advantage in Quantum Cryptography beyond QKD

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In quantum cryptography, fundamental laws of quantum physics are exploited to enhance the security of cryptographic primitives. Many practical use-cases in communication networks involve parties in a miss-trustful settings, who do not know or trust each other. The most fundamental quantum cryptographic primitive in such a mistrustful setting is quantum coin flipping, which provides an asymptotic advantage over its classical equivalent. Experimental implementations of QCF reported to date (e.g., [1-3]) used attenuated lasers, i.e. weak coherent pulses (WCPs), sources based on spontaneous parametric down conversion (SPDC) exploiting entanglement or heralded single photon states inherently limited in their efficiency. Deterministic quantum light sources, providing single photons on-demand, have been subject to intense research over the years and have been proven useful for quantum communication [4]. Implementations of cryptographic primitives beyond QKD using sub-Poissonian light sources, however, are a field yet to be explored.

Here, we experimentally demonstrate the implementation of a quantum strong coin flipping protocol (QSCF) using single photons and confirm not only its quantum advantage over classical realizations but also over implementations using phase-randomized attenuated laser pulses [5]. We achieve this by employing a state-of-the-art deterministic single-photon source based on the Purcell enhanced emission of a semiconductor quantum dot [6] in combination with fast polarization-state preparation enabling a low quantum bit error ratio of 2.8%, required for successful execution of this type of protocol. The specific protocol implemented here accounts for losses, multiphoton pulses emitted by practical photon sources, channel noise, detector dark counts, and finite quantum efficiency [7]. To implement the protocol, we dynamically prepare single-photon pulses in four different polarization states using home-made pulse-pattern generator in combination with a fiber-based electro-optical modulator. The states of the prepared polarization qubits are optimized to achieve both fairness and lowest possible cheating probabilities and are detected in a 4-state polarization analyzer. We achieve a quantum coin flipping rate of 1.5 kbit/s at a clock-rate of 80 MHz. The extracted cheating probabilities of Alice (Bob) confirm fairness of our protocol implementation and indicate a single-photon advantage over both classical coin flipping protocols as well as phase-randomized WCPs with the same mean photon number in our experimental setup. Furthermore, we provide a detailed theoretical study comparing WCP vs. deterministic single-photon sources with results being in excellent agreement with our experimental findings. Our work represents an important step forward in exploiting quantum advantages in realistic settings of a future quantum internet.

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Abstracts

Session 8: Theory

Electron-nuclear entanglement dynamics and photonic resource state generation from quantum dots

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Optically active quantum dots are a leading platform for generating the photonic resource states needed for measurement- or fusion-based quantum computing, quantum networks, and sensing. Generation rates can be increased if the quantum dot spin can be coupled to quantum memories such as nuclear spins. Protocols that take advantage of this capability require a detailed quantitative understanding of electron-nuclear spin entanglement dynamics. I'll discuss our recent progress in utilizing an entanglement metric known as the one-tangling power to obtain a better understanding of these dynamics and describe how the ability to control these dynamics can be used to improve resource state generation.

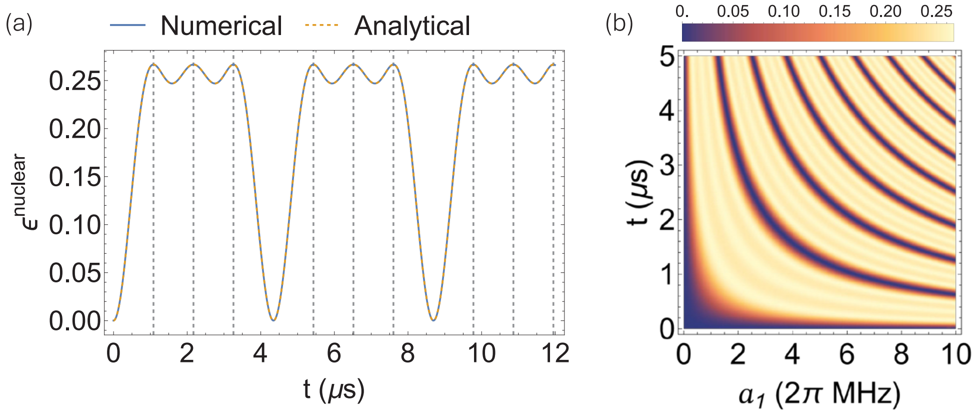

Fig. 1: (a) One-tangling power for a single nucleus coupled to the electron as a function of time. (b) One-tangling power as a function of time and hyperfine coupling strength.

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Microscopic origins of nuclear inhomogeneity in quantum dots

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Nuclear spins in semiconductor quantum dots (QDs) have long stood in the way of efficient QD spin manipulation. The transition from strained self-assembled growth to local droplet-etched (LDE) GaAs QDs brought material homogeneity and low, spatially uniform residual strain. Combined with nuclear spin cooling techniques [1,2], this provides a homogeneous nuclear spin ensemble capable of hosting coherent collective excitations, with controlled coupling to the QD spin [3], which led to the first nuclear quantum-memory demonstration [4].

Nuclei with spin $I > ½$ interact with electric field gradients generated by lattice deformation (biaxial and shear strain), leading to a quadrupolar shift of their nuclear Zeeman splittings appearing as satellite peaks in optically detected nuclear magnetic resonance (NMR) [5]. The same quadrupolar interaction also shapes the effective electron-nuclear spin coupling. Although LDE GaAs QDs are considered nominally strain-free, residual strain, interfaces, and interfacial alloying still generate weak electric field gradients. Furthermore, QDs can also be externally strained via piezoelectrically actuated nanomembranes, enabling tuning their properties [6]. All this makes the details of the NMR spectra particularly informative. Yet reproducing the spectra and the nuclear ensemble properties has remained a long-standing theoretical challenge, while a predictive framework is demanded to guide technological and experimental advances.

We present detailed simulations that start directly from AFM-defined GaAs QD morphology and reproduce isotope-resolved NMR spectra. We systematically analyze the influence of key parameters, such as alloying, compositional gradients, and external strain. By combining continuum and atomistic approaches, we show that dominant spectral features arising from uniform structural strain are superimposed with secondary features originating from local atomistic strain at interfaces and in alloyed regions. We assign spectral peaks to specific atomistic neighborhoods of the nuclei, thus characterizing the spectra in detail.

We minimize the elastic energy within both atomistic and continuum elasticity approaches and weight quadrupolar contributions using electron densities calculated within the $sp^3d^5s^*$ tight-binding and eight-band $\boldsymbol{k}\cdot\boldsymbol{p}$ methods [7]. Systematic cross-comparisons benchmark the approaches. We further assess the predictive power by applying the framework to both GaAs and strained InAs QDs and comparing the results to measured NMR spectra.

Predicting the quadrupolar shift distributions within a feasible model will enable the growth of QDs with tailored nuclear properties. We outline preliminary routes toward enhanced nuclear homogeneity and strain engineering with implications for optimized dynamical nuclear polarization protocols, controlled nuclear-mode addressing, and improved spin-photon interfaces.

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Revisiting the Two-Photon Resonance in Faraday Spin Control

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Semiconductor quantum dots (QDs) not only offer exceptional optical coherence and efficiency when coupled to photonic structures, but also exhibit remarkably long electronic and nuclear spin coherence times, making them promising building blocks for memory-assisted quantum network protocols. Such schemes require both the ability to encode information via quantum control over the spin and the possibility to perform single-shot readout.

While spin control in QDs is possible by applying an in-plane magnetic field (Voigt configuration), the lack of intrinsically cyclic transitions has so far hindered the realization of efficient simultaneous single-shot readout.

In contrast, a magnetic field applied along the growth axis of the quantum dot (Faraday geometry) enables circularly polarized cyclic transitions that allow for efficient single-shot readout. In addition, a small light-hole admixture can be exploited to achieve quantum control of the spin in this highly asymmetric Λ-system using a narrowband stimulated Raman scheme [1].

Here, we theoretically investigate the underlying two-photon electron-spin resonance in Faraday geometry. Starting from the typical Λ-system to describe spin control, we introduce an effective two-level system and analytically derive approximate conditions for two-photon resonances. While the limiting case of a balanced system reproduces well-known results, we show that a time-dependent differential Stark shift between the spin states not only leads to deviations from established resonance conditions but also gives rise to a previously unexplored class of resonances. These insights into resonance behaviour open new possibilities for spin control in QDs.

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