High Yield Devices for Photonic Quantum Implementations (SYPQ)

jointly organised by
the Semiconductor Physics Division (HL) and
the Working Group young Leaders in Physics (AGyouLeaP)

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The symposium aims at discussing the challenges and achievements in realizing photonic devices for quantum applications. This will cover growth, fabrication, quantum optical measurements, and theoretical modelling. Platforms like semicoductors, organic molecules, and transparent materials will be examples of the discussed topics. Particular attention will be posed in discussing and selecting results which have a clear impact in transferring quantum technologies to real world implementations. Focus will be given as well to all techniques that allows boosting not only the device performances but also the fabrication yield (ideally to mass production), like deterministic technologies, lithography and 3D printed approaches.

Overview of Invited Talks and Sessions

(Lecture hall H1)

Invited Talks

SYPQ 1.1	Tue	9:30–10:00	H1	**Designing driving protocols for high-fidelity quantum devices using numerically exact predictions** — •Moritz Cygorek, Erik M. Gauger
SYPQ 1.2	Tue	10:00–10:30	H1	**Challenges towards high efficiency quantum dot single photon sources** — •Arne Ludwig
SYPQ 1.3	Tue	10:30–11:00	H1	**Organic Molecules in photonic quantum technologies** — •Costanza Toninelli
SYPQ 1.4	Tue	11:15–11:45	H1	**Quantum-dot single-photon sources for quantum photonic networks** — •Peter Michler
SYPQ 1.5	Tue	11:45–12:15	H1	**Quantum light sources: entanglement generation in semiconductor nanostructures** — •Ana Predojevic

Sessions

SYPQ 1.1–1.5	Tue	9:30–12:15	H1	**High Yield Devices for Photonic Quantum Implementations**

SYPQ 1: High Yield Devices for Photonic Quantum Implementations

Time: Tuesday 9:30–12:15 Location: H1

Invited Talk SYPQ 1.1 Tue 9:30 H1

Designing driving protocols for high-fidelity quantum devices using numerically exact predictions — •Moritz Cygorek and Erik M. Gauger — Heriot-Watt University, Edinburgh, UK

Improving the quality of quantum devices, such as solid state quantum dots as emitters of non-classical light, is not only a matter of device fabrication. Engineering operation protocols by combining coherent driving, adiabatic rapid passage, Stark tuning, and phonon-assisted state preparation is key to enhancing devices robustness and fidelity. This turns a hardware problem into the software problem of predicting the dynamics of quantum devices. The challenge for solid state devices is the simultaneously strong coupling to phonon environments, strong time-dependent driving, and possibly strong interactions with structured photonic environments. After a series of conceptual developments in less than a decade, it has become possible to describe the dynamics of such devices numerically exactly, i.e., to fully account for all effects described by the microscopic Hamiltonians to arbitrary precision. While prior numerically exact methods had been practicable only for very small idealised quantum systems, now, easy-to-use computational tools are publicly available that provide numerically exact results even for the multi-scale dynamics of small quantum networks strongly coupled to multiple environments with long memory times. Here, I summarise these developments and discuss their impact for the design of driving protocols for real-world quantum device. Furthermore, I discuss the prospects and challenges for a universal solver of arbitrary open quantum systems.

Invited Talk SYPQ 1.2 Tue 10:00 H1

Challenges towards high efficiency quantum dot single photon sources — •Arne Ludwig — Ruhr-Universität Bochum, Germany

A key component for photonic quantum devices is a source of high-fidelity photonic qubits, a single photon source (SPS) [1]. A promising route to create such a device employs semiconductor quantum dots (QDs) in photonic cavities. These approaches exploit the exquisite toolbox of semiconductors, in particular scalable manufacturing.

However, noise processes hampering these [2]. A main contributor to decoherence and low efficiency is random charge rearrangements in the semiconductor environment or the QD itself. A random change of the QD charge state from e.g. Auger processes [3] or photoionization [4] can switch the emitter temporarily off [3,5].

Noise from a fluctuating electrostatic environment is called charge noise. One way to efficiently suppress this, is to embed the QDs in the high purity material undoped region of a p-i-n-diode [6,7]. This approach combined with a tuneable cavity has been pursued to realize a highly efficient fiber-coupled SPS with an end-to-end efficiency of 57% [8].

[1] P. Senellart et al., Nat Nano **12**, 1026 (2017). [2] A.V. Kuhlmann et al., Nat Phys **9**, 570 (2013). [3] A. Kurzmann et al., Nano Lett **16**, 3367 (2016). [4] P. Lochner et al., Phys. Rev. B **103**, 075426 (2021). [5] G. Gillard et al., npj Q Inf **7**, 43 (2021). [6] D. Najer et al., Nature **575**, 622 (2019). [7] L. Zhai et al., Nat Commun **11**, 4745 (2020). [8] N. Tomm et al., Nat Nano **16**, 399 (2021).

Invited Talk SYPQ 1.3 Tue 10:30 H1

Organic Molecules in photonic quantum technologies — •Costanza Toninelli — CNR-INO, LENS Via Nello Carrara 1, 50019 Sesto Fiorentino (FI), Italy

In this contribution I will discuss the prospects of using polyaromatic hydrocarbons as quantum emitters for photonic quantum technologies. I will revise our recent advances in the development of molecule-based single photon sources and related applications. The possibility of scaling up the number of sources on chip will be discussed, in terms of integration strategies and novel tuning methods. Finally I will show recent results on the use of molecules as low-invasivity thermal sensors.

References
[1] S. Pazzagli, et al., ACS Nano 12, 4295, 4303 (2018)
[2] M. Colautti, et al., Adv. Q. Tech. 3, 7 cover (2020)
[3] C. Ciancico, et al., ACS Photonics 6, 12, 3120 3125 (2019)
[4] M. Colautti, et al., ACS Nano (2020) 10.1021/acsnano.0c05620
[5] P.Lombardi et al., Appl. Phys. Lett. 118, 204002 (2021)
[6] R. Duquennoy et al., arXiv:2201.07140v1, accepted in Optica
[7] M. Ghulam et al., arXiv:2202.12635

15 min. break

Invited Talk SYPQ 1.4 Tue 11:15 H1

Quantum-dot single-photon sources for quantum photonic networks — •Peter Michler — University of Stuttgart, Institute for semiconductor optics and functional interfaces, Stuttgart, Germany

In many foreseen implementations of quantum photonic networks, photons must be able to propagate over long distances in silica fibers with limited absorption and wave packet dispersion. When propagating into silica fibers, photons in the so-called telecom C-band (1530-1565 nm) will experience the absolute minimum of absorption whereas in the O-band (1260-1360 nm) they can travel with vanishing dispersion together with limited absorption.

In this talk, we report about recent highlights achieved with quantum dots emitting in the telecom O- and C-band [1,2]. This includes bright Purcell enhanced single-photon sources based on quantum dots in circular Bragg gratings [2] and the study of resonance fluorescence of single In(Ga)As QDs emitting in the telecom C-band [3]. Moreover, we present an efficient and stable fiber-to-chip coupling, which enables the injection of single photons from telecom quantum dots into a silicon-on-insulator chip [4].

[1] S. L. Portalupi, M. Jetter and P. Michler, Semicond. Sci. Technol. 34, 053001 (2019) [2] S. Kolatschek et al., Nano Lett. 21, 7740 (2021) [3] C. Nawrath et al., Appl. Phys. Lett. 118, 244002 (2021) [4] S. Bauer et al., Appl. Phys. Lett. 119, 211101 (2021)

Invited Talk SYPQ 1.5 Tue 11:45 H1

Quantum light sources: entanglement generation in semiconductor nanostructures — •Ana Predojevic — Stockholm University, Stockholm, Sweden

Single quantum dots are established emitters of single photons and entangled photon pairs. By means of resonant excitation they generate photon pairs with high efficiency, low multi-photon contribution, and suitable for entangling schemes such as time-bin entanglement. The entanglement of photons generated by quantum dots can be employed in free-space and fibre-based quantum communication. In addition to this, some applications of entanglement are more versatile if the photons are entangled simultaneously in more than one degree of freedom - hyperentangled, which we also demonstrated using quantum dots. However, the achievable degree of entanglement and the source readiness to be deployed in quantum communication protocols depend on additional functionalities, including high photon collection efficiency. I will present engineered photonic systems that allow for entangled photon pair sources to be more efficient. Also, I will introduce novel methods to characterize sources of entangled photons.