Symposium Ultrafast Quantum Nano-Optics (SYQO)

jointly organized by
the Quantum Optics and Photonics Division (Q),
the Molecular Physics Division (MO), and
the Atomic Physics Division (A)

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The recent years have witnessed an increasing interest in quantum phenomena in complex systems operating at room temperature. A variety of them are topics of intense investigation, ranging from, e.g., chromophores in nanoclusters, to quantum emitters coupled to plasmonic resonators. All of these studies highlight how quantum physics is at work when coherence times are extremely short. This requires an interdisciplinary approach for advancing theoretical methods, in particular time-dependent ab-initio techniques, and experimental techniques, such as multidimensional electronic spectroscopies.

The symposium focuses on the latest advances in the field and provides to the DPG community an opportunity to discuss the intriguing interplay between quantum optics, ultrafast spectroscopy and nanoscience.

Overview of Invited Talks and Sessions

(Lecture hall Paulussaal)

Invited Talks

SYQO 1.1	Fri	11:00–11:30	Paulussaal	**Coherent and incoherent dynamics of colloidal plexcitonic nanohybrids** — •Elisabetta Collini
SYQO 1.2	Fri	11:30–12:00	Paulussaal	**Dissipative Many-Body Dynamics in Atomic Subwavelength Arrays in Free Space** — •Stefan Ostermann
SYQO 1.3	Fri	12:00–12:30	Paulussaal	**Quantum dot sources: efficiency, entanglement, and correlations.** — •Ana Predojević

Sessions

SYQO 1.1–1.5	Fri	11:00–13:00	Paulussaal	**Ultrafast Quantum Nano-Optics**

SYQO 1: Ultrafast Quantum Nano-Optics

Time: Friday 11:00–13:00 Location: Paulussaal

Invited Talk SYQO 1.1 Fri 11:00 Paulussaal

Coherent and incoherent dynamics of colloidal plexcitonic nanohybrids — •Elisabetta Collini — Department of Chemical Sciences, University of Padova, via Marzolo 1, 35131 Padova, Italy — Padua Quantum Technologies Research Center

Polaritonic chemistry exploits strong light-matter coupling between molecules and confined electromagnetic field modes to enable new chemical reactivities. From a chemical point of view, colloidal plexcitonic materials promise to play a pivotal role in this scenario because of their easy and cheap preparation. Plexcitons are hybrid states originating from the mixing of the plasmon resonances of metal nanostructures with molecular excitons. They allow nanoscale confinement of electromagnetic fields and the establishment of strong couplings between light and matter, potentially giving rise to controllable and tunable dynamic phenomena. However, the characterization of the ultrafast coherent and incoherent dynamics of colloidal plexciton nanohybrids remains highly unexplored. Here, 2D electronic spectroscopy is employed to study the quantum coherent interactions active after the photoexcitation of these systems. By comparing the response of different nanohybrids and uncoupled components, the nonlinear photophysical processes at the base of the femtosecond coherent and incoherent dynamics were identified, allowing a step forward toward the effective understanding and exploitation of these nanomaterials.

Invited Talk SYQO 1.2 Fri 11:30 Paulussaal

Dissipative Many-Body Dynamics in Atomic Subwavelength Arrays in Free Space — •Stefan Ostermann — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

The photon emission properties of atomic arrays with subwavelength lattice spacing are modified by light-induced dipole-dipole interactions, giving rise to effects like super- and subradiance. Recent advances in experimental techniques have enabled the generation of well-controlled periodic arrangements of individual atoms in free space. This development has sparked widespread interest in investigating the fundamental physics of these extended long-range interacting structures, as well as in harnessing them as efficient light-matter interfaces for future quantum technologies. While many aspects of the single excitation regime of subwavelength emitter geometries were studied over the past decade, investigating the full dissipative many-body problem involving multiple excitations remains an ongoing research effort. I will present our recent results elucidating some core characteristics of the multi-excitation regime. We characterize the superradiant out-of-equilibrium dynamics for large system sizes and extract the scaling of the superradiant peak with particle number in fully inverted arrays. Additionally, we identify the critical excitation number for superradiance in partially excited arrays in 1D and 2D. Related to this, we show that maximal coupling to subradiant states is achieved if half of the atoms are incoherently excited initially. Finally, I will present an analysis of the steady-state phase diagram for a strongly driven system, with a particular focus on its radiative properties.

Invited Talk SYQO 1.3 Fri 12:00 Paulussaal

Quantum dot sources: efficiency, entanglement, and correlations. — •Ana Predojević — Stockholm University, Stockholm, Sweden

Single quantum dots are established emitters of single photons and entangled photon pairs. By means of resonant excitation they efficiently generate photon pairs that feature low multi-photon contribution and are suitable for entangling schemes such as polarization and time-bin entanglement. However, the achievable degree of entanglement and the source readiness to be deployed in quantum communication protocols depend on additional functionalities, including high collection efficiency of photons. I will present engineered photonic systems that allow for entangled photon pair sources to be more efficient. Also, the cascaded generation of photon pairs intrinsically contain temporal correlations, which negatively affect the ability of such sources to perform two-photon interference, hindering applications. I will show how such correlation interplays with decoherence and temporal postselection, and under which conditions the temporal postselection could improve the two-photon interference visibility. Our study identifies crucial parameters of the source and indicates the path towards achieving optimal performance.

SYQO 1.4 Fri 12:30 Paulussaal

Compact chirped fiber Bragg gratings for single-photon generation from quantum dots — •Vikas Remesh[1], Ria Krämer[2], René Schwarz[1], Florian Kappe[1], Yusuf Karli[1], Thomas Bracht[3], Saimon Covre da Silva[4], Armando Rastelli[4], Doris Reiter[3], Stefan Nolte[2], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institute for Applied Physics, Friedrich Schiller University Jena, Germany — [3]Condensed Matter Theory, TU Dortmund, Germany — [4]Johannes Kepler University Linz, Linz, Austria

To realize a scalable source of frequency-multiplexed single photons, one requires an ensemble of quantum emitters that can be collectively excited with high efficiency. Semiconductor quantum dots hold great potential here. The most efficient scheme is to use chirped laser pulses, due to the robustness against spectral and intensity fluctuations. Yet, the existing methods to generate chirped laser pulses coupled to a quantum emitter are lossy and mechanically unstable, severely hampering the prospects of a practical quantum dot device. Here we present a compact, robust, and plug-and-play alternative for chirped pulse excitation of quantum dots, based on chirped fiber Bragg gratings, and demonstrate the chirped excitation of a GaAs/AlGaAs quantum dot. Our method can be tailored for large dispersion requirements and is a significant milestone in realizing a direct fiber-coupled quantum dot photon source. APL Photonics 8, 101301 (2023)

SYQO 1.5 Fri 12:45 Paulussaal

Observing Ultrafast Coherent Dynamics following Selective Excitation of a Single Quantum Dot — •Darius Hashemi Kalibar, Philipp Henzler, Ron Tenne, and Alfred Leitenstorfer — Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, Germany

Precise observation and control of coherent state evolution are a prerequisite for the application of quantum technologies. However, in many systems, the bandwidth of quantum effects is limited by their relatively slow response times. In contrast, using ultrashort optical pulses to control quantum-confined electrons allows for quantum experiments on the much faster femtosecond timescale. In this work, we describe an all-optical approach for the ultrafast selective initialization of excitonic states in individual CdSe/ZnSe quantum dots at cryogenic temperatures and observe their evolution through pump-probe spectroscopy. Resonantly-tuned 500 fs pump pulses excite the quantum dot from the ground state into trion triplet states. Subsequently, 150 fs probe pulses spanning multiple transitions enable direct time-resolved observation of the quantum dynamics. We observe persistent spin quantum beats between two excitonic states despite femtosecond orbital relaxation of the hole. Control of the polarization of the pump pulses enables selective excitation of a single state, avoiding the beating phenomenon. Together, these advances form a major step towards quantum sensing on ultrafast time and nanometric spatial scales.