Symposium Real-Time Measurements of Quantum Dynamics (SYQD)

jointly organised by
the Semiconductor Physics Division (HL),
the Magnetism Division (MA), and
the Low Temperature Physics Division (TT)

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Time-resolved studies of quantum systems are the key to understanding quantum dynamics at its core. The real-time measurement of individual quantum jumps yields maximal physical insight. This includes electrical and optical detection schemes to monitor individual quantum jumps in nanoscopic devices. It is, furthermore, a prerequisite for coherent control of quantum states and can be used to optimise devices for metrological applications. The symposium is meant to report on recent experimental progress in performing real-time measurements of quantum dynamics, to present recently-developed theoretical methods for analyzing measured data, and to highlight recent successful examples of accessing quantum dynamics via real-time measurements.

Overview of Invited Talks and Sessions

(Lecture hall HSZ 01)

Invited Talks

SYQD 1.1	Thu	9:30–10:00	HSZ 01	**Real-time measurement and control of spin dynamics in quantum dots** — •Seigo Tarucha
SYQD 1.2	Thu	10:00–10:30	HSZ 01	**Quantum Dot arrays for Quantum Information Transfer** — •Gloria Platero, David Fernandez-Fernandez, Juan Zurita
SYQD 1.3	Thu	10:30–11:00	HSZ 01	**Optical Detection of Real-Time Quantum Dynamics in Quantum Dots** — •Martin Geller, Jens Kerski, Eric Kleinherbers, Jürgen König, Annika Kurzmann, Pia Lochner, Axel Lorke, Arne Ludwig, Hendrik Mannel, Philipp Stegmann, Andreas Wieck, Marcel Zöllner
SYQD 1.4	Thu	11:30–12:00	HSZ 01	**Cooper Pair Splitting in Real-Time** — •Christian Flindt
SYQD 1.5	Thu	12:00–12:30	HSZ 01	**Trajectory-based detection in stochastic and quantum thermodynamics** — •Jukka Pekola

Sessions

SYQD 1.1–1.5	Thu	9:30–12:30	HSZ 01	**Real-Time Measurements of Quantum Dynamics**

SYQD 1: Real-Time Measurements of Quantum Dynamics

Time: Thursday 9:30–12:30 Location: HSZ 01

Invited Talk SYQD 1.1 Thu 9:30 HSZ 01
Real-time measurement and control of spin dynamics in quantum dots — •Seigo Tarucha — Center for Emergent Matter Science and Quantum Computing, RIKEN, Wako, Saitama 351-0198, Japan

The progress of quantum information technologies using semiconductor quantum dots has provided novel methods to control and detect quantum dynamics of single electron spins. The quantum information unit (qubit) is prepared using a concept of electron spin resonance and the qubit dynamics is dependent on dephasing or fluctuations of the resonance frequency through interactions with electromagnetic environment. In this talk I will first show experiments on real-time measurements of fluctuating frequencies of the respective spins and exchange-coupled two spins in a double quantum dot. The quantum dot is made in natural Si and also isotopically purified 28Si, which have different magnetic environments of nuclear spins. We use Ramsey interference sequence to derive the auto- and cross-power spectral density of the fluctuating resonance frequencies and address the influences from magnetic and charge noise in the respective quantum dots. We find an evident cross-correlation between two spins arising from the charge noise and devise a model of two-level fluctuators to account for the cross-correlation. Lastly I will show feedback control to suppress the influence on the spin dynamics from the environment.

Invited Talk SYQD 1.2 Thu 10:00 HSZ 01
Quantum Dot arrays for Quantum Information Transfer — •Gloria Platero, David Fernandez-Fernandez, and Juan Zurita — Instituto de Ciencia de Materiales de Madrid (CSIC),Spain

The fabrication and control of semiconductor quantum dot arrays open the possibility to use these systems as quantum links, for transferring quantum information between distant sites, an indispensable part of large-scale quantum information processing. In this talk I will discuss different pulse-based protocols to transfer spin holes between edges of a quantum dot chain with high fidelity. I will show how the spin polarization of the transferred holes can be controlled by tuning the ratio between the SOC and the spin conserving tunneling rate [1]. Also, I will discuss how to transfer entangled hole spin qubits between edge dots. Our theoretical results suggest the feasibility of quantum dot arrays as high-fidelity quantum buses to distribute information between distant sites and perform one qubit gates in parallel.

An alternative way to transfer information between distant sites is mediated by protected topological edge states. I will discuss the long-range particle dynamics mediated by edge states in different quantum dot array configurations [2], which opens a new avenue for quantum state transfer protocols in low dimensional topological lattices.

[1] D. Fernández-Fernández et al., Phys. Rev. App., in press;D. Fernández-Fernández et al., submitted. [2] J. Zurita, C. E. Creffield, G. Platero, Quantum, 5, 591 (2021); ibid, submitted.

Invited Talk SYQD 1.3 Thu 10:30 HSZ 01
Optical Detection of Real-Time Quantum Dynamics in Quantum Dots — •Martin Geller[1], Jens Kerski[1], Eric Kleinherbers[1], Jürgen König[1], Annika Kurzmann[2], Pia Lochner[1], Axel Lorke[1], Arne Ludwig[3], Hendrik Mannel[1], Philipp Stegmann[1], Andreas Wieck[3], and Marcel Zöllner[1] — [1]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]2nd Institute of Physics and JARA-FIT, RWTH Aachen University, 52074 Aachen, Germany — [3]Applied Solid State Physics, Ruhr-University, 44780 Bochum, Germany

Recording every single quantum event in a real-time measurement gives the maximum information of a dynamical quantum system. The obtained time traces can be used in a statistical evaluation to get a deep understanding about the underlying physical mechanisms. We use a self-assembled quantum dot coupled to a reservoir in combination with resonant optical excitation to study phenomena such as electron tunneling [1] and Auger recombination [2] with a time resolution down to single quantum events. The resulting telegraph signal is evaluated by full counting statistics to obtain deep insights into the spin and charge dynamics, where we use factorial cumulants as a very sensitive statistical tool to reduce the influence of statistical and systematic errors [3]. We show that factorial cumulants together with optical excitation push the limits in the detection and analysis of random telegraph data.

[1] Kurzmann et al., PRL 122, 247403 (2019). [2] Lochner, et al. Nano Lett. 20, 1631 (2020). [3] Kleinherbers et al., PRL 128, 087701 (2022).

30 min. break

Invited Talk SYQD 1.4 Thu 11:30 HSZ 01
Cooper Pair Splitting in Real-Time — •Christian Flindt — Department of Applied Physics, Aalto University, Finland

Cooper pair splitters are promising candidates for generating spin-entangled electrons. By splitting the Cooper pairs in a superconductor into different normal-state leads, spin-entanglement between spatially separated electrons can be achieved. In this talk, I will give an overview of our recent works on Cooper pair splitters [1-5]. I will discuss our proposal for observing and characterizing the splitting of Cooper pairs in real-time as well as its experimental realization [2,3]. I will then go on to talk about two proposals for controlling the splitting of Cooper pairs using time-dependent gate voltages [4]. Finally, if time allows, I will discuss how an entanglement witness can be formulated in terms of current cross-correlation measurements, which makes it possible to detect the entanglement of the split Cooper pairs [5].

[1] N. Walldorf, F. Brange, C. Padurariu, and CF, Phys. Rev. B **101**, 205422 (2020)
[2] N. Walldorf, C. Padurariu, A.-P. Jauho, and CF, Phys. Rev. Lett. **120**, 087701 (2018)
[3] A. Ranni, F. Brange, E. T. Mannila, CF, and V. F. Maisi, Nat. Commun. **12**, 6358 (2021)
[4] F. Brange, K. Prech, and CF, Phys. Rev. Lett. **127**, 237701 (2021)
[5] M. Tam, CF, and F. Brange, Phys. Rev. B **104**, 245425 (2021)

Invited Talk SYQD 1.5 Thu 12:00 HSZ 01
Trajectory-based detection in stochastic and quantum thermodynamics — •Jukka Pekola — Aalto University, Helsinki, FINLAND

I start by discussing the relation between jump trajectories and stochastic thermodynamics when applied to electrons and photons in quantum circuits. After that I describe our experiments on electron counting and calorimetry for trajectory analysis. In the theoretical part I discuss the calorimetric detection of single microwave photons in circuit QED setups.

References: [1] Jukka P. Pekola and Bayan Karimi, Rev. Mod. Phys. 93, 041001 (2021). [2] J. P. Pekola and I. M. Khaymovich, Annu. Rev. Condens. Matter 10, 193 (2019). [3] Bayan Karimi and Jukka P. Pekola, Phys. Rev. Lett. 124, 170601 (2020); Phys. Rev. X 12, 011026 (2022).