# Q 61: Trapped Ions (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS 1199

**Invited Talk** Q 61.1 Fri 11:00 HS 1199

**Photonic integration for trapped-ion quantum metrology** — •Elena Jordan[1], Guochun Du[1], Carl-Frederik Grimpe[1], Fatemeh Salahshoori[1], Markus Kromrey[1], Atasi Chatterjee[1], Anastasiia Sorokina[2,3], Steffen Sauer[1,2,3], Anton Peshkov[1,2], Gillenhaal Beck[4], Karan Mehta[5], Stefanie Kroker[1,2,3], Andrey Surzhykov[1,2,3], and Tanja Mehlstäubler[1,6,7] — [1]PTB, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology Braunschweig, Germany — [4]Institut für Quantenelektronik ETH Zürich, Switzerland — [5]School of Electrical and Computer Engineering Cornell University, Ithaca, NY 14850, USA — [6]Institut für Quantenoptik Leibniz Universität Hannover, Germany — [7]Laboratorium für Nano- und Quantenengineering Leibniz Universität Hannover, Germany

Integrated photonics make ion trap setups scalable to large numbers of ions, help to compactify the setup and improve the robustness against vibrations for portable optical clocks and quantum sensors. We are developing ion traps with integrated photonics for quantum metrology. With photonic design structured light can be generated that, combined with improved pointing stability, enables the excitation of forbidden transitions in trapped ions. For the cooling and addressing of $Yb^+$ ions wavelengths from UV to NIR are required. The light is coupled in from optical fibers, distributed via waveguides, and coupled out through the surface of the chip via gratings. Our aim is to employ the traps in portable optical clocks that can be used for geodetic measurements.

Q 61.2 Fri 11:30 HS 1199

**Apparatus design for scalable cryogenic trapped-ion quantum computing experiments** — •Tobias Pootz[1], Lukas Kilzer[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Future applications for trapped ion quantum computers require a signicant increase in the number of ion qubits and excellent interconnectivity. In my talk I will describe the design of cryogenic demonstrator machines for this task, implementing surface-electrode ion traps mounted on a universal interchangeable socket. The apparatus design is based on a vibration-isolated cold head to cool a cryogenic vacuum system to temperatures below 10 K. The system features several hundred DC control lines to support transport of qubits through dedicated trap structures including junctions, storage, detection and manipulation registers. Multi-qubit quantum gates will be implemented through the use of chip-integrated microwave lines. The system has been designed to accommodate the integration of new components for scaling as the development of the underlying enabling technologies progresses, such as chip integrated waveguides. Multiple setups were built. One setup is based on 9Be+ qubits and 40Ca+ ions for sympathetic cooling; a second setup will be based on 43Ca+ qubits and 88Sr+ cooling ions.

Q 61.3 Fri 11:45 HS 1199

**Fabrication of multisegmented ion traps in a specialized cleanroom** — •Alexander Müller[1], Jan Müller[1], Björn Lekitsch[1], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, 55099 Mainz, Germany

Trapped ions are among the leading platforms in quantum computing. We aim to scale up to 50 ions by taking advantage of versatile linear multi-segmented ion traps which combine qubit register reconfigurations [1] and individual addressing of ions in these registers. A fully three-dimensional shaping of electrodes, a homogeneous well-conducting high quality metallic coverage, the precise alignment of trap structures, an excellent optical access, and a fully reliable and repeatable fabrication process are required.

For this we established a special purpose cleanroom. By Selective Laser-induced Etching (SLE) a 3D structure is formed out of fused silica [2]. Metallic sputter deposition results in functional trap chips, which are assembled using a die-bonder, finally fixed on a carrier PCB, and wirebonded for electrical connection of the electrodes. All fabrication steps can be performed in-house and without leaving the cleanroom in a rapid prototyping fashion (<10 days). We report the testing of devices and the trapping of Ca+ ions.

[1] V. Kaushal et al., AVS Quantum Sci.; 2 (1):014101.
[2] S. Ragg et al., Rev. Sci. Instrum.; 90 (10):103203.

Q 61.4 Fri 12:00 HS 1199

**Microfabrication of surface ion traps for operation with Strontium Rydberg ions** — •Simon Schey[1,2], Michael Pfeifer[1,3], Marion Mallweger[2], Natalia Kuk[2], Ivo Straka[2], Clemens Rössler[1], Yves Colombe[1], and Markus Hennrich[2] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]Stockholm University, Stockholm, Sweden — [3]University of Innsbruck, Innsbruck, Austria

Recently, using Rydberg-states for gate operation in trapped ions has been shown to greatly reduce two qubit gate times down to 700ns [1]. Those experiments were performed in a macroscopic Paul trap at room temperature. We propose to perform similar experiments but in a cryogenic environment as well as on a of surface ion trap chip that is industrially microfabricated at Infineon Technologies [2,3]. This will prove further scalability of this gate scheme.

As UV-Lasers are needed for the Rydberg gate operation, we discuss material and design choices for making our ion trap resilient against radiation down to a wavelength of around 240nm and show successful microfabrication of an ion trap on a sapphire substrate.

[1] Chi Zhang et al., Nature 580, 345-349 (2020)
[2] Ph. Holz et al., Adv. Quantum Technol. 3, 2000031 (2020)
[3] S. Auchter et al., Quantum Sci. Technol. 7, 035015 (2022)

Q 61.5 Fri 12:15 HS 1199

**Industrial microfabrication of 2D and 3D ion traps for quantum information processing** — •Yves Colombe[1], Silke Auchter[1], Klemens Schüppert[1], Matthias Dietl[1,2], Alexander Zesar[1,3], Jakob Wahl[1,2], Max Glantschnig[1,4], Christian Flasch[1,4], Simon Schey[1,5], Fabian Laurent[1,6], Michael Pfeifer[1,2], Fabian Anmasser[1,2], Michael Hartmann[7], Leon Dixius[7], Mohammad Abu Zahra[7], Jens Repp[7], Nina Megier[1], Matthias Brandl[7], and Clemens Rössler[1] — [1]Infineon Technologies, Villach, Austria — [2]University of Innsbruck, Innsbruck, Austria — [3]University of Graz, Graz, Austria — [4]PTB, Braunschweig, Germany — [5]University of Stockholm, Stockholm, Sweden — [6]Montan University of Leoben, Leoben, Austria — [7]Infineon Technologies, Oberhaching, Germany

Scaling TIQC to thousands of ions requires microfabricated traps produced in highly reliable facilities. Industrial fabrication provides precise process control as well as in-line measurements tools that ensure high reliability and reproducibility.

Various ion trap designs have been produced at Infineon Technologies cleanroom facilities, including 2D ion trap arrays and 3D traps assembled at wafer level. In this talk I will report on our current work towards large-scale ion traps, including fabrication on dielectric substrates (fused silica, sapphire), through-glass-vias, use of Kelvin probe force microscopy for DC surface potential measurements, integration of fs-laser-written optical waveguides, and development of electronic devices that can operate at 4 K.

Q 61.6 Fri 12:30 HS 1199

**Optical integration in ion-trap chips at Infineon** — •Alexander Zesar[1,2], Jakob Wahl[2,3], Bernhard Lamprecht[5], Philipp Hurdax[5], Klemens Schüppert[2], Clemens Rössler[2], Yves Colombe[2], Silke Auchter[2], Sofia Cano Castro[2,6], Max Glantschnig[2,7], Marco Schmauser[3], Marco Valentini[3], Philipp Schindler[3], Thomas Monz[3,4], and Joachim Krenn[1] — [1]University of Graz, Graz, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]University of Innsbruck, Innsbruck, Austria — [4]Alpine Quantum Technologies GmbH, Innsbruck, Austria — [5]Joanneum Research Materials, Weiz, Austria — [6]Polytecnico di Milano, Milan, Italy — [7]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Trapped ions are among the most researched and advanced quantum computing (QC) hardware platforms. Currently used free-space optics for ion addressing will block upscaling due to beam pointing errors and spatial restrictions. Therefore, future QC architectures with trapped

ions require integrated waveguiding and focusing for scalable and stable placement of laser beams in microfabricated ion-trap chips.

This talk gives a concise overview of photonics and optics integration schemes developed at Infineon. We will discuss some of the challenges that come with femtosecond-laser-written waveguides as well as slab waveguides in conjunction with focusing grating couplers, including fiber-to-chip coupling and integration density. The talk concludes with an outlook on scalable ion-trap chips with integrated photonics as a necessary condition for useful trapped-ion quantum computing.

Q 61.7 Fri 12:45 HS 1199

**How to Wire a 1000-Qubit Trapped-Ion Quantum Computer** — Maciej Malinowski[1], David Allcock[1,2], •Clemens Matthiesen[1], and Chris Ballance[1,3] — [1]Oxford Ionics, Oxford, UK — [2]University of Oregon, Eugene, USA — [3]University of Oxford, Oxford, UK

Scaling up quantum computers requires efficient signal delivery to the quantum processor (the "wiring" challenge). It is likely that integration of control electronics into the processor package will be necessary, but this process is heavily constrained by chip microfabrication and chip operation specifications. Here, we present our WISE (Wiring using Integrated Switching Electronics) architecture as an answer to the wiring question, where judicious integration of simple switching electronics into the ion trap chip is combined with parallel trap electrode control [1]. This significantly reduces the number of signal sources needed, such that a fully connected 1000-qubit trapped ion quantum computer might be operated using only $\sim 200$ signal sources.

[1] M. Malinowski *et al.*, PRX Quantum **4**, 040313 (2023)