TT 32: Nanomechanical systems (joint session HL/TT)

Time: Tuesday 10:00–12:45 Location: POT/0051

TT 32.1 Tue 10:00 POT/0051

Mechanical characterization of freely-suspended crystalline YIG nanodevices — •Jonny Qiu[1,2], Matthias Grammer[4,5], Sebastian Sailler[6], Sebastian T. B. Goennenwein[6], Michaela Lammel[6], Hans Huebl[3,4,5], and Eva Weig[1,2,3] — [1]TUM School of Computation, Information and Technology, Garching, Germany — [2]Zentrum für Quantum Engineering, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany — [4]TUM School of Natural Sciences, Garching, Germany — [5]Walther-Meißner-Institut, BAdW, Garching, Germany — [6]University of Konstanz, Department of Physics, Konstanz, Germany

Efficient quantum transduction, the reciprocal conversion of quantum signals from one energy level to another, is an ongoing challenge in quantum network applications. Engelhardt et al. [1] proposed a microwave to optical converter (MWOC) that co-localizes microwave, magnetic and elastic excitations within a suspended optomechanical crystal (OMC) made of crystalline yttrium iron garnet (YIG).

In this talk, we report our progress towards realizing the MWOC and present freely-suspended YIG nanodevices. We fabricated YIG cantilevers and beams using an electron beam lithography process and a subsequent crystallization by annealing approach. Piezo-driven interferometric spectroscopy reveals the mechanical response modes of these devices, from which we extract Young's modulus and internal stress to design the OMC as a MWOC. We visualize and thus confirm the corresponding mode shapes via laser doppler vibrometry.

[1] F. Engelhardt, et al., Phys. Rev. Appl. 18, 044059 (2022).

TT 32.2 Tue 10:15 POT/0051

Sensing local temperature changes of a silicon nitride nanomembrane under large-amplitude vibration — •Valentin Barth, Mengqi Fu, and Elke Scheer — University of Konstanz, Konstanz, Germany

In MEMS and NEMS, changes in environmental conditions (e.g., a global change in temperature [1]) can alter the motion properties of silicon nitride (SiN) membranes. Vibrational motion may cause the membrane to experience local heating effects.

SiN square membranes (side length: 450 μm, thickness: 500 nm) are used and driven with a piezoelectric actuator. The motion is monitored using digital holographic microscopy. The measurements are carried out with a strong drive, resulting in vibration amplitudes on the order of hundreds of nanometers. Local temperatures are measured via the Seebeck effect using permalloy ($Ni_{81}Fe_{19}$) and gold as thermocouple, which provides a sensitivity of 20 μV/K and is suitable for micrometer-scale measurements [2]. To improve the signal-to-noise ratio and suppress unwanted contributions, the measurement is performed with a lock-in amplifier, where the temperature signal is demodulated at twice the drive frequency. The measured temperature depends on both the position of the thermometer and the vibration amplitude, with values reaching up to 0.5 mK. Besides the temperature signal of the membrane, signals caused by vibrations from neighboring membranes (distanced 1.5 mm) are also detected.

[1] F. Yang et al., Sens. Actuators A Phys. 354, 114307 (2023).
[2] F. L. Bakker et al., J. Appl. Phys. 111, 084509, (2012)

TT 32.3 Tue 10:30 POT/0051

FEBID and FIBID nanowire field emitters integrated with microcantilevers - fabrication and characterization — •Ewelina Gacka[1,2], Gregor Hlawacek[1], Krzysztof Kwoka[2], Tomasz Piasecki[2], Bartosz Pruchnik[2], René Hübner[1], and Teodor Gotszalk[2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328, Dresden, Germany — [2]Department of Nanometrology, Wroclaw University of Science and Technology, 50-370, Wroclaw, Poland

Because micro- and nanomechanical systems are continuously evolving, there is a need to leverage various fabrication technologies. A scanning electron microscope with a gallium focused ion beam, as well as a helium ion microscope, were used to integrate platinum-carbon (Pt-C) and tungsten-carbon (W-C) nanowire field emitters with microcantilevers, serving as deflection sensors. Pt-C and W-C nanocomponents were fabricated using an additive, direct-writing method - focused-electron-/ion-beam-induced deposition (FEBID/FIBID)[1,2]. After growth calibration, the field emission behavior was studied in situ inside a vacuum chamber. The deposited Pt-C and W-C materials were characterized using Kelvin probe force microscopy and transmission electron microscopy. [1] T. Piasecki et al., Nanotechnology 35 (2024), doi: 10.1088/1361-6528/ad13c0. [2] E. Gacka et al., Measurement 234 (2024), doi: 10.1016/j.measurement.2024.114815.

TT 32.4 Tue 10:45 POT/0051

Optimization of Faraday Cage Angled Etching and Its Application Prospects in Silicon Carbide — •Wuzheng Ge[1,2], Ciaran Fowley[1], Jens Zscharschuch[1], Claudia Neisser[1], Artur Erbe[1,2], Philipp Bredol[3], Felix David[3], and Eva Weig[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Dresden University of Technology, Faculty of Electrical and Computer Engineering, 01069 Dresden, Germany — [3]Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany

This work presents the optimization of a Faraday Cage Angled Etching (FCAE) approach for ICP-RIE. By reshaping the plasma potential through the cage's mesh geometry, FCAE steers ions along the cage-wall normal, enabling controllable ion incidence angles. Reproducible 3D triangular cross-section structures were demonstrated on silicon, confirming the effectiveness of ion-direction tuning. The results were also applied to silicon carbide nanomechanical resonators. The enhanced directional ion flux enables direct fabrication of free-standing, stress-free structures in bulk, undoped SiC. This capability offers new pathways for advanced SiC-based MEMS.

15 min. break

TT 32.5 Tue 11:15 POT/0051

Probing Mechanical Nonlinearities with Quantum Dots — •Noah Spitzner, Jona Richter, Emeline Denise Sophie Nysten, Matthias Weiss, and Hubert Krenner — Universität Münster, Münster, Germany

The coupling of quantum dots to mechanical resonances is a well-established approach to investigate the behaviour of mechanical resonators and crystals. Within that approach, the quantum dots (QDs) act as point-like sensors sensitive to dynamical changes to their lattice constant. Vibrations in the host structure modulate the emission energy of the quantum dot, enabling readout of mechanical modes via ultrafast optical detectors. In our hybrid structures, mechanical excitation is achieved by integrating the QD-membrane onto a lithium niobate substrate equipped with finger-like electrodes called interdigitated transducers (IDTs). Applying a radio-frequency (RF) signal to the IDTs generates surface acoustic waves, which propagate on the surface of the substrate, coupling to quantum dots in their path.

This hybrid platform was taken a step further by structuring the QD-membrane into rings hosting mechanical resonances. Frequency sweeps of the RF signal applied to the IDT revealed sharp resonances in the emission-energy modulation exclusively for the quantum dots located within the rings. Interestingly, the resonances appear over a large region of SAW frequencies from 200 MHz to 900 MHz. Moreover, we detect clear signatures of a nonlinear mechanical response e.g. asymmetric lineshapes in the time-modulated optical signal of the QD when the external drive by the IDT is increased.

TT 32.6 Tue 11:30 POT/0051

Dry processing of 3C-silicon carbide nanostring resonators — •Felix David[1,2,3], Yannick Klass[1], Philipp Bredol[1,2,3], and Eva Weig[1,2,3] — [1]Technische Universität München, School of Computation, Information and Technology, Garching, Germany — [2]Technische Universität München, Zentrum für QuantumEngineering (ZQE), Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

We fabricate string resonators from strongly stressed 3C-silicon carbide (SiC) grown on a silicon substrate. In conventional fabrication processes, electron-beam lithography with PMMA is employed to define a metallic hard mask for the subsequent dry etching step via a liftoff process. This requires some wet-chemical process steps, such as HF etching and metal removal, which can destroy samples. Here, we describe an alternative process that avoids all wet-chemical process steps, enabling superior quality. It involves the use of a negative electron-beam resist as an etch mask, as well as the completely reactive-ion etching-based release of the nanostrings. The dry-processed nanostrings can be fabricated with a high yield and exhibit high mechanical quality factors at room temperature. Due to its high reliability, combined with high process speed, it also allows for quick adaptation to new projects, such as multilayer and hybrid mechanical systems.

TT 32.7 Tue 11:45 POT/0051

The best of two worlds: hexagonal boron nitride exfoliated on stressed silicon carbide string resonators — •Philipp Bredol[1], Felix David[1], Junhui Wu[2], Andrey N. Anisimov[2], Takashi Taniguchi[3], Kenji Watanabe[3], Georgy V. Astakhov[2], Artur Erbe[2], and Eva M. Weig[1] — [1]TU Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany — [2]HZDR, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

The boron vacancy (VB) of hexagonal boron nitride (h-BN) is a promising single photon emitter for applications in quantum technologies. Nanomechanical control of the VB would greatly enhance its versatility in such applications, therefore nanomechanical h-BN resonators are of great interest. Here we demonstrate that h-BN can be exfoliated on a chip with a pre-stressed silicon carbide thin-film and subsequently patterned into nanomechanical string resonators with high tensile stress. The resulting h-BN covered string resonators have high mechanical quality factors due to dissipation dilution and show the optically detected magnetic resonance signature of the VB of h-BN. Our fabrication approach allows to decouple the choice of the defect hosting 2D-material from the engineering of the mechanical mode and paves the way to nanomechanical control of single photon emitters in h-BN and other 2D materials.

TT 32.8 Tue 12:00 POT/0051

Cavity optomechanics with van der Waals materials — •Aloysius Farrel[1,3], Lukas Schleicher[1,3], Irene Sánchez Arribas[1,3], Leonard Geilen[2,3], Alexander Musta[2,3], Alexander Holleitner[2,3], and Eva Weig[1,3] — [1]Chair of Nano and Quantum Sensors, TU Munich, Germany — [2]Walter Schottky Institute, TU Munich, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Freely suspended two-dimensional materials are promising platforms for hybrid quantum systems that combine mechanical, optical, and electronic properties. Coupling the optical and mechanical modes of the resonators would be the first step towards such hybrid quantum system.

Here, we present studies of the mechanical resonators with van der Waals materials, such as hBN, on a SiN membrane. We map the spatial mechanical modes of the freestanding and supported 2D materials. Furthermore, we observe an optical nonlinearity in our high-finesse fiber optic cavity setup, which could couple to the mechanical modes. This result helps us understand the optomechanical coupling of the system and leads the way for a hybrid quantum device by incorporating quantum emitters in the system.

TT 32.9 Tue 12:15 POT/0051

Imaging GHz surface acoustic waves in epitaxial graphene cavities — •Mingyun Yuan[1], Alberto Hernández-Mínguez[1], Yi-Ting Liou[2], Jens Herfort[1], Joao M. J. Lopes[1], and Paulo V. Santos[1] — [1]Paul-Drude-Institut, Leibniz Institut im Forschungsverbund e.V., Berlin, Germany — [2]Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany

The imaging of sound has fascinated scientists and the public alike, dating back to Chladni's demonstrations in the 19th century. Nowadays, it is possible to image mechanical vibrations at the nanoscale, enabling direct probing of propagation, scattering and diffraction for high-frequency acoustic waves with short wavelengths. Here, we present the imaging of GHz surface acoustic waves (SAWs) in an epitaxial monolayer graphene nanostructure, based on thermal decomposition of SiC, using atomic-force microscopy (AFM). We observe a near-perfect strain transfer that gives rise to rich acoustic patterns in the phononic cavity formed by the graphene nanostructure. Furthermore, the enhanced acoustic intensity in the graphene region indicates a waveguiding effect, with graphene serving as an atomically thin, embedded shorting layer. Within the cavity, signatures of quantum chaos are observed. The high spatial resolution of AFM enables the investigation of SAW strain transferred onto 2D materials with high precision. The results also demonstrate an epitaxial nanophononic platform for both functional acoustic devices and fundamental studies of quantum phenomena.

TT 32.10 Tue 12:30 POT/0051

Nonlinear vibrational dynamics locally probed by time-resolved electron diffraction — •Kai Nettersheim[1], Alexander Schröder[1], and Sascha Schäfer[1,2] — [1]Department of Physics, University of Regensburg, Regensburg, Germany — [2]Regensburg Center for Ultrafast Nanoscopy (RUN), Regensburg, Germany

Nonlinear dynamics of micro- and nanoscale electro-mechanical systems can be observed using electrical or optical methods. However, these approaches are often limited in their spatial resolution, which leaves the underlying mechanics only partially accessible. Recent advances in ultrafast electron microscopy (UTEM) enable the highly localized probing of nanoscale oscillators, allowing to retrieve detailed information about their atomic structure and material defects.

Utilizing stroboscopic UTEM imaging techniques, we present the characterization of nonlinear mode dynamics in free-standing silicon membranes employing an event-based electron detector with nanosecond temporal resolution [1]. The high-Q resonator is excited using an optical pulse train driving the sample into the nonlinear regime. Due to the use of event-based converged electron beam diffraction (CBED), phase-accurate measurements of the nanoscale structural motion are provided. Whereas at weak driving, the oscillator displays a simple Duffing-type bistability, higher harmonic overtones as well as period doubling dynamics emerge at higher driving amplitudes.

[1] A. Schröder et al., Ultramicroscopy 256, 113881 (2024)