HL 13: Poster Session III

Topics:
- Materials and devices for quantum technology
- Quantum dots and wires
- Functional Metal Oxides for Novel Applications and Devices
- Advanced neuromorphic computing hardware: Towards efficient machine learning

Time: Tuesday 13:30–16:30 Location: P

HL 13.1 Tue 13:30 P

Universal short-time response and formation of correlations after quantum quenches — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

The short-time evolutions of two distinct systems, the pump and probe experiments with a semiconductor and the sudden quench of cold atoms in an optical lattice, are found to be described by the same universal response function. This analytic formula at short time scales is derived from the quantum kinetic-theory approach observing that correlations need time to form. The demand of density conservation leads to a reduction of the relaxation time by a factor of 4 in quench setups. The influence of the finite-trapping potential is derived and discussed along with Singwi-Sjølander local-field corrections including the proof of sum rules. The quantum kinetic equation allows to understand how two-particle correlations are formed and how the screening and collective modes are build up.
Phys. Rev. B 90 (2014) 075303, Phys. Rev. E 66 (2002) 022103, Phys. Rev. E 63 (2001) 20102, Phys. Lett. A 246 (1998) 311

HL 13.2 Tue 13:30 P

Synchronization Properties in Coupled Mode-Locked Lasers — •Clara Rodríguez Roca-Sastre, Stefan Meinecke, and Kathy Lüdge — Institut für Theoretische Physik, Technische Universität, Berlin, Deutschland

Passively mode-locked semiconductor lasers (PMLLs) are simple and compact sources of high-frequency ultrashort light pulses. These devices can be used in novel secure communication schemes and for optical clock synchronization. However, due to the lack of an external reference clock, this class of MLLs exhibits higher timing jitter than their active counterparts [1]. To overcome this detrimental effect, mutual all-optical coupling can be introduced to reduce the timing jitter [2]. This technique also allows access to different synchronization regimes of the laser outputs. To better understand the synchronization regime, we numerically model a coupled system using delay differential equations [1]. Two coupled identical lasers pumped differently can operate with a high degree of in-phase and localized synchronization if one of them is driven in stable FML operation and the detuning between the devices is not too pronounced. Otherwise, the ML output collapses and complex dynamics such as multi-pulse dynamics may arise. The lasers then exhibit mode-locked pulses with a finite number of different intensities. In addition, regions of anti-phase dynamics appear at delay times around fractional integers of the laser resonance round-trip time.

[1] Otto et al., New J. Phys. 14, 113033 (2012).
[2] Simos et al., IEEE JQE 54, 2001106 (2018).

HL 13.3 Tue 13:30 P

Off-resonant excitation swing up of a quantum emitter — •Thomas Bracht[1], Michael Cosacchi[2], Tim Seidelmann[2], Moritz Cygorek[3], Alexei Vagov[2,4], Martin Axt[2], Tobias Heindel[5], and Doris Reiter[1] — [1]Institut für Festköpertheorie, Universität Münster,Germany — [2]Theoretische Physik III, Universität Bayreuth, Germany — [3]Heriot-Watt University, Edinburgh, United Kingdom — [4]ITMO University, St. Petersburg, Russia — [5]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Controlled preparation of a quantum emitter is key for many of its applications, for example as a single photon source. Here, we present a scheme which uses pulses detuned significantly below the excited-state energy that lead to a swing up of the quantum emitter occupation. We show that a two-color excitation leads to high final excited-state occupation and discuss the conditions under which the scheme works. Applied to semiconductor quantum dots, the proposed swing-up scheme results in the emission of high-quality single photons. The main advantage of our scheme compared to Rabi rotations is that no filtering is needed in order to separate the resulting signal from the laser source. Another advantage is that in contrast to off-resonant schemes relying on phonon-assisted transitions, our scheme does not depend on any auxiliary quasi-particles. In summary, we are proposing an experimentally feasible swing-up scheme to excite a quantum emitter yielding high-quality photon emission for quantum technology.

HL 13.4 Tue 13:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be benefitial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

HL 13.5 Tue 13:30 P

Diameter dependent whispering gallery mode lasing effects in quantum dot micropillar cavities — •Imad Limame, Ching-Wen Shih, Johannes Pietsch, Aris Koulas-Simos, Leo Roche, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin

Whispering-gallery modes (WGMs) were first theorized by Lord Rayleigh in 1878 at the St. Paul cathedral. WGMs with lateral emission characteristics occur also in micropillar cavities which is of great interest for integrated quantum nanophotonics. In this work, we present an in depth study of WGM emission in micropillars ranging between 2 and 20 μm in diameter. The samples were grown by mean of metal organic chemical vapor deposition and include multi layers of InGaAs quantum dots as active region. The pillars were processed using electron beam lithography, using a Ni hard mask. This hard mask is only partially removed to create a highly obsorbant surface on the top of the pillar, which suppresses emission through standard vertically emitting micropillar modes. The optical properties were studied by means of micro-photoluminescence spectroscopy (μPL). Investigating the input-output characteristics, the free spectral range, the Q-factor and the beta-factor as function of the pillar diameter provides deep insight into the underlying physics and paves the way for the applicaiton of the developed WGM microlasers as coherent excitation sources in integrated quantum photonic circuits.

HL 13.6 Tue 13:30 P

Continuum of quantized bound quasinormal modes — •Robert Fuchs, Sebastian Franke, Andreas Knorr, and Marten Richter — Technische Universität Berlin, Berlin, Germany

Quasinormal modes (QNMs) have proven to be a useful and intuitive

way to define modes for open cavities. They have been calculated for a variety of problems both in classical electrodynamics, and recently used in a fully quantized description for three dimensional geometries.

However, so far, a quantized description of multi-cavity-structures using QNMs with substantial propagation delays is missing. We show that an extension of the QNM quantization is possible if the cavities are far away from each other so that retardation effects are important.

The related quantization approach leads to a set of non-bosonic operators with a continuous spectrum. In the multi-cavity theory, this continuum serves as a bath which can be used to describe photon propagation between the separately quantized cavities. Using multi-time correlation functions we are able to construct a systematic formulation to describe the inter-cavity transfer determined by QNM parameters.

HL 13.7 Tue 13:30 P

Fiber-pigtailing quantum-dot cavity-enhanced light emitting diodes — Lucas Rickert[1], •Frederik Schröder[1], Timm Gao[1], Christian Schneider[2,3], Sven Höfling[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany — [3]Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany

Semiconductor quantum dots embedded in engineered microcavities are considered key building blocks for photonic quantum technologies [1]. The direct fiber-coupling of respective devices would thereby offer many advantages for practical applications [2]. Here, we present a method for the direct and permanent coupling of electrically operated quantum-dot micropillar-cavities to single-mode fibers [3]. The fiber-coupling technique is based on a robust four-step process fully carried out at room temperature, which allows for the deterministic coupling of a selected target device. Using the cavity mode electroluminescence as feedback parameter, precise fiber-to-pillar alignment is maintained during the whole process. Permanent coupling is achieved in the last process step using UV curing of optical adhesive. Our results are an important step towards the realization of plug-and-play benchtop electrically-driven single-photon sources.

[1] T. Heindel et al., Appl. Phys. Lett. 96, 011107 (2010)
[2] T. Kupko et al., arXiv.2105.03473 (2021)
[3] L. Rickert et al., arXiv.2102.12836 (2021)

HL 13.8 Tue 13:30 P

Hyperspectral imaging for deterministic quantum dot microcavities — •Quirin Buchinger[1], Magdalena Moczała-Dusanowska[1], Łukasz Dusanowski[2], Tobias Huber[1], and Sven Höfling[1] — [1]Technische Physik, Universität Würzburg, 97074 Würzburg, Germany — [2]Department of Electrical and Computer Engineering, Princeton University, 08544 Princeton (NJ), USA

For many photonic quantum communication schemes, including quantum networks, indistinguishable single photons or entangled photon pairs are required. Semiconductor quantum dots (QDs) in microcavities are a promising source due to their high quantum efficiency [1], photon indistinguishability [2], and outcoupling efficiency. As a disadvantage these self-assembled QDs are randomly distributed over the sample and have inhomogeneosly distributed emission wavelengths.

Here, we present an approach using hyperspectral imaging to locate self-assembled QDs and to integrate them deterministically into microcavities. We image InGaAs-QDs in a GaAs-Membrane and perform subsequent processing of Circular-Bragg-grating cavities. We show possibilities and solutions to improve the spatial accuracy through marker design, data acquisition and image processing. Further, we discuss the combination of imaging and acquisition of single spectrums at thereby identified QDs to reduce the needed time compared to hyperspectral imaging without a trade-off on spectral and spatial information.

[1]Michler et al. Science, 290, 2282-2285 (2020)
[2]Santorio et al. Nature, 419, 594-597 (2002)

HL 13.9 Tue 13:30 P

Mobility spectrum analysis on three-dimensional topological insulator $BiSbTeSe_2$ — •Jimin Wang[1], Alexander Kurzendorfer[1], Lin Chen[1], Zhiwei Wang[2], Yoichi Ando[2], Yang Xu[3], Ireneusz Miotkowski[3], Yong P. Chen[3], and Dieter Weiss[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, German — [2]Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany — [3]Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907, USA

We conducted mobility spectrum analysis on a high quality 3D topological insulator film of $BiSbTeSe_2$ to extract mobility μ, and carrier density n. Top and bottom gates were applied to tune the carrier density on top and bottom surfaces independently. At 1.5 K, when conduction is entirely dominated by the Dirac surface states, we always find two dominant conduction channels (top and bottom surfaces), with $\mu = 500 - 3000\,\mathrm{cm}^2/(\mathrm{Vs})$, and n on the order of $10^{12}\,\mathrm{cm}^{-2}$. However, at sufficiently high temperature ($T = 85\,\mathrm{K}$), when the bulk contributes, a third channel with maximum mobility $\mu \sim 400\ \mathrm{cm}^2/(\mathrm{Vs})$, and n on the order of $10^{11} - 10^{13}\,\mathrm{cm}^{-2}$ opens. Our data show the feasibility of the method to analyze the different conduction channels in a topological insulator, being also promising for other similar material systems.

HL 13.10 Tue 13:30 P

Feedback-induced chaotic emission from a GaAs-QW high-contrast grating microcavity structure — •Aris Koulas-Simos[1], Melanie Hoeschele[1], Jiaqi Hu[2], Hui Deng[2,3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Applied Physics Program, University of Michigan, Ann Arbor, Michigan 48109, USA — [3]Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA

We investigate the optical and quantum optical properties of a high-contrast grating microcavity structure based on GaAs multiple quantum wells subject to optical feedback. Power-dependent microphotoluminescence (μPL) studies reveal the typical s-shaped form in the I/O curve with a pronounced kink signifying the lasing onset, accompanied by an abrupt linewidth narrowing. The effect of the optical feedback is visible in the shift of the threshold to lower excitation powers. Additional angle-resolved PL measurements show a condensation to lower k-states and spectrally narrower emission. In power-dependent photon-autocorrelation, enhanced bunching and revival peaks with a period equal to the round-trip time of the external cavity are pronounced, indicating chaotic emission as a result of the optical feedback [1]. This is again verified by calculating the photon-autocorrelation function $g^{(2)}(\tau)$ through single-shot intensity trace measurements with a streak camera.

[1] F. Albert et al., *Nat. Comm.* **2**, p. 1-5 (2011)

HL 13.11 Tue 13:30 P

Spectral manipulation of coherent acoustic phonons in a graphite nanofilm observed by ultrafast electron diffraction — •Arne Ungeheuer, Ahmed Hassanien, Mashood Mir, Arne Senftleben, and Thomas Baumert — University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Femtosecond-laser-excited nanomechanical strain-waves in thinfilm-structures allow for a series of quantized resonant modes with amplitudes that depend on the photoinduced spatiotemporal strain-distribution in the material [1]. We investigate the possibilities to amplify specific higher harmonic modes in a graphite nanofilm, employing a NIR femtosecond-laser double pulse excitation-scheme. We present results from ultrafast electron diffraction studies for different relative pulse-delays within the double-pulse sequence, yielding constructive or destructive interference for selected coherent acoustic phonon harmonics.

[1] F. Hudert et al.: Phys. Rev. B 79, 2009.

HL 13.12 Tue 13:30 P

Laser controlled charge-carrier dynamics in pyrene-doped $MoSe_2$ monolayer — •Matheus Jacobs[1], Jannis Krumland[1], and Caterina Cocchi[1,2] — [1]Institut für Physik und IRIS Adlershof, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Physics, Carl von Ossietzky Universität Oldenburg,26129 Oldenburg, Germany

In the last years, the interest in transition metal dichalcogenide monolayers have grown enormously due to their unique electronic structure and light-matter coupling properties. Combining these materials with carbon conjugated molecules can give rise to new materials with enhanced opto-electronic performance, specially when excited by coherent radiation. In the framework of real-time time-dependent density functional theory, we investigate the ultrafast charge-carrier dynamics at the interface formed by pyrene molecules physisorbed on a $MoSe_2$ monolayer. By monitoring the effect of the incident pulse intensity

on the energy and the electron transfer on the hybrid heterostructure, we identify a striking nonlinear response of the system, which in turn impacts the charge-carrier dynamics and the nature of cahrge transfer from the inorganic to the organic components.

HL 13.13 Tue 13:30 P

Validity of the Siegert relation in partially-coherent regimes — •Monty Drechsler, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

With increasing miniaturization of coherent light sources to the diffraction limit and below, their emission properties change and new effects appear. Therefore, a description in the context of quantum optics is required. An objective in studying such nano light sources is their classification. In this context, the investigation of the statistical nature of photon correlations plays a major role. We are able to access information about photon correlations quantified by $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$ using a master-equation or a cluster-expansion approach. We discuss the temporal behavior of these correlation functions in different device regimes from the quantum limit of a single emitter to larger systems. When combining the theoretical prediction with experiments we are confronted with the limited time resolution of detectors used in the measurement of correlations function. To treat this issue, a generalized Siegert relation has been used previously [1][2]. Here, we quantify when such an approach is justified.

[1] Kreinberg et al., Light Sci Appl 6, e17030 (2017)
[2] Kreinberg et al., Laser & Photonics Reviews 14, Nr. 12, 2000065 (2020)

HL 13.14 Tue 13:30 P

Top-down fabrication of silicon nanophotonic structures for hosting single-photon emitters — •Nagesh S. Jagtap[1,2], Michael Hollenbach[1,2], Ciaran Fowley[1], Woo Lee[3], Manfred Helm[1,2], Georgy V. Astakhov[1], Artur Erbe[1], and Yonder Berencén[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Korea Research Institute of Standards and Science (KRISS), Yuseong, 305-340 Daejeon, Republic of Korea

Silicon, the ubiquitous material for computer chips, has recently been shown to be instrumental for hosting sources of single-photons emitting in the strategic optical telecommunication O-band (1260-1360 nm)[1], the so-called G center. To increase the brightness and the photon extraction efficiency of single G center, the coupling of these centers into photonic structures is strong.

This work presents a top-down approach avoiding the use of ion beam-based etching methods for fabricating high-quality defect-free photonic structures such as silicon nanopillars, which can host single-photon emitters. This method builds upon a wet-chemical process known as metal-assisted chemical etching. We report the successful fabrication of two-dimensional arrays of vertically-directed waveguiding silicon nanopillars. We also show the etch chemistry dependence on the Si wafer resistivity along with its effect on the etch rate and the sidewall roughness of pillars for a variety of pillar diameters.

References:[1] M. Hollenbach, et al. Opt. Express 28,26111-26121

HL 13.15 Tue 13:30 P

Sensitivity to high energy Proton irradiation of 670 nm VCSELs in emitter and receiver mode — •Heinz-Christoph Neitzert — Salerno University - DIIn, Fisciano (SA), Italy

Vertical Cavity Surface Emitting Lasers (VCSELs) have recently found increasing interest also for space applications, for example for ultra-compact atomic clocks and intra-satellite data-links. Besides their application as efficient emitters also their application as resonant-cavity type photo-receiver has been demonstrated. The radiation stability of commercial VCSELs emitting at 670nm bas been tested with the exposition to 68 MeV protons with different fluence values up to 10^13 protons/cm^2. Besides the conventional electrical and electro-optical characterization under forward bias conditions, also the reverse bias characteristics up to device breakdown and the receiver characteristics under white light LED illumination have been investigated. Even for the highest proton fluence value only a very small change of the laser threshold current and slope efficiency values has been observed, confirming that these VCSELs can be operated successfully in space or in a high energy physics environment. Regarding their optical receiver properties up to 10^12 protons/cm^2, only a minor decrease of the primary photocurrent was observed. Only for the highest proton fluence a more substantial decrease in open circuit voltage and primary photocurrent and also a increase of the reverse bias current due to defect related tunnelling, before the inset of avalanche breakdown, has been found.

HL 13.16 Tue 13:30 P

Carrier dynamics and modulation properties in tunnel- injection based quantum-dot structures — •Michael Lorke[1], Igor Khanonkin[2], Stephan Michael[1], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Haifa, Israel

For tunnel-injection (TI) quantum-dot (QD) lasers record high small signal modulation bandwidth and improved performance of 1.55μm InAs QDs on InP-based hetero-structures were reported, which underscores their application potential for high-speed optical communication networks. However, large signal modulation, which really is the fingerprint of applicability in optical communication, is much less investigated. We present a theoretical analysis of TI laser and amplifier devices by combining material realistic electronic structure calculations with a detailed description of the carrier dynamics. Based on these investigations, we can give design guidelines to optimize the modulation bandwidth and turn-on delay.

HL 13.17 Tue 13:30 P

Wave Digital Emulation of Hydra's Neuronal Activity — •Sebastian Jenderny[1], Karlheinz Ochs[1], Christoph Giez[2], Alexander Klimovich[2], and Thomas Bosch[2] — [1]Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany — [2]Christian-Albrechts University Kiel, Zoological Institute, Kiel, Germany

Modeling real neuronal networks by electrical circuits is especially interesting as it can reveal novel design principles. A promising model organism for this purpose is Hydra, a freshwater polyp with rich behavioral patterns despite its neuronal network only consisting of roughly 3000 neurons. Modeling Hydra's nerve net by an electrical circuit is, however, challenging as only calcium imaging measurements instead of electrophysiology are available. The neuronal activity associated to these calcium imaging measurements are difficult to mimic by electrical circuits as they are based on fluorescence traces instead of voltage and current measurements. In this work, we present a circuit-based approach to mimic these fluorescence traces utilizing the fact that the latter can be used to determine the intracellular calcium concentration. For this purpose, we make use of the Morris-Lecar model already accounting for calcium currents and hence allowing to calculate a calcium concentration comparable to the one inferred from the fluorescence traces. A wave digital emulation of our circuit approach shows the successful mimicking of exemplary neuronal activity of Hydra.

HL 13.18 Tue 13:30 P

Light-sensitive Resonant Tunneling Diodes for single photon detection — •Sebastian Krüger[1], Andreas Pfenning[2], Fabian Hartmann[1], Fauzia Jabeen[1], and Sven Höfling[1] — [1]Technische Physik, Julius-Maximilians Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4

Double barrier resonant tunneling diodes (RTDs) are versatile optoelectronic devices with a multitude of possible applications. The focus of interest is the application for terahertz oscillation and the detection of single photons. Especially the downtime-free photodetection has an advantage compared to the state-of-the-art techniques, which are using avalanche multiplication. The capability of single-photon detection has been demonstrated in [1]. The low efficiency of around 10% is limiting. We present our work on RTD photodetectors based on AlGaAs/GaAs DBQW with GaAsSb quantum well (QW) close to the double barrier structure [2]. The strained ternary alloy, GaAsSb, is grown on GaAs. The type II band alignment leads to better *hole* confinement compared to InGaAs-QW or quantum dots (QD). The photodetection based on minority charge carrier accumulation at the DBS in RTDs, is sensed by the influence of their electrostatic potential. It leads to an additional voltage drop over the DBS and shifts the I(V) characteristics towards lower voltages [2]. [1] J. C. Blakesley, et al., Physical Review Letters 94, 067401 (2005). [2] A.Pfenning, et al., Applied Physics Letters 107, 081104 (2015).

HL 13.19 Tue 13:30 P

Towards Scalable Reconfigurable Electronics: Fabrication of Schottky Barrier Field-Effect Transistors using Flash Lamp Annealing — •Muhammad Bilal Khan, Sayantan Ghosh, Slawomir Prucnal, Rene Hübner, Artur Erbe, and Yordan M. Georgiev — Institute of Ion Beam Physics And Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden

To complement the scaling down of complementary metal-oxide-semiconductor (CMOS), new device concepts have been introduced. One such concept is the reconfigurable field-effect transistor (RFET). In the most general case, an RFET is a silicon nanowire (SiNW) based device. The SiNW is silicided at both ends, which results in silicide-Si-silicide Schottky junctions. Typically, two distinct gate electrodes are placed on silicide-Si junctions. By controlling the electrostatic potential on the gate electrodes, the RFET is programmed to the p- or n-polarity. We report on the fabrication and electrical characterization of top-down fabricated SiNW based RFETs. Flash lamp annealing based silicidation process is developed, which enables control over the silicidation process. Uni-polar transfer characteristics are obtained using two top-gates. The effect of implementing various gate dielectric materials (SiO_2, Al_2O_3 and hBN) is studied to enhance device electrostatics.

HL 13.20 Tue 13:30 P

Space-charge effects in high-coherence electron pulses — •Alexander Schröder, Christopher Rathje, Niklas Müller, Jonathan Weber, Nora Bach, and Sascha Schäfer — Institute of Physics, University of Oldenburg, Germany

Ultrafast transmission electron microscopy (UTEM) enables the imaging of ultrafast nanoscale dynamics, utilizing an optical-pump/electron-probe approach within a high-resolution transmission electron microscope [1]. The spatio-temporal resolution in this technique sensitively depends on the phase-space structure of the employed ultrashort electron pulses. Whereas needle-shaped photoemitters were demonstrated to deliver high-coherence electron pulses in the single-electron regime, at larger bunch charges significant Coulomb interactions within the pulse need to be considered [2].

Using the newly constructed Oldenburg UTEM, we investigate the impact of Coulomb interactions on the longitudinal phase-space structure of electron pulses. Depending on the illumination intensity on the photoemitter, we observe a fluence-dependent shift and broadening of the electron energy distribution which is compared to a multi-particle simulation taking into account the expanding electron pulse close to the emitter tip. The impact of the initial electron energy after photoemission, the acceleration field and the bunch charge on the spatio-temporal electron pulse structure at the sample are discussed.

[1] A. Feist et al., Ultramicroscopy, 176, 63 (2017)
[2] N. Bach et al., Structural Dynamics 6, 014301 (2019)

HL 13.21 Tue 13:30 P

Solving the Vertex Cover Problem with a Wave Digital Model of an Ising Machine — •Bakr Al Beattie and Karlheinz Ochs — Ruhr University Bochum, Bochum, Germany

The efficient solution of NP-problems is an unresolved computational challenge with many real-world applications. Ising machines are promising for solving these types of problems. The idea is to map a problem onto the Ising Hamiltonian and let an Ising machine find the ground state, which corresponds to the solution of the problem. These machines are designed so they have the natural tendency to converge to the ground state of the Hamiltonian. Multidimensional wave digital algorithms are known to be massively parallel, and they are additionally robust for emulating large electrical networks, like the coupled oscillator network of an Ising machine. In this work, a wave digital model mimicking the phase dynamics of an ideal Ising machine is derived and generalized to support solving Ising problems containing the Zeeman term. To prove usefulness and quality of this wave digital Ising machine, we solve a vertex cover problem.

HL 13.22 Tue 13:30 P

Decision-Making Processes by a Kuramoto Model with Hebbian Learning: Circuit Synthesis and Wave Digital Emulation — •Sebastian Jenderny, Dennis Michaelis, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Decision-making processes are an interesting topic often studied in synchronizing oscillatory networks. Here, synchronization is, on an abstract level, related to learning. In this context, the Hebbian learning rule can be interpreted as the increasing and decreasing coupling strength between oscillators with a small and a large phase difference, respectively. This can for example be implemented by the Kuramoto model, being a simple and well-studied model for oscillatory networks. Our aim is to synthesize an electrical circuit of the Kuramoto model with Hebbian learning with which decision-making processes can be mimicked. For this purpose, we derive a memristor model accounting for the Hebbian learning rule. We then develop a corresponding wave digital model and utilize it to mimic the decision-making process associated with the observation of optical illusions.

HL 13.23 Tue 13:30 P

A Memristive Circuit for a Delay-Based Supervised Classifier — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Supervised learning based on artificial neural networks is a major principle for many pattern recognition tasks. Corresponding circuit implementations are often based on implementing synaptic weight changes. In this work, we propose a different approach based on learning delays instead of synaptic weights. For this purpose, we synthesize an electrical circuit for a dynamic axon model. The resulting circuit is based on memristive Jaumann structures in combination with delay elements. We utilize this circuit to design a neural network for the supervised learning of gait patterns. Here, the learning is based on the circuit selecting delay lengths in a self-organized way, which further introduces an additional degree of freedom compared to the synaptic weight approach. A wave digital emulation verifies our approach by showing that the axonal delays associated with the trained gait patterns are successfully learned, leading to correct classification results.

HL 13.24 Tue 13:30 P

Mimicking Delay-Based Self-Sustaining Gait Pattern Generators — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Hardware implementations of gait pattern generators are an active field of research especially in robotics, where recent approaches are based on neural networks. Most of the latter implementations, however, only consider synaptic weight changes. In contrast to this, we design a gait pattern generator being able to learn and generate self-sustaining gait patterns based on a neural network adjusting its axonal delays. For this purpose, we synthesize a memristive circuit of a dynamic axon model serving as the basis for the neural network. Here, the circuit realization of the axon is based on Jaumann structures with memristors. A wave digital emulation of the resulting complete circuit verifies our approach by showing the successful learning and generation of self-sustained gait patterns of a dog.

HL 13.25 Tue 13:30 P

Towards an Improved Anticipation Circuit with Self-Organized Resonance-Frequency-Adaption — Karlheinz Ochs and •Sebastian Jenderny — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Inspired by the ability of an amoeba to anticipate environmental changes, an RLC circuit with a memristor in parallel has been proposed as an anticipation circuit. Here, the memristor enables a self-organized Q-factor adaption. Since this circuit's functionality is limited to an excitation with its resonance frequency, further research has been done to achieve an additional self-organized resonance-frequency adaption. Existing approaches are based on utilizing memcapacitors instead linear capacitors, where the memcapacitor models are very sophisticated. In contrast to this, in this work we develop a physically more meaningful memcapacitor to use it for an improved anticipation circuit. A wave digital emulation of the resulting circuit shows a self-organized resonance-frequency adaption, supporting the Q-factor adaption of the memristor.

HL 13.26 Tue 13:30 P

Optimal Topology Formation of Memristive Neuronal Networks — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

The topology formation of neuronal networks during their ontogenesis is of great importance since it lays the foundation for the neuronal

networks being well adapted for future tasks. While the synapse formation is the most popular part of this aspect, it is also important to take axon growth into account. This is because the latter can be assumed to play a key role in the emergence of optimal communication paths of neuronal networks in terms of delays. In this work, we synthesize an electrical circuit abstractly mimicking the topology formation of neuronal networks with respect to delays by making use of memristors. The resulting circuit can be used to find the optimal communication paths of a neuronal network by finding its minimal spanning tree, which is verified by LTspice simulations.

HL 13.27 Tue 13:30 P

CMOS back-end compatible Metal-$Hf_{0.5}Zr_{0.5}O_2$-Al_2O_3-Metal ferroelectric tunnel junction devices for neuromorphic applications — •Keerthana Nair[1,2], Marco Holzer[1,2], Sourish Banerjee[1], Catherine Dudourdieu[1,2], and Veeresh Deshpande[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Freie Universität Berlin, Physical Chemistry, Arnimallee 22, 14195 Berlin, Germany

$Hf_{0.5}Zr_{0.5}O_2$ (HZO) ferroelectric layer provides an opportunity for CMOS back-end-of-line integrable devices owing to low crystallization temperature (around 400°C). Ferroelectric tunnel junction (FTJ) memory devices based on HZO feature ultra-low power consumption and have potential for multiple resistance states necessary for neuromorphic applications. FTJ architecture based on the Metal-Ferroelectric-Dielectric-Metal stack allows high ON/OFF ratio with thicker ferroelectric layer (10-12nm). In this work, we demonstrate 400°C-crystallized Metal-HZO-Al_2O_3-Metal FTJ architecture with TiN and W metals. Utilizing the coercive field distribution of the domains, we demonstrate multiple resistance states through partial switching operations and switching pulse-width modulations. The influence of cycling waveform on the ON/OFF ratio (which directly impacts achievable multiple resistance states) will be discussed. The intermediate resistance state stability will also be discussed. Our study also investigates the role of the process conditions, dielectric thickness and metal placement on attaining high ON/OFF ratio back-end compatible FTJ devices.

HL 13.28 Tue 13:30 P

Epitaxial BaSnO3 thin films without extended defects on lattice matched LaInO3 substrates — •Daniel Pfützenreuter, Zbigniew Galazka, Robert Schewski, Klaus Irmscher, Martin Albrecht, and Jutta Schwarzkopf — Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2, 12489 Berlin, Germany

BaSnO3 is a semiconducting perovskite material offering an electron mobility of 320 cm2/Vs at a carrier density of 8E19 cm-3 at room temperature in a bulk crystal. Epitaxial thin films however, always have a much lower electron mobility, which is ascribed to a high density of threading dislocations emerging in the films as a consequence of a large lattice mismatch between substrate and film.

LaInO3 crystals with (110) surface orientations were applied as a novel orthorhombic substrate for the epitaxial growth of BaSnO3 thin films due to its negligible lattice mismatch. We revealed by means of reflection high energy electron diffraction, energy dispersive x-ray analysis and atomic force microscopy that a slight Ba-doping in the LaInO3 substrates helps to stabilize the substrate surface at elevated temperatures and under reducing atmosphere, which are the typically used pulsed laser deposition conditions for the growth of BaSnO3 thin films. Transmission electron microscopy measurements confirm the growth of fully strained BaSnO3 thin films without extended defects on LaInO3:Ba substrates. Temperature dependent Hall-effect measurements of a BaSnO3 film doped with 0.5 % La exhibit a Hall-mobility of 69 cm2/Vs at room temperature and 99 cm2/Vs at 20 K at a constant charge carrier density of 3.8E19 cm-3.

HL 13.29 Tue 13:30 P

β-Ga2O3 material for vertical power devices: challenges to the epitaxy process — •Ta-Shun Chou, Saud Bin Anooz, Raimund Grüneberg, Vi Tran Thi Thuy, Zbigniew Galazka, Klaus Irmscher, Palvan Seyidov, Martin Albrecht, and Andreas Popp — Leibniz-Institut für Kristallzüchtung, Berlin, Germany

β-Ga2O3 is a promising ultra-wide bandgap (~4.8 eV) semiconductor material. A breakdown field strength up to 8 MV/cm is expected from theoretical calculation, which makes it attractive for power electronic applications and a competitor to SiC and GaN. Especially a vertical architecture for β-Ga2O3-based transistors can exploit the high potential of this material and will benefit from a low on-resistance at a given breakdown voltage in combination with less power losses within a transistor switching operation. To fulfill the requirements of the vertical device, extremely low doped homoepitaxial thin films with thicknesses of several um and high crystallinity are necessary.

In this contribution, we present the growth development to achieve step-flow β-Ga2O3 grown layer by MOVPE on Mg-doped β-Ga2O3 (100) substrates with a thickness above 1 um by applying a high growth rate. This improvement can be related to the possible formation of a Ga adlayer which is widely reported already for the GaN system. In addition low, Si doping concentrations down to and below 1E17 cm^-3 were demonstrated while maintaining mobilities comparably high as previous results based on low growth rate and low thickness layers. The developed epitaxy process is a key enabler for the growth of (100) β-Ga2O3 material for vertical power device applications.

HL 13.30 Tue 13:30 P

Influence of group III dopants on the properties of SnO(001) films grown via plasma-assisted molecular beam epitaxy — •Kingsley Egbo, Georg Hoffmann, Andrea Ardenghi, Alexandra Papadogianni, Jonas Laehnemann, and Oliver Bierwagen — Paul-Drude-Institut für Festkörperelektronik, 10117 Berlin, Germany

Most metal oxides show a propensity for n-type conductivity, few oxides show p-type character. Metastable tin monoxide (SnO) is among the few p-type oxide semiconductors and its unintentional p-type conductivity is believed to be controlled by Sn-vacancies. Few studies have also suggested the possibility for bipolar doping in SnO. In this study, the growth of SnO(001) doped with the group III La, In and Ga on YSZ(100) substrates by plasma-assisted MBE is investigated. Structural properties of the doped SnO(001) films were studied by x-ray diffraction, Raman spectroscopy and scanning electron microscope. Detailed electrical properties of the doped films are obtained from Hall Effect measurements. Hole concentration, p of ~0.8-2.0 x 1019 cm-3 and resistivity, ρ of 0.15-0.30 Ω-cm respectively is obtained from room temperature hall measurement of unintentionally doped SnO (001). We find that p increases to ~ 4.0-5.0 x 1019 cm-3 and ρ decreased to 0.04-0.063 Ω-cm for Ga doped films. In contrast, thin films doped with In and La show reduction in p and remarkable increase in ρ with increasing dopant concentration. Our results reveal that p-type conductivity in SnO can be improved by Ga acceptors while La and In likely acts as compensating donors in SnO. These results offer an opportunity for exploring bipolar doping in SnO.

HL 13.31 Tue 13:30 P

The role of Sr deficiency in SrTiO3 thin films grown by metal-organic vapor phase epitaxy — •Aykut Baki, Julian Stöver, Tobias Schulz, Houari Amari, Carsten Richter, Jens Martin, Klaus Irmscher, Martin Albrecht, and Jutta Schwarzkopf — Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2 in 12489 Berlin

SrTiO3 is widely studied due to interesting physical properties such as its high permittivity at room temperature, resistive switching and strain induced ferroelectricity. However, the underlying physical origin of these effects is not fully understood. In order to investigate the influence of structural defects on the physical properties, we performed the growth of SrTiO3 films by liquid-delivery spin metal-organic vapor phase epitaxy, which takes place nearby the thermodynamic equilibrium and at high oxygen partial pressures ensuring growth of films with high quality and negligible amount of oxygen vacancies. In this study, homoepitaxial SrTiO3 thin films were grown on 0.5 wt.% niobium doped SrTiO3 (100) substrates with varying Sr/Ti ratio in the gas phase. This provides single-phase stoichiometric and deliberately off-stoichiometric thin films with an intentionally incorporated Sr deficiency. Even films with Sr deficiency of up to 20 % were grown without the formation of any extended defects or foreign phase. In-situ high-resolution x-ray diffraction and transmission electron microcopy measurements verified a negligible amount of oxygen vacancies in the films and the absence of conductive oxygen filaments at typically applied switching voltages in a metal-oxide-semiconductor structure. The observed physical properties are Sr-deficiency related.

HL 13.32 Tue 13:30 P

Doping of β-Ga2O3 in a plasma assisted MBE using a SiO source. — •Andrea Ardenghi[1], Georg Hoffmann[1], Oliver Bierwagen[1], Piero Mazzolini[2], Andreas Falkenstein[3], and Manfred Martin[3] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [2]Department of Mathematical, Physical and Computer Sciences, Parma University, Italy — [3]Institute of Physical Chemistry, RWTH Aachen University, Aachen, Germany

β-Ga2O3 is the most likely candidate for the next generation of power electronic devices but, achieve high quality doped sample is still challenging. To obtain n-doping for Ga2O3 the main candidate are Sn, Ge and Si. Between them Si-doped samples showed the higher mobility, making Si the most interesting doping source. Using a silicon source as dopant in PAMBE can be difficult since, due to the oxygen plasma, the source will be oxidized. In Kalarickal work[1], the flux from the Si source were highly influenced by the oxygen pressure, due to the formation and desorption of SiO. In order to avoid this problem a study similar to the one reported by Hoffmann et al[2]. was carried on a SiO source. Another advantage of the SiO source is the low cell temperature in comparison with Si and SiO2. From our results temperatures between 600-800°C should give us doping concentration in the range of 10e17 to 10e20 cm-3. The SiO source will be used for the growth of Si-doped Ga2O3 layers by PAMBE and the results will be reported.

[1]Kalarickal, Nidhin Kurian, et al. Applied Physics Letters 115.15 (2019).

[2]Hoffmann, Georg, et al. APL Materials 8.3 (2020).