HL 4: Semiconductor Lasers

Time: Monday 9:30–12:45 Location: H33

HL 4.1 Mon 9:30 H33

Spin lasing in bimodal quantum dot micropillar cavities — •Niels Heeermeier[1], Tobias Heuser[1], Jan Grosse[1], Natalie Jung[2], Markus Lindemann[2], Nils Gerhard[2], Martin Hofmann[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universiät Berlin, D-10623 Berlin, Germany — [2]Lehrstuhl für Photonik und Terahertztechnologie, Fakulktät für Elektrotechik und Informationstechnik, Ruhr-Universität Bochum, D-44780 Bochum

Spin-controlled lasers have been shown to provide ultra-fast polarization dynamics in excess of 200 GHz. In contrast to conventional semiconductor lasers their temporal properties are not limited by the intensity dynamics, but are governed primarily by the birefringent mode splitting that determines the polarization oscillation frequency. Another class of modern semiconductor lasers are high-beta emitters which benefit from enhanced light-matter interaction due to strong mode confinement in low-mode-volume microcavities. In such structures, the emission properties can be tailored by the resonator geometry to realize for instance bimodal emission behavior in slightly elliptical micropillar cavities. We utilize this feature to demonstrate and explore spin-lasing effects in bimodal high-beta quantum dot micropillar lasers. The studied microlasers show spin laser effects with polarization oscillation frequencies up to 15 GHz controlled by the ellipticity of the resonator. Our results reveal appealing prospects for very compact and energy-efficient spin lasers and can pave the way for future purely electrically injected spin lasers enabled by short injection path lengths. Laser and Photonics Reviews 2022, 16, 2100585.

HL 4.2 Mon 9:45 H33

Temperature-dependent lasing operation of hybrid semiconductor nanowire - metal grating plasmonic nanolasers — •Francesco Vitale[1], Daniel Repp[2], Thomas Siefke[2], Uwe Zeitner[2], Thomas Pertsch[2], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D-07743 Jena — [2]Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena, Albert-Einstein-Straße 15, D-07745 Jena

Nanowire(NW)-based semiconductor-insulator-metal (SIM) plasmonic structures represent a benchmark platform for the next generation of hybrid nanolasers, capable of sustaining sub-wavelength hybrid lasing modes, which, in turn, lead to an overcoming of diffraction-limited mode footprints and an acceleration of the lasing dynamics, when compared to their photonic counterparts. In this work, we report on the realization and optical investigation of hybridized SIM platforms, in which single ZnO NWs are deterministically overlaid onto metal gratings (MGs), FIB-milled into a 70 nm Al layer with a nanometric Al_2O_3 spacer on top. By performing ns-excitation steady-state micro-PL, we study the spectral and temporal properties of such hybrid platforms, as a function of the cavity geometry (i.e. NW size, grating period and NW-trench orientation) and temperature. We report about room-temperature lasing in some of these hybrid NW-MG structures and lowering of the lasing threshold compared to the planar SIM plasmonic nanolasers.

HL 4.3 Mon 10:00 H33

Field-resolved high-order sub-cycle nonlinearities in a terahertz quantum cascade laser — •Josef Riepl[1], Jürgen Raab[1], Pavel Abajyan[2], Hanond Nong[2], Joshua Freeman[3], Lianhe H. Li[3], Edmund H. Linfield[3], A. Giles Davies[3], Andreas Wacker[4], Tim Albes[5], Christian Jirauschek[5], Christoph Lange[6], Sukheep S. Dhillon[2], and Rupert Huber[1] — [1]University of Regensburg, Germany — [2]Université de Paris, France — [3]University of Leeds, UK — [4]Lund University, Sweden — [5]Technical University of Munich, Germany — [6]TU Dortmund University, Germany

Employing ultrafast electron dynamics in quantum cascade lasers (QCLs) holds enormous potential for intense, compact mode-locked terahertz (THz) sources, squeezed THz light, frequency mixers, and comb-based metrology systems. Yet the important sub-cycle dynamics have been notoriously difficult to access in operational THz QCLs. Here, we perform the first ultrafast two-dimensional high-field spectroscopy of a free running THz QCL. The detected strong incoherent and coherent nonlinearities up to eight-wave mixing do not only reveal extremely short gain recovery times, but also reflect the nonlinear polarization dynamics of the QCL laser transition for the first time. A density-matrix approach reproducing all nonlinearities and their ultrafast evolution, allows us to map the coherently induced trajectory of the Bloch vector. The observed nonlinearities benefit from resonant enhancement in a regime of negative absorption and bear potential for various future applications, ranging from efficient intracavity frequency conversion and mode proliferation to passive mode locking.

HL 4.4 Mon 10:15 H33

Tuning nanowire lasers via hybridization with two-dimensional materials — •Edwin Eobaldt[1], Francesco Vitale[1], Maximilian Zapf[1], Margarita Lapteva[1], Christof Neumann[2], Andrey Turchanin[2,3], Giancarlo Soavi[1,3], and Carsten Ronning[1,3] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, 07743 Jena, Germany — [3]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Semiconductor nanowires have attracted great scientific attention due to their remarkable waveguiding properties and their intrinsic capability to lase under sufficiently high excitation, thus, paving the way towards nanoscaled coherent light sources and the realization of all-optical circuits. After the spectral and temporal characteristic of single nanowire lasers have been extensively studied during the past decade, today's research focuses on their effective integration into functional and nanoscaled environments. In this regard, the hybridization of semiconductor nanowire lasers with two-dimensional materials could offer new capabilities for a dynamical emission tuning enabled by charge transfer processes at the heterointerface. As a proof of concept, hybrids systems containing ZnO nanowires on top of MoS_2 monolayers were investigated by micro-photoluminescence measurements. By further adopting a deterministic transfer approach, it was possible to study hybridization-related changes of the lasing emission on one and the same nanowire.

HL 4.5 Mon 10:30 H33

Generalization of the Siegert relation — •Monty Leon Drechsler[1,2], Frederik Lohof[1,2], and Christopher Gies[1,2] — [1]Institute for Theoretical Physics, University of Bremen, Bremen, Germany — [2]Bremen Center for Computational Materials Science, University of Bremen, Bremen, Germany

The Siegert relation connects the first- and second-order coherence properties of light. While it is valid for thermal light, this relation is routinely extended also to the partially coherent regime of high-β nanolasers, where it aids in the identification of the lasing threshold [1]. We test the validity of this extension by introducing a generalized Siegert relation. Based on the cluster expansion method we derive a full two-time quantum optical theory and combine it with our new approach, allowing us to revise the Siegert relation in different device regimes. We find that correlations lead to deviations from the Siegert relation and in particular highlight the influence correlations related to sub- and superradiance [2].

[1] Kreinberg et al., Laser & Photonics Reviews 14, 2000065 (2020)
[2] Drechsler et al., arXiv:2204.02747v2 (accepted for publication in Appl. Phys. Lett.)

HL 4.6 Mon 10:45 H33

Development of a 850 nm VCSEL array for real world QKD via the BB84 and decoy state protocol — •Moritz Birkhold, Michael Zimmer, Sergej Vollmer, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

Quantum key distribution offers fundamental advantages over classical key distribution. If done correctly a perfectly private key (e.g. a one time pad) can be exchanged between two parties and any eavesdropping attack will be detected. This could be an intresting feature for e.g. worldwide financial applications but the technological hurdles to overcome are numerous.

Here we show the advances towards a complete eight VCSEL array with an integrated polarization grating in the light emission window, to create quantum states and transmit the quantum key. The basic structure is grown by metal-organic vapor-phase epitaxy (MOVPE).

Then this structure is processed to allow data transmission in the GHz regime. Varoius methodes including a co-planar contact geometry are used to achieve this. A vektor network analyzer is than used to measure the scattering parameter as well as the transmission bandwith. Finally a eye diagramm is recorded to determine the data rate. The polarization grating is defined by an electron beam lithography and etched with an ICP machine to allow light output in four different polarizations. The pulses of the eight different VCSEL are evaluated for indistinguishability.

30 min. break

HL 4.7 Mon 11:30 H33

Investigations on high-β silver-coated InP-based metallic nanolasers and their spectral line shape behavior — •Monty Leon Drechsler[1], J. Buchgeister[1], A. Koulas-Simos[2], K. Laiho[2], G. Sinatkas[2], T. Zhang[3], J. Xu[3], F. Lohof[1], F. Jahnke[1], C. Gies[1], W. W. Chow[4], C.-Z. Ning[3], and S. Reitzenstein[2] — [1]University of Bremen, Bremen, Germany — [2]Technical University of Berlin, Berlin, Germany — [3]Tsinghua University, 1303 Beijing 100084, China — [4]Sandia National Laboratories, Albuquerque, New Mexico, USA

We investigate a silver-coated InP-based metallic nanolasers with a diameter of several 100 nm and β-factor close to unity, pushing the device in the regime of quantum optics. We use a quantum optical semiconductor laser model utilizing an equation of motion approach together with the cluster expansion technique to analyze the device. Photon correlations quantified by $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$ are an essential tool for this research. Information about the energy spectrum and the detection characteristics of photons is encoded in them. In this study, an unconventional behavior of the spectral line shape was found. We observe that the line shape takes a Gaussian profile above the laser threshold. The exciting question arises whether the Gaussian line shape can be used as an indicator of laser activity. In previous works, a similar behavior has been reported, but no explanation was given. We provide an explanation for this behavior of the line shape in the framework of an open-cavity multimode model.

HL 4.8 Mon 11:45 H33

Extraction of silver losses at cryogenic temperatures through optical characterization of Ag-coated plasmonic nanolasers — •Aris Koulas-Simos[1], Georgios Sinatkas[1,2], Taiping Zhang[3], Jia-Lu Xu[3], William E. Hayenga[4], Qiang Kan[5], Ruikang K. Zhang[5], Mercedeh Khajavikhan[4,6], Cun-Zheng Ning[3,7], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institute of Integrated Photonics, RWTH Aachen University, Campus Blvd. 73, Aachen 20 52074, Germany — [3]Department of Electronic Engineering, Tsinghua University, Beijing, 100084, China — [4]CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL, USA — [5]Institute of Semiconductors, Chinese Academy of Sciences, Beijing, 100083, China — [6]Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, CA, USA — [7]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, 85287, Arizona, USA

We present a rigorous method for the extraction of silver losses at temperatures T from 10 K to 180 K at NIR wavelengths through T-dependent μPL studies on silver-coated InP-based nanolasers in conjunction with cavity simulations. The numerical algorithm maps the changes of the Q-factor, estimated at transparency, into the imaginary part of silver permittivity. The results are in good agreement with theoretical predictions estimating a drop of one order from room to cryogenic temperatures. This data is long missing from the literature and sets a pathway for the optimization of plasmonic nanolasers.

HL 4.9 Mon 12:00 H33

Quantum-optical study of an InGaAsP metallic cavity nanolaser: A systematic approach to the identification of lasing — •J. Buchgeister[1], M. L. Drechsler[1], F. Lohof[1], C. Gies[1], A. Koulas-Simos[2], K. Laiho[2], G. Sinatkas[2], T. Zhang[4], J. Xu[4], Q. Kan[6], R. K. Zhang[6], C.-Z. Ning[4,5], S. Reitzenstein[2], W. W. Chow[3], and F. Jahnke[1] — [1]Universität Bremen, Germany — [2]Technische Universität Berlin, Germany — [3]Sandia National Laboratories, USA — [4]Tsinghua University, China — [5]Arizona State University, USA — [6]Institute of Semiconductors, China

Semiconductor nanolasers as small-scale sources of coherent light have become increasingly important for applications in the data industry for their size, power-efficiency, and modulation speed. Determining the presence of lasing, however, is challenging due to the near-thresholdless behaviour of ultra-efficient devices, which requires going beyond I/O characteristics. The research presented here focuses on a quantum-optical study of a silver-coated InGaAsP nanolaser by means of a full quantum-mechanical semiconductor laser theory. We calculate the time-resolved single- and two-photon correlation function, allowing us to identify the onset of coherent emission with confidence. Our theoretical model can match the experimentally obtained data using a single set of realistic parameters and hence presents a comprehensive strategy for the identification of lasing while being extensible to those gain materials requiring a more pronounced focus on quantum-material aspects, like TMDCs.

HL 4.10 Mon 12:15 H33

Random Lasing with Dye-doped Fluorescent Aerogels — •Matthias Kestler, Theobald Lohmüller, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

Aerogels are a translucent, amorphous network of colloidal particles, which scatter light at visible wavelengths. Doping an aerogel matrix with fluorescent dyes or nano-particles enables their wider use for optical applications, including random lasing. Here, we report on the synthesis of fluorescent silica aerogels by supercritical drying of dye-doped silica gels. By our refined process, we obtain large, porous samples, where scattering events lead to closed photon paths that act as optical oscillators in the micrometer range. We analyze the corresponding photo-luminescence, amplified stimulated emission and random lasing spectra that are obtained for different dye-loaded aerogel samples. Random lasing is confirmed by different characteristic features like a lasing threshold, bandwidth narrowing and strongly fluctuating Anderson localized modes. Furthermore, we find that the extraordinary thermal stability of aerogels enables the use of high laser pumping energies without visible sample degradation.

HL 4.11 Mon 12:30 H33

Towards a novel vertical external-cavity surface-emitting laser based on a grating waveguide structure — •Peter Gierss[1], Ana Ćutuk[1], Maxim Leyzner[2], Uwe Brauch[2], Marwan Abdou Ahmed[2], Michael Jetter[1], Thomas Graf[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Institut für Strahlwerkzeuge, University of Stuttgart, Pfaffenwaldring 43, 70569 Stuttgart

Vertical external-cavity surface-emitting lasers (VECSELs) provide favorable properties compared to other laser systems. The external cavity allows for incorporation of additional optical elements like birefringent filters or absorbers for passive mode-locking which makes it very attractive for various applications. While the possibility of band-gap engineering and a broad gain spectrum are also advantageous, the heat dissipation from the active region due to the thick distributed Bragg reflector (DBR) is a drawback.

A novel approach is a VECSEL based on a grating waveguide structure (GWS) paired with a low-refractive-index heat-spreader below the active region. The absence of a DBR improves the heat removal while the guided-mode resonances from the GWS should provide good coupling of the pump and laser field as well as the high reflectivity necessary for the laser operation. We present the progress towards the realization of an AlGaInP-based GWS-VECSEL for laser emission in the red spectral range.