NDSL 2025: Nonlinear Dynamics in Semiconductor Lasers 2025

Weierstrass Institute for Applied Analysis and Stochastics

Berlin, June 16-18, 2025

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Contents

Dear Participant,

Welcome to the Weierstrass Institute for Applied Analysis and Stochastics in Berlin! We hope you enjoy your stay both at the institute and in our city.
For your convenience, please find some useful information below:

- **Building Access:** Entry to the building is granted upon showing your participant badge. Please ensure you wear it at all times when entering the premises.
- **Lectures:** All lectures will take place in the Erhard Schmidt Lecture Room, located on the ground floor.
- **Poster session & Get-Together:** This will be held on **Monday, June 16 from 5:15 PM**. Light refreshments, including sandwiches and drinks, will be provided.
- **Smoking Policy:** Smoking, including electronic cigarettes, is strictly prohibited inside the building. As coffee breaks will be held on the ground floor, please use this opportunity to step outside if you wish to smoke.
- **WiFi Access:** You can connect to WiFi using the personal login card provided at registration. Alternatively, Eduroam is also available throughout the building
- **Lunch Options:** A variety of restaurants and snack bars are located near the Institute. Please refer to the handout titled “Places to Have Lunch"for recommendations
- **Workshop Dinner:** The dinner will take place at Maximilians Restaurant, Friedrichstr. 185-190, 10117 Berlin on **Tuesday, June 17 at 6:00 PM.**

If you have any questions or need assistance, please don’t hesitate to contact a member of the organizing team.
Yours sincerely,

Organizers.

Nonlinear Dynamics in Semiconductor Lasers 2025

Weierstrass Institute for Applied Analysis and Stochastics
Erhard-Schmidt Lecture Room, Mohrenstr. 39, 10117 Berlin

June 16 | Monday

8:30 - 8:50 **Registration**
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10:15 – 10:30 **Navia Kleemann**
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Near field and spectral study of four-wave mixing in multimode VCSELs

11:25 – 11:50 **Deb Kane**
Coherence Collapse – How collapsed?

11:50 – 12:15 **Cristina Masoller**
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Impact of slow thermal effects on dynamics of vertically emitting Kerr microcavities

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14:00 – 14:25 **Sergei K. Turitsyn**
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Resonance and delay effects in delay-based photonic reservoir computing

14:50 – 15:15 **Kathy Lüdge**
Photonic Reservoir Computing with Quantum Dot Lasers: Impact of Charge-Carrier Dynamics

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Hyper-parametric and $\chi(2)$ solitons in microresonators

16:10 – 16:35 **Tobias Herr**
Frequency combs from nanostructured microresonators

16:35 – 17:00 **Darko Zibar**
Subspace tracking: a novel measurement method to test the standard phase noise model of optical frequency combs

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WIAS main building (4th floor)
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9:50 – 10:15 **Yi Yu**
Simulating Nanolasers with Extreme Dielectric Confinement

10:15 – 10:30 **Monty Drechsler**
Quantum fluctuation in mode-locked single-section semiconductor quantum dot lasers

10:30 - 11:00 **Coffee Break**

11:00 – 11:25 **Frank Jahnke**
Optical Gain in Lasers Based on Two-Dimensional TMDC Semiconductors

11:25 – 11:40 **Dmitri Boiko**
Self-confident light-current-voltage analytical model for QW saturable electroabsorber in a ridge waveguide laser structure

11:40 – 12:05 **Gadi Eisenstein**
Coherent interactions and quantum properties of short pulses propagating in a quantum dot gain medium

12:05 – 12:30 **Nikolay Rosanov**
Recent advances in low-cycle electromagnetic pulses

12:30 - 12:40 **Group Photo**
12:40 - 14:00 **Lunch Break**

14:00 – 14:25 **Kestutis Staliunas**
Light Trapping by Non-Hermitian Thin Films

14:25 – 14:50 **Angela Thränhardt**
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14:50 – 15:05 **Thorsten Ackemann**
Laser patterns and supersolids of light

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Dynamic optical injection of mode-locked quantum-dot lasers for high-speed optical sampling

15:55 – 16:20 **Peng Huanfa**
Chip-Scale Kerr Frequency Combs for Ultra-Broadband Optical Arbitrary Waveform Generation

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Long-wavelength microresonator-based frequency combs

16:45 – 17:00 **Dmitri Boiko**
200pJ pulse energy monolithic mode locking in GaInAs/GaInAsP vs GaInAsP/GaInP QW systems

from 18:00 **Workshop Dinner**
Restaurant Maximillians
Friedrichstraße 185-190, 10117 Berlin

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Spatio-temporal dissipative solitons in optical cavities

9:50 – 10:15 **Daria Dolinina**
Synchronization between Kerr cavity solitons and broad laser pulse injection

10:15 – 10:30 **Margarida Facao**
Role of packaging induced stress on filamentation characteristics of broad area semiconductor lasers

10:30 - 11:00 **Coffee Break**

11:00 – 11:25 **Guillaume Huyet**
Property of frequency combs under noisy optical injection

11:25 – 11:50 **Otti D'Huys**
Excitability and stochastic effects in a spiking laser network

11:50 – 12:05 **Berta Martínez-Pàmias**
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Design of wavelength stabilized Bragg reflection waveguide laser for parametric fluorescence

Poster 2 **Maria Ana Cataluna**
Understanding mode-locked quantum-dot lasers using the dispersion-scan technique

Poster 3 **Ko Dogyun**
Estimation of the second-order coherence function using quantum reservoir and ensemble methods

Poster 4 **Ruiling Weng**
Time Crystal Coarsening in Active Mode-Locked Lasers

Poster 5 **Lilli Kuen**
Numerical study of time dependent dynamical simulations of PCSELs

Poster 6 **Lutz Mertenskötter**
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1 Abstracts

Laser patterns and supersolids of light

Ackemann, Thorsten

University of Strathclyde, Scotland, UK

Bose-Einstein condensates are macroscopic quantum states of atoms showing superfluid properties, i.e. allowing atoms to flow without friction. In contrast, crystals consist of a periodic arrangement of atoms that do no move within the structure. Supersolids intriguingly combine these properties, as they possess both periodic order and superfluidity. Supersolid behaviour was initially proposed in the context of low-temperature phases of helium and they are also expected to exist in the crust of neutron stars. However, evidence for supersolidity remained elusive in condensed-matter physics in spite of significant research effort and direct experimental evidence of supersolid structures was only recently obtained in experiments using ultracold atoms using in dipolar gases [1] and cavity QED systems [2]. A second fairly recent development in quantum simulation is the approach of ‘ quantum fluids of light"', i.e. the realization that the similarity between the Nonlinear Schroedinger Equation in nonlinear optics and the Gross-Pitaevskii Equation ultra-cold matter physics is not only a mathematical analogue but that concepts like the Landau criterion for superfluidity can be applied fruitfully to light fluids [3]. Broad-area lasers are a nonlinear optical system exhibiting spontaneous formation of structured states [4]. In the spirit of “quantum fluids of light"', I propose to revisit laser patterns as supersolids of light as

- They break spontaneously the U(1) phase symmetry as an atomic BEC does.
- They break spontaneously the translational symmetry of space as a crystal does.
- They show self-focusing nonlinearities providing the interactions necessary for superfluidity (carrier mediated saturable Kerr-nonlinearity).

I will review the experimental results on structures in broad-area vertical-cavity surface-emitting lasers [5] pointing out the similarities and differences to the interpretation as light supersolids. In particular, as the laser cavity has dissipation, a light supersolid is not an equilibrium phenomenon, but a flow equilibrium similar to polariton condensates or photon condensates in semiconductor microcavities. I will discuss the connection to the very active subject of photon thermalization and photon condensation in semiconductor lasers [6]. An experiment to measure the thermal background of the laser supersolid is currently assembled.

References

[1] F. Boettcher, et al., Phys. Rev. X 9, 011051 (2019); L. Chomas, et al., Phys. Rev. X 9, 021012 (2019)
[2] J. Leonard, et al., Nature 543, 87 (2017)
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[4] K. Staliunas, Phys. Rev. A 48, 1573 (1993); J. Lega et al., Phys. Rev. Lett. 73, 2978 (1994)
[5] M. Schulz-Ruhtenberg et al., Appl. Phys. B 81, 945 (2005); I. Babushkin et al. Phys. Rev. Lett. 100, 213901 (2008)
[6] S. Barland et al., Opt. Exp. 29, 8368 (2021); R.C. Schofield et al., Nature Phot. 18, 1083 (2024); M. Pieczarka et al. Nature Phot. 18, 1090 (2024)

200pJ pulse energy monolithic mode locking in GaInAs/GaInAsP vs GaInAsP/GaInP QW systems

Boiko, Dmitri
CSEM SA, Switzerland

Coauthors: Severin Oeschger, Patrick Flückiger, (CSEM SA), Sylvain Boust, Maxime Meghnagi, Tom Vimont, Guillaume Daccord, François Duport, Eva Izquierdo, Jean-Pierre Legoec, Antoine Elias, Michel Garcia, Olivier Parillaud, Michel Krakowski (III-V Lab)

Mode locked (ML) high pulse energy (~200pJ) tapered lasers emitting 3-6 GHz pulse trains in of a few ps width hold a promise to find numerous applications such as two-photon absorption excitation of fluorescence for time resolve measurements, two-photon polymerization or driving THz photoconductive antennas. Monolithic lasers with that high pulse energy were pioneered by CSEM and III-V Lab [1] and later were also demonstrated by FBH [2] utilizing different QW compositions, with cavities of 6 to 13 mm long. In this communication, we compare analytical solutions of Haus-New master equation for tapered ML lasers realized in very different material systems of GaInAs/GaInAsP and GaInAsP/GaInP QWs and, respectively, emitting at 980 or 905 nm wavelength (projects MLSCL and HiLight). The difference originates from the gain, cavity dispersion and length. Interestingly, while 13 mm long GaInAs/GaInAsP lasers follow a classical picture of ML when low frequency envelope can be avoided and a stable ML can be reached with the pump current, the 6 mm long GaInAsP/GaInP lasers are capable of high pulse energy ML in a narrow range of parameters. Moreover, they reveal very unexpected behavior in function of the gain bandwidth, gain compression, cavity losses and absorber bias. At the same time, for both designs, the output pulse energy scales in the same direction in function of the number of QWs, phase-amplitude coupling (Henry's factor), taper angle, large optical cavity and ridge waveguide widths. These findings will simplify future designs of such lasers.

References

[1] M. Krakowski, P. Resneau, M. Garcia, E. Vinet, Y. Robert, O. Parillaud, B. Gerard, S. Kundermann, N. Torcheboeuf, D. L. Boiko, IEEE J. Sel. Topics Quantum Electron., 25, 1100615 (2019).
[2] S. Wohlfeil, H. Christopher, J. Fricke, H. Wenzel, A. Knigge, and G. Tränkle, Electron. Lett., 59, e12736 (2023).

Self-confident light-current-voltage analytical model for QW saturable electroabsorber in a ridge waveguide laser structure

Boiko, Dmitri
CSEM SA, Switzerland

Coauthors: Severin Oeschger, Patrick Flückiger, (CSEM SA), Sylvain Boust, Maxime Meghnagi, Tom Vimont, Guillaume Daccord, François Duport, Eva Izquierdo, Jean-Pierre Legoec, Antoine Elias, Michel Garcia, Olivier Parillaud, Michel Krakowski (III-V Lab)

Monolithic mode-locked lasers with 200pJ pulse energy were pioneered by CSEM and III-V Lab [1] and later were also demonstrated by FBH [2]. The design of such lasers greatly simplifies if there is an adequate analytical description for the saturable electro-absorber. In this communication, we report on such a simple and self-consistent light-current-voltage model. Previously, self-consistent model was proposed by Ryvkin et al [3] for SESAM. However, as opposed to the Quantum Confined Stark effect (QCSE), it is based on Franz-Keldysh effect in a bulk semiconductor and represents SESAM′s p-i-n heterostructure as a capacitor in an open external circuit. It does not account for the absorber bleaching and the carrier transport. Here, we report a complete analytical LIV model that accounts for the QCSE, SRH and radiative recombination in the QWs, carrier capture and escape to the barriers, carrier drift and diffusion in the i region, built-in barrier due to depletion. The model was verified in experimental Hakki-Paoli gain measurements, absorber recovery time measurements utilizing time-correlated single photon counting as well as the IV curve measured at the absorber terminals in a two section ridge waveguide GaInAsP/GaInP lasers. Good agreement was reached. In particular, the exitonic absorption seen in the gain spectrum at -3V bias and indicating flat band operating conditions of QW well agrees with extracted corrections due to QCSE energy shift of the absorption edge with the bias.

References

[1] M. Krakowski, P. Resneau, M. Garcia, E. Vinet, Y. Robert, O. Parillaud, B. Gerard, S. Kundermann, N. Torcheboeuf, D. L. Boiko, IEEE J. Sel. Topics Quantum Electron., 25, 1100615 (2019).
[2] S. Wohlfeil, H. Christopher, J. Fricke, H. Wenzel, A. Knigge, and G. Tränkle, Electron. Lett., 59, e12736 (2023).
[3] B. S. Ryvkin, K. Panajotov, and E. A. Avrutin, J. Appl. Phys. 103, 103102 (2008)

Long-wavelength microresonator-based frequency combs

Bournet, Quentin
Max-Born-Institut, Germany

Coauthors: Stephan Amann, Nathalie Picqué (Max-Born-Institut for Nonlinear Optics and Short Pulse Spectroscopy)

Soliton microcombs at long wavelengths (> 2000 nm) open up new possibilities in optical sensing and spectroscopy due to the unique ability to generate low-noise combs with large line spacing (>100 GHz). Although a crystalline microresonator-based comb at 2500 nm was first reported over a decade ago [1], soliton microcombs pioneered using the low-loss silicon platform [2,3] have remained scarce. Today, the low-loss thin-film 4H silicon-carbide-on-insulator platform [6] is creating enhanced opportunities for long-wavelength soliton microcomb generation with broad spectra and low oscillation thresholds. This talk will provide an overview of the technology of long-wavelength frequency combs based on microresonators, focusing on recent advances using the silicon-carbide platform. Emerging applications, such as hyperspectral imaging in the condensed phase, will be discussed.

References

[1] C. Y. Wang, et al., Nat Commun 4, 1345 (2013).
[2] M. Yu, et al. Optica 3, 854-860 (2016).
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German federal government (BMBF)

Dynamic optical injection of mode-locked quantum-dot lasers for high-speed optical sampling

Cataluna, Maria Ana
Heriot-Watt University, United Kingdom

We show how dynamic dual-tone optical injection can be used for rapid and wide tunability of the pulse repetition rate of a mode-locked quantum–dot laser. This new approach enabled a broad, continuous and flexible control of the pulse repetition rate — with tuning ranges up to 480 MHz for a 20 GHz laser, representing a maximum fractional tunability of 2.4%. We present our results on high-speed optical sampling by cavity tuning using this dynamic dual-tone optical injection method to modulate the laser (OI-OSCAT), with the potential for intriguing features such as a dynamic instantaneous scan rate. Finally, we will also show how dynamic subharmonic injection locking can also be used to reduce the bandwidth of the required RF modulation, thus reducing costs and increasing the applicability of the above techniques.

Understanding mode-locked quantum-dot lasers using the dispersion-scan technique

Cataluna, Maria Ana
Heriot-Watt University, United Kingdom

Monolithic mode-locked lasers are promising as compact, wall-plug-efficient sources of ultrashort pulses. In order to gain further understanding about these sources and deliver this promise, it is essential to fully characterize these pulses, in both phase and amplitude. However, this is a challenging task, as these pulses have picoJoule-level energies or less, picosecond durations and are typically chirped. We have succeeded in this endeavour thanks to a highly-sensitive setup based on the dispersion-scan (or d-scan) technique, enabling new insights into the pulse dynamics of passively-mode-locked quantum-dot lasers. With the help of self-calibrating d-scan algorithm, we were also able to pinpoint the emergence of pulse train instabilities in the mode-locking regime of these lasers, as well as quantify these instabilities, enabling further understanding on the pulse generation and its stability limits. The technique used here can be more generally applied to other low-power, picosecond and sub-picosecond lasers and should be of interest for application to a wide range of on-chip, integrated sources of ultrashort pulses.

Turbulence-like phenomena in liquid crystal light valves

Clerc, Marcel
Universidad de Chile

Turbulence is a complex spatiotemporal behavior and a fundamental concept in fluid dynamics, which has been extended to other systems out of equilibrium, such as nonlinear optics, chemistry, active matter, and economics. This phenomenon is referred to as turbulence-like and is distinguished by its sensitivity to initial conditions and the statistical coupling of modes of different scales that exhibit power laws. We investigate the self-organization of unidimensional and two-dimensional aperiodic patterns. Based on a liquid crystal light valve with optical feedback, we observed aperiodic patterns with power laws in the temporal and spatial spectrum density of the light intensity, and their pseudo envelope and phase characteristic of spatiotemporal complexity. Theoretically, a local model describes the system close to nascent bistability and spatial instability. Numerical simulations of this model show chaotic spatiotemporal patterns whose temporal and spatial spectra have exponents similar to those observed experimentally. We characterize the observed chaotic dynamics by estimating the largest Lyapunov exponent. In this talk, we will describe the results above.

Excitability and stochastic effects in a spiking laser network

D'Huys, Otti
Maastricht University, Netherlands

Neuromorphic photonics - the photonic implementation of excitable nodes - can lead to applications in data processing and photonic computing platforms. On the other hand, photonics has long served as a hardware platform for the exploration of complex dynamics. We present experimental, numerical and analytical results of a network of up to 500 semiconductor lasers with non-linear optoelectronic feedback. The network configuration can be tuned from one to all to globally coupled. A key feature of this system is that the coupling takes place through the slowly evolving electronic signal - our experimental setup can be seen as a network with adaptive coupling.

The system is modelled by a set of stochastic differential equations with three different time scales: the fast (optical) time scales describe the semiconductor laser dynamics and the slow time scale describes the electronic signal in the feedback loop. We consider independent noise terms in the laser intensities, based on spontaneous emission noise. We also include electronic noise in the coupling variable, that is common for the whole network.

We study experimentally and numerically the excitable character of the network, by recording the response to an external perturbation. We show that increasing the network size has a stabilizing effect on the excitability, making the response more consistent, when only considering noise in each node. However, such effect is not reproduced in the experiment. We find that the inclusion of electronic noise in the coupling counteracts this effect, and reproduces the experimental data. We explain the interplay of the network dynamics, noise in the nodes and noise in the adaptive coupling in framework of slow-fast dynamics, and the existence of a separatrix in phase space.

Estimation of the second-order coherence function using quantum reservoir and ensemble methods

Dogyun, Ko
Institute of Physics, Polish Academy of Sciences, Poland

We propose a machine learning approach to estimate g2(0), which may offer a practical solution to simplify g2 measurements. This approach is based on the decision-tree ensemble methods enhanced by quantum reservoir computing. We validate the effectiveness of this hybrid quantum–classical method across various physical optical systems. We also extend the analysis to the relevance of the out-of-distribution generalization to analyze the generalization ability of a training model to estimate g2(0) across distinct systems and/or of the same system with different parameters.

Synchronization between Kerr cavity solitons and broad laser pulse injection

Dolinina, Daria
Ferdinand-Braun-Institut (FBH), Germany

We explore the bifurcation mechanisms responsible for the loss of synchronization between the soliton repetition rate and the frequency of externally injected pulses in a Kerr optical cavity. To investigate the case where the pulse repetition period is close to the cavity round-trip time the Lugiato–Lefever equation is used. Our findings indicate that desynchronization typically arises via an Andronov–Hopf bifurcation. Moreover, we propose a simple and intuitive condition that predicts the onset of this instability. We also extend the analysis to the more general case where the pulse repetition period is close to a rational fraction M/N of the cavity round-trip time, using a neutral delay differential equation to capture the cavity dynamics. It is shown that soliton solutions can exist under such conditions, provided that the amplitude of the injected pulses is sufficiently high—specifically, it must scale proportionally with the factor M. The loss of synchronization can again occur through an Andronov–Hopf bifurcation. This bifurcation takes place when the local injection amplitude at the soliton position drops below a threshold value, which scales as M times the critical amplitude associated with the saddle-node bifurcation in a uniformly injected system. The synchronization range is likewise found to grow proportionally with M.

Quantum fluctuation in mode-locked single-section semiconductor quantum dot lasers

Drechsler, Monty
Universität Bremen, Germany

Mode-locked quantum dot lasers facilitate the generation of ultrashort, high-intensity light pulses. Established theories for mode locking are based on a classical description of the light field. Focusing on the inclusion of spontaneous emission effects, we have developed a quantum-optical theory of mode locking in quantum-dot lasers. Starting from a many-body Hamiltonian, equations of motion for relevant expectation values and correlation functions are derived using the cluster expansion technique. We discuss characteristics of the laser, highlighting the differences between the semiclassical and quantum optical treatment of the light field. The locking mechanism through population pulsations is explained in detail. It turns out that the electronic relaxation dynamics play a crucial role for pulse generation and quantum fluctuations limit the quality of mode locking. A key result is the fundamental lower bound on the beat-note spectrum width imposed by spontaneous emission, for which we provide an analytical expression.

Coherent interactions and quantum properties of short pulses propagating in a quantum dot gain medium

Eisenstein, Gadi
Technion, Israel

Optical pulses with durations shorter than the coherence time in quantum dot gain media induce coherent interactions. For a single excitation pulse, effects such as Rabi oscillations and coherent revival have been demonstrated while two pulses enable observation of Ramsey fringes and photon echoes. These have been observed often using X-FROG characterization accompanied by a semi-classical numerical model. What is missing is those previous experiments are the quantum properties of the pulses emerging from the quantum dot gain medium. Addressing the quantum properties requires adding a homodyne measurement set up in which the pulses to be analyzed serve as the signal and a replica of the excitation pulse serves as the local oscillator. However, the pulses interacting with the gain medium, not only inducer coherent interactions but also broaden from 100 fs to roughly 1 ps. This means that the homodyne measurements depend on the temporal overlap between the two pulses feeding the two detectors of the homodyne system. It turns out that the balance detection system can also serve for cross correlation what enables to replicate the X-FROG pattern under Rabi oscillations, and this enables to choose an optimum sampling point for homodyne characterization. Homodyne charact erization together with the inverse Radon transform yield Wigner functions that depend on this sampling position and more important on the excitation pulse energy. The measurements yield sequences of Wigner functions that exhibit simple coherent states, quadrature squeezed states and for very high input pulse energies, non-Gaussian squeezed states. The most intriguing property is the fact that the various Wigner function types are cyclical with input pulse energy so that they repeat for increases in energy by a factor of four which amounts to 2π changes in the pulse area. Hence we observe quantum squeezing that is governed by Rabi oscillations.

Role of packaging induced stress on filamentation characteristics of broad area semiconductor lasers

Facao, Margarida
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Clamping packaging of broad-area semiconductors laser bars offers the advantage of preventing the vertical displacement of the individual emitters within the laser array, typically leading to the so called near field curvature or smile effect [1]. However, this packaging technique can negatively impact other aspects of the beam quality, particularly by enhancing filamentation effects. In particular, the filamentation observed in stress-packaged lasers exhibits a strong dependence on the laser pump current. In this work, we compare several models [2,3,4] based on their ability to accurately represent the filamentation behavior experimentally observed in the broad-area lasers packaged by the company Monocrom. These models describe the governing equations of the optical field and carrier density with different levels of approximations. The filamentation characteristics are analyzed through various numerical outputs, namely, modulational instability results, optical nonlinear mode composition, and time-averaged optical intensity profiles obtained by full integration of the evolution equations.

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[2] J. Marciante and G. Agrawal, Spatio-temporal characteristics of filamentation in broad-area semiconductor lasers, IEEE Journal of Quantum Electronics 33, 1174 (1997).
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Coherent pulse interactions in mode-locked semiconductor lasers

Gurevich, Svetlana
Institute for Theoretical Physics, Germany

We study the dynamics of multipulse solutions in a passive mode-locked laser. First, we demonstrate that the many pulses emitted by a harmonic mode-locked laser are not necessarily coherent with each other. Further, we discuss how minute optical feedback stemming from parasitic elements such as intracavity lenses or from an external mirror can impact on the coherence of the emission of passive mode-locked laser operated in the long cavity limit. We base our analysis upon the well established Haus master equation. We demonstrate that the dynamics of such a high dimensional problem can be successfully described by some effective equations of motion for the pulses' phases and positions. Analyzing the reduced vector field permits disclosing a highly complex dynamics where coherent and incoherent interactions compete.

Frequency combs from nanostructured microresonators

Herr, Tobias
DESY and Universität Hamburg, Germany

Microresonator frequency combs are compact sources of high-repetition-rate optical waveforms and have established themselves as a transformative photonic technology [1]. They can be implemented by coupling semiconductor lasers to high-quality factor nonlinear microresonators and arise through nonlinear optical self-organization. Recent advances in subwavelength nanostructuring of microresonators make it possible to modify the resonant modes on a resonance-by-resonance basis. These modifications affect the energy flow within nonlinear microresonators and enable novel systems with reduced operational complexity, improved stability, and potential for new functionality [2,3].

References

[1] T.J. Kippenberg, A.L. Gaeta. M. Lipson, M.L. Gorodetsky, Dissipative Kerr solitons in optical microresonators, Science 361, 6402 (2018).
[2] A. Ulanov et al., Synthetic reflection self-injection-locked microcombs, Nature Photonics 18, 294-299 (2024).
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Property of frequency combs under noisy optical injection

Huyet, Guillaume
Université Côte d’Azur, France

We study the properties of optical frequency combs under the injection from a noisy source. We show that noise destabilise the combs that can be restored from optical feedback.

Optical gain in lasers based on two-dimensional TMDC semiconductors

Jahnke, Frank
Universität Bremen, Germany

Monolayers of transition metal dichalcogenides (TMDs) are structures similar to graphene with an optical bandgap in the visible spectral region and promising optical properties for applications in optoelectronic devices. Despite growing interest, lasers incorporating TMD monolayers as the gain medium are still scarce in the literature. The underlying mechanisms of lasing-including recombination of free carriers (plasma lasing), emission from defect states, and gain from bound excitonic complexes such as excitons and trions-remain incompletely understood. We compare the material gain of the monolayer TMDs MoS_2, $MoSe_2$, WS_2, and WSe_2 on a SiO_2 substrate to that of standard quantum well laser structures, considering a range of excited carrier densities. Our theoretical investigations are based on ab-initio electronic state calculations (DFT ground-state GW) in combination with a many-body theory for excited carriers on a self-consistent GW level for carrier-carrier and carrier-phonon interaction. The central result of our study is that the material gain in TMDs can be two orders of magnitude higher than in the quantum-well system. This enhancement, however, is accompanied by the need for higher excitation densities and a significant gain rollover for elevated excitation densities due to many-body effects. We also examine how the high material gain manifests as modal gain in typical nanolaser structures, thereby exploring the suitability of monolayer TMDs as active media for semiconductor lasers.

Resonance and delay effects in delay-based photonic reservoir computing

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Semiconductor lasers subject to time-delayed self-feedback are rich dynamical systems which can be utilized for computing purposes. These systems are particularly well suited for time-multiplexed reservoir computing applied to solving temporal tasks such as chaotic timeseries forecasting. To optimize the performance of such systems a thorough understanding of the dynamics of the laser is needed, as well as the interplay between timescales of the laser, the feedback, the time-multiplexing of the input data and the dynamics of the target system. In this talk we will discuss the influence of the feedback delay time with regard to these points. We will discuss how the feedback delay-time influences the topology of the virtual network interpretation of the reservoir and the role it plays in delay-embedding the input data.

Time crystals in active mode-locked lasers

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We demonstrate experimentally the existence of time-crystal states in the dynamics of an actively mode-locked semiconductor laser. Our findings are well reproduced by a recently developed time-delayed model adapted to large gain and losses.

Coherence collapse - How collapsed?

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The rapid transition from continuous wave to chaotically varying output power observed, at a threshold level of optical feedback (OF), in a semiconductor laser with delayed OF (SLDOF) system, deserved the dramatic term “coherence collapse” that Daan Lenstra assigned it in 1985 [1]. In the intervening decades several research groups have measured the first order temporal coherence time (or length), among a raft of other quantifiers, to characterise the output of the SLDOF system. This measure has been applied also to other nonlinear dynamical laser systems. A very short coherence time/length is expected to correspond to the chaotic output of the coherence collapsed regime. The light is expected to be incoherent. However, most of these studies have not taken appropriate account of the functional variation in temporal coherence. After a reminder of the relevant physical optics, the systematics of temporal coherence in the coherence collapsed regime of an experimental SLDOF system [2] will be presented. Some of the results will surprise.

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Competitive dynamics of self mode-locking and passive mode-locking in quantum dot and quantum well lasers

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We investigate pulse generation mechanisms in an InAs/InP quantum dot (QD) laser and an InGaAsP/InP quantum well (QW) laser, both in monolithic configurations and with a QW laser in an external cavity setup. All lasers are two section devices. They are either driven in a passive mode-locking (PML) setup, where the long section is pumped with gain current and a reverse absorber voltage is applied to the short section, or in a configuration where both sections are pumped with gain current to exclude PML processes, allowing only self mode-locking (SML) processes. Our results show that the QD laser remains unaffected by the applied absorber voltage, consistently generating pulses solely through self mode-locking (SML) processes. Conversely, the QW laser has a transitional zone where neither PML nor SML predominates, and no mode-locking can be detected. We assume that in this zone, PML and SML processes are in competition, with neither process able to dominate. This competition continues until the gain current surpasses a certain value, at which point SML becomes dominant. In further experiments, we set up the QW laser in an external cavity configuration. The laser facets were modified, with the outcoupling facet provided with an anti-reflection coating. We believe that the high pulse repetition rate of 50 GHz in the monolithic setup may have exceeded the recovery time of the absorber. The external cavity setup extends the resonator length and, thus reduces the pulse repetition rate to 1 GHz. This allows the absorber section significantly more time for the recovery process and indeed enabled pulse generation by PML.

Impact of slow thermal effects on dynamics of vertically emitting Kerr microcavities

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We study the dynamics of a vertically emitting micro-cavity containing a Kerr nonlinearity that is subjected to detuned optical injection. To this end, we present an extended model that allows investigation of the influence of cavity heating, which shifts the microcavity resonance and thus the detuning on a slow time scale. As a consequence of this scale separation, we uncover a canard scenario featuring mixed-mode oscillations and chaotic spiking. When the microcavity is coupled to a long external feedback loop, subjecting it to strong time-delayed optical feedback, we can examine the additional influence of the time delay on excitability dynamics, as well as the impact of thermal effects temporal localized states that evolve on the delay timescale.

Numerical study of time dependent dynamical simulations of PCSELs

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Photonic crystal surface-emitting lasers (PCSELs) [1] utilize a two-dimensional photonic crystal to achieve surface emission and light amplification. We investigate dynamical simulations of PCSELs, focusing on the fundamental mode. These simulations are performed using the time-dependent three-dimensional coupled-wave theory [2,3]. We analyze numerically the shape of the fundamental mode with respect to numerical parameters and the current distribution used within the simulations.

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Scaling effects in semiconductor lasers: The impact of cavity size on dynamics and detectability

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The history of laser dynamics now goes back more than four decades, and semiconductor lasers have played a major role in the development of its fundamental aspects as well as in the exploration of its potential applications. However, one aspect that has remained in the background is the role played by the size of the devices. In this talk, I will discuss the influence of the resonator volume on the dynamics, the modifications that can result from scaling the cavity size, and the physical origin of the size sensitivity of the dynamics. I will also mention experimental issues related to the progressive reduction in photon number associated with the cavity volume and the resulting difficulties in detecting and characterising the dynamics. Finally, issues related to the intrinsic stochasticity of smaller devices and its potential influence on both the dynamics and its detectability will be examined.

Photonic reservoir computing with quantum dot lasers: Impact of charge-carrier dynamics

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Reservoir computing (RC) with active optical devices offers an energy-efficient approach for analog computing. One promising application is time-series forecasting for which memory as well as nonlinearity is important. Semiconductor lasers with optical self-feedback show complex emission dynamics as well as a high dimensional charge-carrier dynamics that is coupled to the light within the cavity. Both effects are beneficial for the performance of photonic RC systems. By tuning the scattering timescales between the charge-carriers and the delay time of the feedback, the dynamic response of the laser can be finely adjusted. We present a systematic investigation of how the system response time and the specific task requirements determine the optimal operation conditions for time series prediction. We find that first, a concise understanding of the nonlinear dynamic response and the bifurcation structure of the chosen dynamical system is necessary in order to use its full potential for RC and to prevent operation with unsuitable parameters. Second, the data input scheme crucially changes the performance as it changes the direction of the perturbation and therewith the nonlinearity. Third, lasers with pronounced relaxation oscillations outperform those with strongly damped dynamics, even if the underlying charge carrier dynamics is more complex. Thus, optimal reservoir computing performance relies not only on a high internal phase space dimension, but also on the effective utilization of these dynamics through the output sampling process.

Dynamics of phase synchronization in a coupled laser system for quantum random number generation

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We present an experimental and numerical investigation of the dynamics of two coupled lasers system in an Indium Phosphide photonic integrated circuit (PIC). The PIC, developed by the quantum technology company Quside Technologies, is designed to be a quantum random number generator (QRNG) based on the phase diffusion effect extracting randomness from spontaneously emitted photons. The device integrates two distributed feedback lasers, that are simultaneously and periodically modulated above and below threshold to obtain a random phase at each pulse. The light interferes in a multimode interferometer (MMI) which combines the lasers' outputs and directs the light into two photodetectors, generating one random number per optical pulse and reaching gigabit per second rates.

This work focuses on the transient dynamics towards synchronization of the two weakly mutually coupled lasers within the PIC. Coupling arises from residual back-reflections in the MMI, causing mutual injection of light between lasers and, under suitable conditions, leading to optical phases synchronization phenomena that can compromise the randomness quality. We employ a rate equation model to numerically simulate the coupled lasers dynamics, carefully tuning the model parameters to match the experimental observations. The model includes spontaneous emission noise and considers instantaneous coupling, as the coupling delay time is considerably smaller than the system's characteristic times (turn-on jitter and relaxation oscillations period). By comparing experimental and simulated interference pulses, we have observed that the model successfully reproduces qualitative key features of the experimental measurements, confirming the validity of the numerical simulation.

Our results provide insight into the transient temporal evolution towards synchronization of the two lasers and display the interference signal probability distribution distortion caused by the coupling. The transformation of the probability distribution exhibits the alteration of the system's randomness and therefore, the work enables a better understanding and optimization of the photonic QRNG device operation.

Experimental study of the coherence of the light emitted by a semiconductor laser with optical feedback and current modulation

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It is well known that semiconductor lasers are highly sensitive to external optical feedback. In this talk, I will present experimental studies on the effect of feedback on the coherence of laser light, using the speckle technique. Speckle is a noisy spatial structure generated by the interference of coherent waves as they propagate through a diffusive medium. The speckle contrast is a measure of the degree of coherence of light. Using a multimode fiber as the diffusive medium, we found that, during laser turn-on, with sufficiently strong feedback, the speckle contrast increases abruptly (revealing an abrupt increase in light coherence), while without feedback it increases gradually [1]. A comparison of the speckle contrast in speckle images generated with a multimode fiber or with a single-mode fiber and an optical diffuser has allowed us to differentiate the effects of feedback on the spatial and temporal coherence of laser light. Under sufficiently strong optical feedback, when the laser current is increased from a value below the threshold to a value much higher than the threshold, low and high speckle contrast regions alternate: the low contrast ones are associated with multimode emission, and the high contrast ones with single-mode emission [2]. We also studied whether, by combining the effects of current modulation and optical feedback, we could further reduce the speckle contrast. We found that while modulation does not decrease the minimum contrast, with appropriate modulation parameters it can completely suppress the high contrast regions. Our findings may be relevant for applications using diode lasers for illumination [4], since optical feedback and current modulation can reduce the speckle contrast by approximately 40 over a wide range of pump currents.

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Self-injected quantum-dash mode locked lasers for frequency comb generation

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Optical frequency combs have emerged as a promising approach towards compact and efficient light sources that provide a multitude of tones for parallel WDM transmission, spectroscopy, LiDAR or microwave photonics. In this talk, we will first introduce the concept of optical frequency combs and their wide range of applications. For the generation of optical frequency combs, monolithic semiconductor passively mode-locked lasers are very attractive components, offering distinct and unique features in terms of compact chip design, low power consumption with efficient power conversion capabilities, wide optical bandwidth with a flat optical spectrum, low phase noise, and ultra-short pulse generation down to a few hundred femtoseconds. We will focus our talk on semiconductor mode-locked lasers, in particular quantum dash based lasers, and the different stabilization schemes we have developed to improve both coherence and phase correlation between optical comb lines.

Chip-scale Kerr frequency combs for ultra-broadband optical arbitrary Waveform Generation

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Chip-scale Kerr frequency comb generators have emerged as novel light sources that can provide broadband spectra with a multitude of phase-locked, narrow-linewidth optical tones, evenly spaced by free spectral ranges (FSR) of tens or even hundreds of gigahertz. These characteristics make the devices well-suited as high-performance, multi-wavelength light sources for miniaturized optical systems, offering the potential to disrupt a wide range of highly relevant applications in science and industry. In this talk, we will present our recent progress on the RF-synchronized Kerr soliton comb sources and the associated applications in ultra-broadband signal processing. We will cover numerical dynamic models, hybrid integration technologies, as well as system demonstrations of ultra-broadband optical arbitrary waveform generation exploiting RF-synchronized Kerr soliton comb sources.

Single-quantum-dot devices for photonic quantum technologies: Design, deterministic nanofabrication, and application perspectives

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The integration of solid-state quantum emitters into practical quantum information technologies demands nanofabrication platforms that offer both precision and high process yield. Among the most promising candidates are self-assembled semiconductor quantum dots (QDs), renowned for their excellent emission characteristics. However, the random spatial and spectral distributions of these QDs pose a significant challenge for integration using conventional lithography and rigid fabrication techniques. To overcome this limitation, we present a flexible and deterministic fabrication approach that combines high-precision cathodoluminescence spectroscopy with high-resolution electron beam lithography [1].

In this talk, I describe the fundamentals and application examples of in situ electron beam lithography (iEBL) as an advanced deterministic nanofabrication platform for photonic quantum devices. Details of the iEBL process are discussed, and its high potential for the deterministic fabrication of single-emitter devices for applications in photonic quantum technology is presented. Examples include electrically controlled high-performance single-photon sources (SPS) based on circular Bragg gratings for brightness enhancement [2, 3], and scalable integrated quantum circuits [4, 5].

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Near field and spectral study of four-wave mixing in multimode VCSELs

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We study the dynamics of multimode VCSELs with an elliptical oxide aperture for datacom [1]. We develop a dynamical model, accounting for spatial hole burning and coherent frequency mixing, allowing for a very close comparison with experimental results [2]. In the experiment, we observe high-intensity peaks in the relative intensity noise (RIN), as well as many sidebands in the optical spectrum: spectral features that are detrimental for datacom applications [3]. We analytically show that the occurrence of such RIN peaks and sidebands is the nontrivial result of four-wave mixing between transverse modes. A spectrally resolved near-field measurement [4] of the sidebands observed in the optical spectrum allows to directly associate them with specific lasing modes and confirms this interpretation. As a result, we are able to provide a few design rules of thumbs to avoid the occurrence of unwanted spectral features in VCSELs for high-speed and datacom applications. A study of possible modifications to the presented picture, due to more complex phenomena of polarization switching and hopping, is currently ongoing.

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Recent advances in low-cycle electromagnetic pulses

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Recent advances in obtaining increasingly shorter electromagnetic pulses make it relevant to analyze the properties of extremely short - low- and half-period pulses. In this report, based on the strict equations of Maxwell's electrodynamics, the general properties of the field structure in such pulses are revealed. Already from the expression for the probability of excitation of quantum objects, it is shown that the efficiency of this process for short pulses is determined by their key characteristic - the electric area of the pulse, that is, the integral over time of the electric field strength. The efficiency of generation of electron-positron pairs in the collision of short counter pulses behaves similarly. The possibility of nontrivial features of the polarization structure of short pulses is discussed. A number of methods for generating low-cycle and unipolar (with a non-zero area) pulses, in particular, in quantum wells, as well as methods for controlling their shape are presented. Possible applications of ultrashort pulses in holography of rapidly changing objects and induction of dynamic gratings in media are discussed.

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Time crystal coarsening in active mode-locked lasers

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We report the experimental observation of coarsening dynamics between time-crystalline states in an actively mode-locked (AML) laser. Using a ring cavity setup incorporating a semiconductor amplifier and a Mach-Zehnder modulator, we identify bistable time-crystal configurations emerging at half the modulation frequency. Sharp transitions between these states, interpreted as domain walls, undergo spontaneous coarsening when small perturbations are applied to the modulation. This leads to the annihilation of defects and selection of a single state over time. Our results are consistent with time-delayed theoretical models and reveal front dynamics driven by symmetry breaking in photonic time crystals.

Hyper-parametric and $\chi^{(2)}$ solitons in microresonators

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Dissipative solitons and associated low-noise chip-scale frequency comb sources offer significant promise for science and technology. Spectroscopy, data processing and time-keeping applications create demand to investigate methods of spectral translation of solitons while possibly retaining the C-band pump source. Here, we will present results on how to engineer silicon-nitride and lithium-niobate microresonators to frequency convert the c-band pump across near-infrared towards the visible spectrum. We will introduce a family of hyperparametric solitons in the silicon-nitride platform, which emerge when a far detuned parametric cw-signal becomes bistable, and also discuss a series of results on parametric and other types of $\chi^{(2)}$ solitons.

Light trapping by non-Hermitian thin films

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One of the exceptional features of non-Hermitian systems is the unidirectional wave interactions. Simultaneous modulation of the real and the imaginary part of the interaction potentials (of the refractive index and the gain/loss in the case of optical systems) can result in unequal coupling coefficients between the fields of different parts of the system. The unidirectional coupling can be arranged between internal fields and external radiation as well. At a particular (exceptional) point, the situation can be achieved where the external radiation is coupled into the system, but the internal radiation cannot escape backwards. In this way, the incident radiation can be trapped inside the non-Hermitian system and, eventually, can be efficiently absorbed there. We realize this idea in non-Hermitically modulated thin films. The modulation consists of a Hermitian part - the periodic corrugation of the surfaces of a thin film, and a non-Hermitian part - the modulation of losses along the film. We prove numerically and demonstrate experimentally that the incident radiation, coupled with such a non-Hermitian thin film, is unidirectionally trapped into a planar mode of the film, does not escape from the film (or escapes weakly due to experimental imperfections), and is efficiently absorbed there.

Photonic and phononic structures across scales: from art installations to semiconductor lasers

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This contribution presents a cross-disciplinary overview of photonic and phononic structures explored in recent years, with a particular focus on their relevance to semiconductor laser systems. The range of applications and physical dimensions is broad-spanning from nanoscale structures within laser cavities to large-scale installations on the order of several meters. When rescaled to the respective wavelengths, these systems reveal structural similarities that facilitate theoretical modeling but often challenge experimental implementation. By discussing various wave phenomena in photonic and phononic crystals, this work aims to highlight shared underlying principles and their potential for advancing device design in nonlinear and laser-based systems.

Spatio-temporal dissipative solitons in optical cavities

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The theory of dissipative structures, either in time or in space, has been mainly established in the framework of the nonlinear Schrodinger equation. However, this paradigmatic equation suffers from collapse dynamics and unfortunately no bounded solutions are possible in two or more dimensions. In this contribution we discuss the formation of dissipative solutions in nonlinear cavity optics. Two dissipative systems are considered: the driven Kerr cavity subjected to optical injection and the optical parametric oscillator. These localized states are either isolated, bounded, or clustered, and they form well-defined patterns. They are stationary states in the reference frame and move with the group velocity of light inside the cavity. The number of localized two or three-dimensional peaks and their distribution in the transverse plane are determined by the initial conditions [1,2,3]. As the injected beam intensity increases, the localized peaks lose their stability, and the cavity field exhibits giant pulses of short duration. Statistical characterization of the pulse amplitude reveals a long-tailed distribution indicating the occurrence of extreme events [4].

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Extreme learning machine using semiconductor optical amplifier

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Mapping input signals to a high-dimensional space is a critical concept in various computing paradigms. I will discuss extreme learning machine computing approach using commercially available semiconductor optical amplifier and telecom technologies developed for high-speed optical data transmission.

Design of wavelength stabilized Bragg reflection waveguide laser for parametric fluorescence

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The development of photon pair sources is of vital interest in quantum cryptography. One possibility for the generation of photon pairs is spontaneous parametric down conversion (SPDC), which requires phase matching of the involved waves. The semiconductor material AlGaAs has been shown to be a promising source due to its high nonlinear coefficient χ_2 and the possibility of laser integration. In order to compensate for its high material dispersion, properly designed waveguides have to be developed. One promising device is the Bragg reflection waveguide (BRW), which consists of a core region surrounded by several pairs of reflector layers. It supports a leaky mode, called Bragg mode, at 775 nm and guided modes at 1550 nm. As the effective index of the Bragg mode is smaller than the refractive indices of the core and the reflector layers phase matching with the fundamental modes at twice the wavelength is realized. Additionally, the high optical confinement in the core region allows for laser integration through the introduction of an active region and appropriate doping. However, as the SPDC process is highly frequency-sensitive, minor changes in the lasing frequency can prevent the creation of photon pairs. This can occur through current induced shifts or mode hopping inherent to Fabry-Pérot (FP) lasers. Therefore, we designed a distributed Bragg reflection (DBR) laser to stabilize the lasing wavelength and to select the pump wavelength for the SPDC process. From 1D z eigenmode expansion algorithm we determined that a grating with high modal reflectivity can be realized depending on the etch depth.

A time-delayed renewal model for Kerr frequency combs

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We derive a time-delayed system (TDS) for Kerr optical frequency combs containing an arbitrary dispersion relation in the form of an integral kernel. In the framework of TDSs this is called a renewal equation. Beyond direct numerical simulations, we were able to study a family of solitonic solutions, in presence of Kelly side-bands, through path continuation by using an experimental release of DDE-Biftool. This TDS model appears as an alternative to the well-known Ikeda Map and Lugiato-Lefever equation, allowing to simultanously perform numerical path-continuation while taking into account both the multiple modes of the cavity as well as the presence of Kelly sidebands.

Simulating nanolasers with extreme dielectric confinement

Yu, Yi
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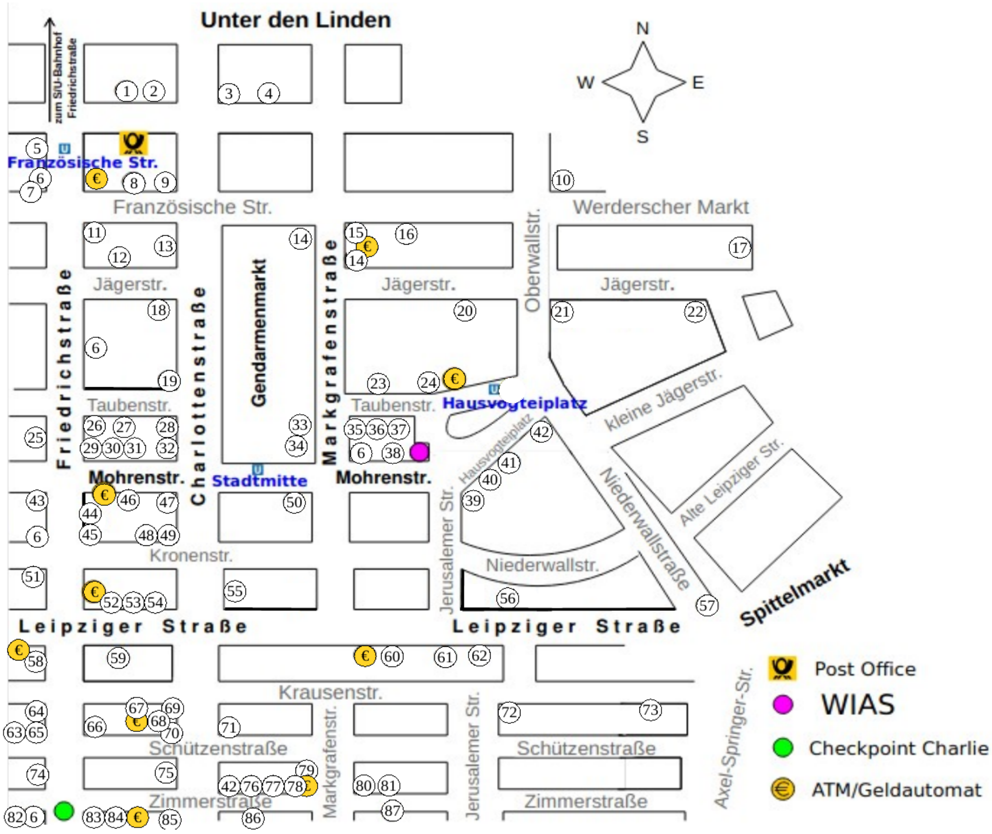
I will present our recent work on nanolasers that exploit extreme dielectric confinement of both photons and electrons, achieving a sub-diffraction-limited mode volume and continuous-wave lasing at room temperature. Due to the strong localization of carriers, spatial effects become important. I will discuss the numerical method that combines FDTD and FEM approaches to capture the spatial information of carriers, optical pumping, and spontaneous emission in simulating the nanolasers.

2 Places to have lunch



1	Subway	30	dean & david	59	Otito Vietnamese Food
2	Sagrantino	31	nanoosh	60	Schnell
3	Gendarmerie Restaurant	32	Maredo	61	Lidl
4	Austernbank	33	Moët & Chandon	62	China-City Restaurant
5	Lindner	34	Dom Curry	63	Velis
6	Einstein Kaffee	35	Shan Rahimkan Café	64	Schäfers
7	Bocca di Bacco	36	La Perle	65	Ristorante Pizza Pasta
8	Borchard	37	THU MY marie	66	The Coffe Shop
9	Charlotte & Fritz	38	Chupenga	67	City Supermarket
10	Coffee 2 go	39	Bless	68	Zwimpf
11	Galéries Lafayette	40	Steinecke	69	Lungomare
12	Bonanza Coffee Roasters	41	Good Time	70	Huong Lua
13	Lin	42	The coffee shop	71	Bistro les amis
14	Erdinger am Gendarmenmarkt	43	Kamps	72	Alto
15	Julian & Elisa	44	auf die Hand	73	Hashtag Coffeshop
16	Beef Grill Club	45	nosh nosh	74	Coffee Fellows
17	Town Bar	46	Seaside	75	Small Garden
18	Augustiner am Gendarmenmarkt	47	Rausch	76	ishin
19	Lutter und Wegner	48	sapa	77	Ma'loa
20	Little Green Rabit	49	cadadia	78	Burger, Huong Sen
21	Lunch Time	50	Hilton	79	Mix & Match, Pagashi Luu
22	Noamì	51	Alnatura	80	Soup Kultur
23	Brasserie	52	Monkey Donuts	81	Rustrôt
24	Braufactum	53	La Donna	82	Mc Donalds
25	soul	54	Rewe	83	KFC
26	Caras	55	Planet Wein	84	juice!
27	Rewe, Penny	56	Fontana di Trevi Ristorante	85	Chili Coffee
28	Newton	57	Farmer's Market	86	Caramel
29	Frittenwerk	58	Gregory's Coffee	87	Springer Building