Frequency combs
Fundamentals & Applications
Second Edition

September 9-10, 2024
Ghent, Belgium

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Access to the dinner

The conference dinner will be held at "SGOL," a typical Belgian restaurant:

Emile Braunplein 40, 9000 Gent, Belgium

However, you don't need to know how to get there; a boat will drop us off!

Monday, September 9th: Program

FREQUENCY COMBS
Fundamentals & Applications

09:30 Welcome - Coffee

Chairman: Bart Kuyken, Ghent University (Belgium)

9:55 **Opening session**
Nicolas Englebert, Bart Kuyken, and François Leo

10:00 **UV frequency comb generation and application**
Birgitta BERNHARDT, Graz University of Technology (Austria)

10:30 **Surprise!**
Nathalie PICQUE, Max-Born Institute (Germany)

11:00 **Frequency microcombs in the normal-dispersion region**
Xiaoxiao XUE, Tsinghua University (China)

11:30 **Temporal dissipative solitons in hybrid resonators: from internal phase modulation to parity-time symmetric designs**
Simon-Pierre GORZA, Université libre de Bruxelles (Belgium)

12:00 **Stability Enhancement via Interaction of Continuous Waves and Laser Cavity-Solitons in Micro-Resonators**
Alessia PASQUAZI, Loughborough University (England)

12:30 Lunch

Chairman: Simon-Pierre Gorza, Université libre de Bruxelles (Belgium)

14:00 **Ultrabroadband Resonant Frequency Doubling in linearly uncoupled microresonators**
Camille-Sophie BRES, EPFL (Switzerland)

14:30 **Ultrafast Quadratic Nonlinear Nanophotonics: From Superior Components to Advanced Circuits**
Alireza MARANDI, California Institute of Technology (United States)

15:00 **Thin Film Lithium Niobate Photonics based Frequency Comb Sources**
Marko LONCAR, Harvard University (U.S.)

15:30 **Titanium:Sapphire-on-insulator for broadband tunable lasers and high-power amplifiers on chip**
Kasper VAN GASSE, Ghent University (Belgium)

16:00 **Soliton Microcombs: From frequency combs to emergent nonlinear dynamics**
Tobias KIPPENBERG, EPFL (Switzerland)

16:30	Coffee Break and group picture
17:00	Poster session and appetizers
19:00	Guided boat trip in the Ghent rivers
20:15	Dinner – SGOL

Poster session

FREQUENCY COMBS

Fundamentals & Applications

The session will take place on **Monday, September 9th at 5 pm**, with some drinks and crisps. The titles and abstracts of the 35 posters are given below. The author's last name alphabetically sorts posters.

Design of Silicon Quantum Squeezer

A silicon squeezer optimizes high-level squeezing through strategic pump parameter selection and cavity engineering. Waveguide dimensions, cladding materials, bend radii, and coupler settings are fine-tuned to enhance four-wave mixing and signal confinement in integrated balanced detection systems.

Mouhamad Al Mahmoud, Ghent University - IMEC, Department of information Technology (INTEC) (Belgium)
mouhamad.almahmoud@ugent.be

Reservoir Computing based on Cavity Solitons

In this poster we aim to discuss the plausibility of integrating two previously unrelated areas of research. Specifically, our goal is to experimentally demonstrate reservoir computing (RC) based on cavity solitons (CSs).

Amir Arsalan Arabieh, Ph.D. Student (Belgium)
amirarsalan.arabieh@ulb.be

A family of periodic solutions of pure-quartic nonlinear Schrödinger equation

We look for periodic solutions of a generalized nonlinear Schrödinger equation (gNLSE) with pure quartic dispersion. We numerically determine, and compare to their NLSE counterpart, their existence range and modulational instability gain.

Andrea Armaroli, Ferrara (Italy)
andrea.armaroli@unife.it

Multipartite entanglement in bright frequency comb out of a Silicon Nitride microring

We investigate, in CV regime, multipartite entanglement between frequency modes out of a SiN micro-resonator working above its oscillation threshold. We theoretically show the transition from a bipartite to a multipartite regime as a function of the pump power. We implemented a setup and we analyzed quantum correlations between 4 modes, showing a transition between different regimes.

Adrien Bensemhoun, Université Côte d'Azur - CNRS (France)
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Stability of Active Temporal Cavity Solitons under High-Power Extraction Regime

Active Cavity Solitons (ACSs) have been developed to address the challenge of extracting high power from Cavity Solitons (CSs) without compromising their stability. This work demonstrates that even for 90% power extraction, the ACS still exists and remains stable.

Haftamu Gebreslassie Berhe, Université Libre de Bruxelles (Belgium)
haftamu.berhe@ulb.be

Inverse-Designed Reflectors and Wavelength-Division-Multiplexers

We fabricate and characterize silicon nitride microresonators formed between pairs of inverse-designed integrated photonic mirrors. Additionally, inverse-designed silicon nitride wavelength-division multiplexers are designed and fabricate with separate channels in the O- and C-band.

Toby Bi, Max Planck Institute for the Science of Light (Germany)
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Chirped Bragg gratings for on-chip pulse compression in the mid-infrared

There are still no ultrashort pulsed sources in the mid-infrared. A chirped pulse and a chirp filter are required to generate ultrashort pulses. Here, we demonstrate the first chirped Bragg grating filters in the mid infrared with a chirp up to -50ps².

Annabelle Bricout, Université Paris Saclay (France)
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Time-Multiplexed Dual Comb Spectroscopy with Electro-Optically Modulated Combs

We demonstrate a novel technique for signal-to-noise ratio (SNR) improvement of dual comb spectroscopy (DCS) through time multiplexing of interferogram. We provide an experimental proof-of-concept of the technique in an all-fiber frequency-agile DCS setup.

Debanuj Chatterjee, University of Lille (France)
debanuj.chatterjee@univ-lille.fr

Fast response based on vector dual pulse nanophotonic supercontinuum generation

We mainly investigate a vector dual-pulse pump to launch the supercontinuum generation and the dynamics of pulse-to-pulse interactions in nanophotonic waveguides by means of the Fourier transform spectroscopy (FTS), by which we can characterize both linear and nonlinear response in a rapid way.

Yongyuan Chu, Shanghai University (China)
Cyyforever@shu.edu.cn

Towards mid-infrared Kerr frequency-comb generation in silicon-germanium resonators

This poster presents preliminary theoretical and experimental investigations concerning the generation of Kerr frequency combs in the long-wave infrared range (~8 μm wavelength) in microresonators processed on the silicon-germanium graded-buffer platform.

Hamza Dely, Université Paris-Saclay (France)
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Cavity-Enhanced Kerr Comb Spectroscopy On-Chip

By coupling a THz rate Kerr microcomb to the microring resonator cavity, we demonstrate a broadband (~250 nm) measurement of the microcavity integrated dispersion, which can be naturally used for spectroscopy. Further, we provide a simple simulation example for water spectroscopy.

Andrei Diakonov, Hebrew University of Jerusalem (Israel)
andrei.diakonov@mail.huji.ac.il

Optical Parametric Solitons in Fiber Cavity for optical computing

Nonlinear fiber optics presents a promising platform for advanced optical computing applications. This poster presents a preliminary numerical and experimental study of parametric cavity solitons in this context.

Clément Dupont, ULB (Belgium)
clement.dupont@ulb.be

Z-cut, ultralow-loss, tightly-confined LN PICs for nonlinear applications

We demonstrated a fully etched LN waveguide platform with loss down to 5.8 dB/m in sub-meter long waveguide. Coherent supercontinuum generation with 1 octave spanning in all normal dispersion waveguides has been demonstrated.

Yan Gao, Chalmers University of Technology (Sweden)
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Temporal cavity solitons in mutually coherent driven active resonators

Cavity solitons (CS) are pulses of light that travel indefinitely in driven optical cavities. Due to their nature of the balance between chromatic dispersion and Kerr nonlinearity, they don't spread. At the same time, they don't dissipate, as losses are compensated by external driving. The recently published works present the new concept of active cavity solitons (ACS). By adding in the setup intracavity amplification, but still operating under lasing threshold, robust nonlinear attractors emerge. In this work we continue investigation of ACS by creating two identical coherent active cavities. Mutually coherent active cavities open up the possibility for novel dual comb systems for spectroscopy and metrology applications. Such a system will also allow us to characterize the timing jitter of cavity solitons.

Sofya Glazyrina, ULB (Belgium)
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Dual Frequency Comb @ AIPT

We present our AIPT dual comb generation techniques using a single mode-locked fiber laser. Dual-comb formation inside the laser cavity has been studied. The applications of ranging distance, strain, and temperature sensing are also demonstrated.

Hani Kbashi, Aston University (United Kingdom)
h.kbashi@aston.ac.uk

Multi-frequency Brillouin lasing: Towards Brillouin driven dual-comb sources

In this poster we demonstrate the operation and quality of an integrated dual-frequency Brillouin laser and propose the implementation in a dual-Brillouin-Kerr microcomb for self-starting, high-coherence between combs and a frequency offset near the pump-line.

Yvan Klaver, University of Twente (Netherlands)
y.klaver@utwente.nl

Monolithically integrated active/passive GaAs laser platform including high-Q ring resonators

Our efforts to realize passive high-Q ring resonators together with gain regions emitting around 1064 nm on the same GaAs-based chip are presented. The resulting PIC platform is enabled by spatially selective quantum well removal and two-step epitaxy.

Jan-Philipp Koester, Ferdinand-Braun-Institut (FBH) (Germany)
jan-philipp.koester@fbh-berlin.de

Fourier transform spectroscopy using broadband coherent light sources (in the THz)

Typical Fourier-transform infrared spectrometers rely on thermal sources, providing excellent spectral coverage from near- to mid-infrared (MIR) but struggling to deliver adequate power in the terahertz (THz) region. Their incoherent nature leads to low interference contrast. Here, we develop a spectrometer based on nonlinear frequency conversion of ultrashort laser pulses (23 fs) in nonlinear optical crystals, producing coherent coverage from MIR to THz suitable for non-destructive sample analysis.

Agata Kotulska, Wroclaw University of Science and Technology (Poland)
agata.kotulska@pwr.edu.pl

Soliton Vortex Comb Generation in an AlGaAs Microresonator for Self-Torque Pulse Synthesis

We demonstrate bright soliton generation at room temperature within a grating-dressed AlGaAs-on-insulator microresonator and the simultaneous emission of phase-locked vortices, enabling the synthesis of self-torque pulses from the soliton vortex comb.

Yang Liu, Technical University of Denmark (Denmark)
yangliu@dtu.dk

Wafer-Scale Manufacturing of Photonic Molecule Microcombs

We demonstrate that photonic molecule microcombs can be manufactured in a 4-inch subtractive manufacturing process in silicon nitride and achieve 98% yield of DKS formation at an average CE above 50%.

Carmen Haide López Ortega, Chalmers University of Technology (Sweden)
haide@chalmers.se

A L-Band Quantum Walk Comb Laser

We demonstrate an external cavity frequency-modulated optical frequency comb in the near-IR, using direct modulation of the gain medium in a unidirectional ring cavity to generate the comb and control its properties, such as bandwidth and power per line.

Lucius Miller, ETH Zürich (Switzerland)
millerlu@student.ethz.ch

On-chip dual quantum walk comb near 7.5 μm wavelength

We experimentally demonstrate an on-chip dual quantum walk comb source near the 7.5 μm wavelength, which provides high control of comb properties, such as bandwidth, and fast spectroscopy capabilities at sub-microsecond timescales.

Miguel Montesinos-Ballester, ETH Zurich (Switzerland)
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Stabilization of Quantum Cascade Laser Frequency Combs with Near-Infrared Light Illumination

Quantum cascade lasers are ideal candidates for mid-infrared frequency comb generation but their stabilization is necessary to achieve high performance. Using a near-infrared laser illuminating the front facet of the QCL, we demonstrate several possibilities for comb stabilization and applications.

Alexandre Parriaux, Laboratoire Temps-Fréquence - Université de Neuchâtel (Switzerland)
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Lasing on hybridized soliton frequency combs

A pair of coupled semiconductor ring lasers generates a frequency comb consisting of the hybridized cavity modes, producing phase-locked tones that anti-cross. Coherent waveform reconstruction reveals these hybridized combs manifesting as pairs of bright and dark picosecond solitons circulating simultaneously.

Pawan Ratra, Harvard University (United States)
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Microresonator frequency comb with improved efficiency via pump recycling in a gain medium

We demonstrate the use of a chip-based optical gain medium to boost the power of microcomb lines. Our amplifier does not rely on an additional pump laser, but recycles residual pump light from the microcomb.

Bastian Ruhnke, Deutsches Elektronen-Synchrotron DESY (Germany)
bastian.ruhnke@desy.de

Widely repetition-rate-tunable THz on-chip comb

We overcome the fundamental limit of free spectral range depending on laser cavity dimensions by demonstrating a monolithic, on-chip THz comb with a continuously tunable repetition rate from 4 up to 16 GHz.

Giacomo Scalari, ETH Zürich (Switzerland)
scalari@phys.ethz.ch

High brightness coherently driven active fiber cavity soliton crystals by optical gain clamping

We overcome the gain saturation in active Kerr resonators through optical gain clamping, allowing both high finesse and high intracavity power. We then leverage both effects for the generation of perfect soliton crystals with tunable repetition rate.

Corentin Simon, Université libre de Bruxelles (Belgium)
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Beyond the Linear Sweep of Frequency-Modulated Combs – Multi-Pulse Generation in Single-Section Diode Lasers

Frequency comb generation with a linearly swept instantaneous frequency is a phenomenon occurring in many single-section semiconductor lasers. Here, we unveil a different emission profile consisting of bunches of pulses with a strong CW component.

Lukasz Sterczewski, Wroclaw University of Science and Technology (Poland)
lukasz.sterczewski@pwr.edu.pl

High-power on-chip hyperparametric oscillators

Our silicon nitride microring resonator based on Kerr nonlinearity exhibits a conversion efficiency >74%, and the highest on-chip signal power >200 mW.

Yi Sun, Chalmers (Sweden)
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Transdimensional dynamics of Kerr cavity solitons

We study the bifurcation and stability of 1D, 2D and 3D Kerr cavity solitons in their transdimensional reimges by consolidating three models into a unified one-dimensional framework with a dimension parameter.

Yifan Sun, Université libre de Bruxelles (Belgium)
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WHISPERING GALLERY MODES MICROSPHERE FOR COHERENT VISIBLE LIGHT SOURCES

Microcavities with high quality factors (Q-factors) are essential for enhancing light-matter interactions, and we are investigating the potential to develop visible coherent light sources using rare-earth-doped microspheres. In this study, we experimentally demonstrate the fabrication and characterization of both passive and active silica microspheres. Notably, we report a Q-factor of up to 10^8 at 420 nm for passive spheres and provide preliminary characterization of the fluorescence spectra of dysprosium-doped silica microspheres around 580 nm.

Abhishek Sureshkumar, University of Rennes (France)
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Mid-infrared frequency-comb generation on Ge-rich SiGe platform

Different methods for mid-infrared optical frequency-comb generation on SiGe platform are reported. Electro-optic frequency-comb generation, allowing their generation using CW QCL, as well as supercontinuum generation, which broaden a given input optical frequency-comb are presented.

Victor Turpaud, Université Paris-Saclay (France)
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High-Q Fabry-Pérot microresonator based self-injection locked chip-scale laser

We demonstrate semiconductor laser diode self-injection locking to a chip-integrated side-coupled Fabry-Pérot microresonator, achieving a Lorentzian linewidth below 400 Hz, limited by thermorefractive noise. We also develop a theoretical model to describe our observations.

Alexander Ulanov, Deutsches Elektronen-Synchrotron DESY (Germany)
alexander.ulanov@desy.de

Phase-stabilised self-injection-locked Kerr comb

Full phase-stabilization of an electrically driven self-injection-locked Kerr comb is demonstrated. Utilizing low-voltage signals (< 1.5 V), independent control of the comb's offset and repetition rate frequencies is achieved, enabling phase-locking of the comb to external frequency references.

Thibault Wildi, DESY (Germany)
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Tuesday, September 10th : Program

FREQUENCY COMBS

Fundamentals & Applications

Chairman: Nicolas Englebert, California Institute of Technology (United States)

09:00 **Mid-infrared frequency combs generation in semiconductor lasers**
Benedikt SCHWARZ, TU Wien (Austria)

09:30 **Integrated semiconductor ring laser frequency combs**
Dmitry KAZAKOV, IMEC (Belgium)

10:00 **Quantum computing and quantum simulation over the optical frequency comb via machine-learning-driven photon-number-resolving measurements**
Olivier PFISTER, University of Virginia (United States)

10:30 Coffee Break

Chairman: Kaser Van Gasse, Ghent University (Belgium)

11:00 **Recent advances in microcombs: from to wafer-level processing to precision frequency synthesis**
Victor TORRES-COMPANY, Chalmers University (Sweden)

11:30 **Phase-stabilized chip-scale microcombs**
Tobias HERR, CFEL (Germany)

12:00 **Robust operation of microcombs in AlGaAs-on-insulator microresonators**
Minhao PU, DTU (Denmark)

12:30 **Room Temperature Sputtered SiN Frequency Combs and Hz-Level Spectroscopy**
Pascal DEL'HAYE, Max Planck Institute (Germany)

13:00 Lunch

Chairman: François Leo, Université libre de Bruxelles (Belgium)

14:30 **New microcomb architectures for ultra-stable microwave synthesis**
Kerry VAHALA, California Institute of Technology (United States)

15:00 **Are all modelocked Kerr combs cavity solitons?**
Alex GAETA, Columbia University (United States)

15:30 **Microresonator frequency combs for deployable optical atomic clocks**
Kartik SRINIVASAN, NIST (United States)

16:00 **Closing session**
Nicolas Englebert, Bart Kuyken, and François Leo

16:05 Coffee Break - Last discussions

Wednesday, September 11 : Imec visit

The guided tour will start at 10.15 am (general presentation and cleanroom visit) at the IMEC Tower (Remisebosweg 1, 3001 Leuven, Belgium) and will be done around noon. IMEC is in Leuven, within easy reach of Ghent by direct train (one hour). There's a fast connection between Leuven and Brussels airport, as well as the Brussels international train station (Brussels South Station).

Nicolas Englebert and Kasper Van Gasse will meet you at the Gent-Sint-Pieters train station to guide you toward IMEC/Leuven.

Talk titles and abstracts

The titles and abstracts of the 20 invited talks are given below (ordered by author's last names).

FREQUENCY COMBS

Fundamentals & Applications

UV frequency comb generation and application

Birgitta Bernhardt, TU Graz (Austria)
bernhardt@tugraz.at

Ultrabroadband Resonant Frequency Doubling in linearly uncoupled microresonators

Camille Bres, EPFL (Switzerland)
camille.bres@epfl.ch

Room Temperature Sputtered SiN Frequency Combs and Hz-Level Spectroscopy

Pascal Del'Haye, Max Planck Institute (Germany)
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I will present recent results on ultra-low loss room temperature sputtered silicon nitride waveguides and microresonators for soliton frequency comb generation. The room temperature silicon nitride process could be used for heterogenous photonic integration, e.g. with optical modulators, lasers and electronic components. In addition I will present a new method for Hz-level referencing of a modulated scanning diode laser, which can be used for characterization of photonic components. In particular, we use this technique to precisely measure microresonator mode spectra close to the zero dispersion wavelength.

Are all modelocked Kerr combs cavity solitons?

Alexander Gaeta, Columbia University (US)
alg2207@columbia.edu

Temporal dissipative solitons in hybrid resonators: from internal phase modulation to parity-time symmetric designs

Simon-Pierre Gorza, Universlite libre de Bruxelles (Belgium)
simon.pierre.gorza@ulb.be

I will discuss two recent developments in the field of dissipative temporal solitons: the manipulation and control of the state of a cavity soliton by high-bandwidth internal phase modulations and the emergence of dissipative solitons in coupled active-passive cavities. Dissipative solitons are typically generated in mode-locked lasers or in coherently driven Kerr resonators, where they are called Kerr cavity solitons. Alternatively, frequency combs are also routinely produced by electro-optic modulation of a continuous wave, which has the advantage of being more versatile. Here, I will consider the dynamics of cavity solitons in a hybrid Kerr cavity that incorporates an electro-optic phase modulator acting as an external potential. I will show how and to what extent solitons trapped in potentials can be efficiently manipulated and controlled, for instance, to cancel the soliton Raman frequency shift. Our experimental observations are made with an active fiber cavity in which the modulator loss is compensated by a gain medium to maintain the high finesse needed to enable the formation of cavity solitons. This active scheme, already successfully implemented to demonstrate active cavity solitons and parametric solitons in fiber resonators, led us to consider the formation of dissipative solitons in systems where the loss is not compensated in the same cavity but in a

coupled resonator. This configuration forms a parity-time symmetric laser, and in this framework, we show that, besides PT-cavity solitons sustained by coherent driving, mode-locked pulses can spontaneously emerge by selective breaking of the parity-time symmetry. Here, we experimentally demonstrate this mode-locking mechanism and discuss the respective roles of the coupling and the inter-resonator detuning, as well as the gain saturation in the pulse formation. We envision that this novel scheme for the generation of dissipative solitons could be transposed to any nonlinear system with two coupled components, one experiencing gain and the other loss, such as coupled ring resonators on a chip.

Phase-stabilized chip-scale microcombs

Tobias Herr, DESY (Germany)
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Microresonator frequency combs (microcombs) hold great potential for precision optical metrology, signal generation, and optical data processing. Chip-scale systems with minimal complexity have been demonstrated using self-injection locking, which relies on random scattering defects in the resonator. Here, we discuss how synthetic reflection in nanostructured resonators can enable reliable self-injection locking without relying on random defects. In addition, we show how these combs can be fully phase-stabilized using integrated microheaters and CMOS-compatible low-voltage control signals. These results contribute to the development of a truly chip-scale and scalable frequency comb technology.

Soliton Microcombs: From frequency combs to emergent nonlinear dynamics

Tobias Kippenberg, EPFL (Switzerland)
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Thin Film Lithium Niobate Photonics based Frequency Comb Sources

Marko Loncar, Harvard University (US)
loncar@seas.harvard.edu

Ultrafast Quadratic Nonlinear Nanophotonics: From Superior Components to Advanced Circuits

Alireza Marandi, Caltech (US)
marandi@caltech.edu

Robust operation of microcombs in AlGaAs-on-insulator microresonators

Pu Minhao, DTU Fotonik (Denmark)
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The AlGaAs-on-insulator has been considered a promising platform for ultra-efficient microcomb sources, with micro-watt-level threshold Kerr comb generation already demonstrated thanks to its exceptional nonlinearity. However, generating dissipative Kerr soliton combs on this platform remains challenging due to the pronounced thermo-optic effect. We show that a proper thermal management in AlGaAsOI microresonators enable soliton generation and extend the soliton existence range towards 100 GHz, which enable a robust soliton operation for practical implementation of microcomb sources.

Stability Enhancement via Interaction of Continuous Waves and Laser Cavity-Solitons in Micro-Resonators

Alessia Pasquazi, Loughborough University (England)
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We investigate the nonlinear formation and recovery of a bonded state comprising a soliton and a continuous wave (CW), where the soliton is red-detuned and the CW is blue-detuned relative to the microcavity resonance slopes. Our results indicate that the blue-detuned CW and the soliton emerge in separate regions of the erbium laser spectrum, where the amplifier's slow resonant nonlinearity shows a different sign. Real-time observations using Dispersive Fourier Transform (DFT) reveal an elastic bonding between these states, facilitated by the system's modal structure and slow nonlinearities. This research offers important insights into the dynamic interactions of complex laser states and proposes possible improvements to the stability of solitary regimes

Quantum computing and quantum simulation over the optical frequency comb via machine-learning-driven photon-number-resolving measurements

Olivier Pfister, University of Virginia (US)
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I will describe a full architecture for universal fault tolerant photonic quantum computing by encoding quantum information over continuous-variable qumodes, e.g. quantum optical fields. This leverages the massive scalability of the optical frequency comb spectrum of optical parametric oscillators. One path to fast-tolerance then relies on re-encoding qumodes into qubits by bosonic codes such as Gottesman-Kitaev-Preskill (GKP) states. I will show how all the necessary building blocks can be generated from the Gaussian qumode cluster states emitted by a single OPO, complemented by photon-number-resolved measurements, which are the only required non-Gaussian experimental resource. I will also touch on our latest results using machine learning to drive such measurement-based quantum processing toward the generation of squeezed cat states (which are deterministic precursors to GKP states) as well as of cubic and quartic phase states.

Mid-infrared frequency combs generation in semiconductor lasers

Benedikt Schwarz, TU Wien (Austria)
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Optical frequency combs (OFCs) are pivotal in modern optics, with diverse applications spanning fundamental science, sensing, and spectroscopy. Traditional methods for generating short optical soliton pulses in passive media, such as optical fibers and microresonators, have proven effective for producing stable OFCs with broad optical spectra. However, these methods typically require external optical pump lasers and additional bulky components, adding complexity to the system. Direct frequency comb generation in semiconductor lasers presents an intriguing alternative, offering potential benefits in integration and system simplicity, but it also faces several challenges. In this talk, we address these challenges by focusing on the direct generation of OFCs in mid-infrared semiconductor lasers, specifically quantum and interband cascade lasers. Following a general introduction to the field, we will review the nonlinear dynamics of these lasers and explore the most promising strategies for frequency comb generation, including frequency-modulated combs, conventional mode-locking, soliton generation, and RF-driven combs.

Microresonator frequency combs for deployable optical atomic clocks

Kartik Srinivasan, NIST (US)
kartik.srinivasan@nist.gov

An optical frequency comb plays a key role in optical atomic clocks, by phase coherently dividing the frequency of a stabilized laser to a microwave frequency that is electronically detected and counted. Recent advances in photonic integrated circuits have enabled the generation of chip-scale frequency comb sources that have the potential to dramatically reduce size, weight, and power, though they also come with their own unique challenges. In this talk, I will discuss our labs efforts to engineer and harness unique nonlinear optical phenomena in chip-scale frequency combs for optical clock applications

Recent advances in microcombs: from to wafer-level processing to precision frequency synthesis

Victor Torres-Compagny, Chalmers University of Technology (Sweden)
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Recent advances in photonic integration are creating renewed prospects for the realization of laser frequency combs on a chip, enabling applications that benefit from the potential for mass production and portability. I will discuss advances in optical frequency synthesis and novel solutions for wafer-scale processing of super-efficient microcombs.

Integrated semiconductor ring laser frequency combs

Dmitry Kazakov, IMEC (Belgium)
dmitry.kazakov@imec.be

Traditionally, frequency comb generators based on Fabry-Perot semiconductor lasers have relied on active mode-locking via gain modulation at the laser cavity's roundtrip frequency or passive mode-locking using an intracavity saturable absorber. Recently, self-mode-locking has emerged, producing frequency-modulated (FM) instead of pulsed or amplitude-modulated (AM) combs. New approaches involve locking the modes of an integrated laser cavity in a ring cavity geometry. These ring laser resonators share many characteristics with passive nonlinear microresonators and can be described using similar theoretical models. They also adapt driving schemes from Kerr microcombs. This talk will cover the progress made in this field over the past five years, focusing on the latest results in semiconductor ring quantum cascade lasers. The discussion will highlight their potential for photonic integration, resilience to optical feedback, and the generation of dark and bright solitons through purely electrical or hybrid optical-electrical driving methods.

Titanium:Sapphire-on-insulator for broadband tunable lasers and high-power amplifiers on chip

Kasper Van Gasse, Gent Universiteit (Belgium)
kasper.vangasse@ugent.be

We present the demonstration of a novel Titanium:Sapphire-on-insulator (Ti:SaOI) nanophotonic platform. This platform allows to implement the unparalleled performance of Ti:Sapphire laser crystals on a nanophotonic chip. This novel platform enables the realization of gain waveguides with the widest gain bandwidth of any on-chip platform and pulse amplification up to a record 2.3 nJ of pulse energy. Moreover, we will present the realization of a widely tuneable laser that is used as the optical control for a cavity quantum electrodynamics experiment with artificial atoms in silicon carbide.

New microcomb architectures for ultra-stable microwave synthesis

Kerry Vahala, Caltech (US)
vahala@caltech.edu

Compact and integrable microwave signal sources that outperform quartz and sapphire electronic systems have become of keen interest in recent years on account of applications in air and space borne systems. And microcombs in combination with the method of optical frequency division provide a way to realize these systems. We first review pulse-pair mode locking in microcombs using high-Q silicon nitride resonators. Both operation in normal and anomalous dispersion modes will be addressed. Also, the ability to frequency tune dispersive waves for maximal signal-to-noise locking to a high-stability reference cavity will be demonstrated. The application of these new platforms for record-low phase noise microwave synthesis using chip-integrable components will then be presented.

Frequency microcombs in the normal-dispersion region

Xiaoxiao Xue, Tsinghua University (China)
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Frequency microcombs in the normal-dispersion region are particularly attractive for their high energy conversion efficiency and deterministic accessibility. However, spontaneous excitation of normal-dispersion frequency combs is nontrivial due to the lack of modulational instability (MI) in an ordinary microresonator. Special designs are usually required. Here, we review the strategies for microcomb generation in the normal-dispersion region. We present a systemic analysis of the MI gain in a normal-dispersion microresonator with mode perturbations. We find a novel mechanism of triggering MI through loss perturbations applied to the pump mode, which has been overlooked in previous studies. We also demonstrate a novel scheme of robust frequency comb generation in the normal-dispersion region with bi-directional pumping.