HL 22: Focus Session: Emerging Semiconductor Laser Concepts

The fabrication and study of semiconductor lasers lie at the heart of the field of solid-state photonic devices. Current research efforts are driven by the incorporation of emerging emitter materials such as organic dyes, quantum dots or 2D materials on the one side, and by harnessing novel and complex photonic mode engineering concepts like in the case of topological lasers or coupled laser arrays. Combining these two directions opens a rich research direction and paves the way to new fundamental phenomena as well as engineering perspectives for ultra-compact laser devices with additional features and functionalities.

Organizers: Christian Schneider (Universität Oldenburg), Sebastian Klembt (Universität Würzburg)

Time: Friday 10:00–12:45 Location: H4

Invited Talk HL 22.1 Fri 10:00 H4
Two-dimensional gain materials for new nanolaser concepts —
•Christopher Gies — Institut für Theoretische Physik, Universität Bremen

The talk will give an overview of the many-facetted physics of nanolasers. A particular focus will be on the gain properties when using TMD (transition metal dichalcogenide) monolayers and heterostuctures inside optical microresonators to design a new class of nanolasers [C. Gies and A. Steinhoff, Laser&Photonics Review 2021, 2000482]. Operating close to the ideal limit, high-β lasers require extra effort in unambiguously identifying laser operation. For this, quantum-optical studies have become the state of the art. Atomically thin TMD semiconductors hold much promise for optoelectronics, but have yet to demonstrate their application potential in new technologies. We will discuss possible gain mechanisms in TMD based nanolasers and identify signatures of lasing operation in these devices. For this, the interplay of excitonic effects caused by strong Coulomb interaction, and plasma effects in the high-excitation-density regime, need to be taken into consideration.

Invited Talk HL 22.2 Fri 10:30 H4
Room-temperature polariton lattices for quantum simulation
— •Stephane Kena-Cohen — Polytechnique Montreal, Montreal, Canada

Polaritons are quasiparticles that form in semiconductor microcavities when the light-matter interaction rate is faster than the dissipation rate. At high densities, these quasiparticles can condense into a single macroscopic state that behaves qualitatively like a conventional laser. In addition to possessing intrinsically low lasing thresholds, the strong nonlinearities and tunability of polaritons is currently being exploited to realize efficient nonlinear devices and for quantum information.

In this talk, we will describe 2 platforms that allow for the formation of room-temperature polariton lasers: organic semiconductors and halide perovskites. We will describe the basic physics behind such devices and recent experiments where lattices were used to realize analog quantum simulators (e.g. XY Hamiltonian) under ambient conditions.

Invited Talk HL 22.3 Fri 11:00 H4
Topological nanocavity lasers and topological high-power lasers —
•Yasutomo Ota[1,2], Yasuhiko Arakawa[2], and Satoshi Iwamoto[2,3,4] — [1]Keio University — [2]Nanoquine, The University of Tokyo — [3]RCAST, The University of Tokyo — [4]IIS, The University of Tokyo

Topological photonics offers ways to advance optical resonator design. In particular, resonators based on topological edge states emerging at the exteriors of bulk optical structures have been intensively studied because they behave robustly against certain disorders. Combinations of such topological cavities with gain materials also gather enormous interest as a straightforward route to topological lasers. In this contribution, we discuss our recent efforts on topological lasers based on 0D edge states supported in 1D photonic topological structures. We realized single-mode topological nanocavities by interfacing two topologically-distinct photonic crystal nanobeams. Combined with quantum dot gain, we demonstrated the first topological nanocavity laser. Furthermore, we theoretically extended the concept of the 0D topological cavity design to high-power lasers. We considered sizable arrays of coupled resonators that form topological optical bands. In a similar manner to the topological nanocavity, by interfacing two topologically-different cavity arrays, we designed topological interface modes broadly-distributed among the whole systems. Properly supplying gain to the system, we numerically uncovered the possibility of robust single mode lasing from the broad-area mode, paving the way to high-power and high-beam-quality topological lasers.

15 min. break.

Invited Talk HL 22.4 Fri 11:45 H4
Topological Insulator Lasers —
•Miguel A. Bandres[1], Steffen Wittek[1], Gal Harari[2], Mordechai Segev[2], Demetrios N. Christodoulides[1], and Mercedeh Khajavikhan[3] — [1]CREOL, University of Central Florida — [2]Technion, Haifa, Israel — [3]University of Southern California

Topological insulators are a new phase of matter with insulating bulk but robust edge conductance. These topological edge states are extremely robust, propagate in a unidirectional manner immune to imperfections, defects, or disorder, and as such they are promising unprecedented advantages in technological applications. In recent years, research in topological photonics has flourished with numerous photonic platforms. Until recently research on topological systems in all fields of science was carried out in entirely passive and linear settings. However, the idea of introducing gain and nonlinearity to topological systems has raised many challenges and fundamental questions.

Recently, we demonstrated that topological protection can be combined with gain and loss to give rise to a new kind of laser whose lasing mode is a topologically protected edge mode, a topological insulator laser. The topological insulator laser displays slope efficiency that is considerably higher than in the corresponding trivial realizations even in the presence of defects and disorder, and operates at a single lasing mode even considerably above threshold. These results paved the way towards the new era of active topological photonics, in which topological protection, nonlinearity, and gain, combined in nontrivial ways, to give rise to new active photonic devises.

Invited Talk HL 22.5 Fri 12:15 H4
When polariton condensates have dissipations or have no excitons —
•Hui Deng — University of Michigan, Ann Arbor, MI USA

Microcavity exciton-polaritons are formed in a semiconductor with strong exciton-photon coupling and low carrier density. They have been widely studied as a weakly interacting boson gas that can form a Bose-Einstein condensation (BEC) like many-body state in a solid. However, the cavity dissipation and fermionic nature of the electrons can lead to phenomena outside the well established framework for quasi-equilibrium polariton condensation. We discuss two such examples. We first discuss the formation of limit cycles with two coupled condensates, as a result of dissipative coupling and polariton nonlinearity. We then look "inside" the polaritons and reveal an electron-hole-photon condensate that share similar spectral properties as a polariton BEC but with a microscopic origin similar to a BCS-state.