KFM 5: Whispering Gallery Mode Resonators II

Organizer: Christoph Marquardt - Max Planck Institute for the Science of Light - Erlangen

Time: Monday 15:00–18:10 Location: EMH 025

Invited Talk KFM 5.1 Mon 15:00 EMH 025

Whispering-gallery-like modes in two and three dimensional microcavities — •Martina Hentschel — Technische Universität Ilmenau, Institut für Physik, Weimarer Str. 25, 98693 Ilmenau

Optical microcavities and microlasers have gained a lot of interest as fascinating model systems for fundamental research and because of their high potential in nanophotonic applications. Their properties are often determined by the resonances of the cavity, i.e., its geometry. The focus of this talk will be on whispering-gallery (WG) type resonances, their dependence on the dimensionality of the system, the role of geometric phases, and the resulting far-field characteristics and application potential, e.g., in sensors.

WG-like resonances form in rotational invariant and even in non-invariant systems such as the so-called Limaçon shape. Their properties depend also on the dimensionality of the system as does the resulting emission characteristics, thereby opening new possibilities of their use in, e.g., sensing applications [1]. We also show that WG-like modes can be strongly influenced in the presence of geometric (Berry, Pancharatnam) phases, for example in the Möbius strip cavity, and how the geometric phase and polarization properties can be controlled by the cavity shape.

[1] J. Kreismann, S. Sinzinger, and M. Hentschel, Phys. Rev. A 95, 011801(R) (2017).

KFM 5.2 Mon 15:30 EMH 025

Hybrid photonic-plasmonic whispering-gallery-mode resonators — •Carolin Klusmann[1], Jens Oppermann[2], Patrick Forster[1], Carsten Rockstuhl[2], and Heinz Kalt[1] — [1]Insitute of Applied Physics, KIT, Karlsruhe, Germany — [2]Institute of Theoretical Solid State Physics, KIT, Karlsruhe, Germany

Hybrid photonic-plasmonic systems combining high-Q dielectric whispering-gallery-mode (WGM) resonators with plasmonic elements are a promising platform to study cQED-phenomena or nonlinear effects. In this contribution, we investigate the modal characteristics of a wedge-like polymeric WGM resonator coated with a thin silver layer which is evanescently coupled to a tapered fiber. The hybrid system is carefully engineered to support three distinct categories of eigenmodes: photonic modes, surface-plasmon-polariton modes, localized at the metal-dielectric interface, as well as hybrid modes. Owing to similar Q-values for both photonic and hybrid modes, and owing to the high sensitivity of the resonance wavelengths to tiny variations in the resonator geometry and permittivity, an assignment of the experimentally observed resonances with the simulated eigenmodes is challenging. Hence, an experimental ansatz is required to identify the measured resonances. FEM simulations considering the interaction with the input waveguide suggest, that measuring the coupling strength of the eigenmodes as a function of the relative horizontal distance between fiber and resonator edge in combination with a polarization dependent excitation allows for an unambiguous classification of the modes. We verify this experimentally.

KFM 5.3 Mon 15:50 EMH 025

High-Q Integrated lithium niobate thin film Whispering Gallery Resonators for Frequency Conversion — •Richard Wolf[1], Ingo Breunig[1,2], and Karsten Buse[1,2] — [1]Department of Microsystems Engineering - IMTEK, University of Freiburg, 79110 Freiburg, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques, 79110 Freiburg, Germany

For realizing non-linear optical frequency converters, lithium niobate whispering-gallery-resonators (WGRs) are most promising due to their high field enhancement by small mode volumes and high Q-factors. Thus, with bulk-WGRs in millimeter size, e.g. optical parametrical oscillation with μW-threshold and conversion efficiencies could be demonstrated. However, WGRs are still rare in commercial products due to the serial and thus expensive fabrication like diamond-blade-cutting with subsequent mechanical polishing. Therefore, integrating WGRs on chip by parallel MEMS fabrication techniques becomes a substantive topic. Compared to bulk WGRs also a 1000 times smaller mode volume can be achieved, especially by using lithium niobate thin film substrates ridge-waveguide WGRs with high refractive index contrast and thus strong light confinement. We report on integrated WGRs based on lithium niobate thin films, made by parallel and thus scalable MEMS fabrication techniques. By using a coupling scheme with tunable coupling efficiency we could couple more than 95 % of pump light into our resonators and achieved intrinsic Q-factors higher than 10^6. We studied non-linear optical effects like second harmonic generation, sum frequency generation and stimulated Raman scattering.

KFM 5.4 Mon 16:10 EMH 025

Self-pumped three-wave mixing in laser-active whispering-gallery resonators — •Simon J. Herr[1], Karsten Buse[1,2], and Ingo Breunig[1,2] — [1]Department of Microsystems Engineering - IMTEK, University of Freiburg, 79110 Freiburg, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, 79110 Freiburg, Germany

High-Q whispering-gallery resonators (WGRs) made from lithium niobate (LN) have proven to be an excellent platform for highly efficient three-wave mixing. Typically, frequency conversion is induced by pumping whispering-gallery modes (WGMs) of the resonator by means of an external narrow-linewidth light source. Due to the high field enhancement within the high-Q cavity, light-matter interaction is strongly enhanced. Here, we present an important step towards further integration, by using the high-Q cavity not only for nonlinear optics but also for the generation of narrow-linewidth laser light, which is required for pumping nonlinear optical processes. This is achieved by implementing laser-active ions into the host material of the WGR. Importantly, the laser active ions can be excited with cheap light sources, while lasing in high-Q WGMs leads to an intrinsically mode-matched and narrow-linewidth laser oscillation, capable of pumping nonlinear optical processes within the very same high-Q cavity. With these highly integrated devices, self-frequency doubling is achieved in neodymium-doped lithium niobate. A radially poled quasi-phasematching structure allows for self-optical parametric oscillation.

20 min break

KFM 5.5 Mon 16:50 EMH 025

Near infrared cathodoluminescence measurements on paraboloidal and conical silicon photonic nanoresonators — •Sebastian W. Schmitt, Klaus Schwarzburg, and Catherine Dubourdieu — Helmholtz-Zentrum Berlin für Materialien und Energie

Due to the indirect band-to-band transition, spontaneous emission rates in silicon (Si) are low and efficient Si-based solid state lighting remains challenging. The confinement of spectrally matched optical modes can amplify spontaneous emission rates of electronic transitions in Si nanophotonic resonators. Hereby, the amplification is proportional to Q/V, where Q is the quality factor and V is the volume of the resonant mode. This so-called Purcell effect could successfully be applied to improve the performance of Si-based light emitters. Here, Si acts as active or passive resonator material amplifying intrinsic band-to-band or defect transitions or the transitions of added gain media. We show cathodoluminecence (CL) measurements performed in a scanning electron microscope on two novel types of Si photonic resonators with inverted conical and inverted paraboloidal geometry. CL scanning of the resonators by the electron beam at different heights shows a selective excitation of optical whispering gallery modes in the near-infrared wavelength range. A discussion of the excited modes with respect to Q-factor, polarization, relative intensity and resonator geometry shows that the nanoresonators permit a strong and tunable light amplification in the telecom window and accordingly are suitable building blocks for small on-chip solid state lighting devices.

KFM 5.6 Mon 17:10 EMH 025

Whispering Gallery Modes in Self-Assembled Microspheres of Highly Fluorescent Polymers — Daniel Braam[1], Guenther Prinz[1], Kenichi Tabata[2], Soh Kushida[2], Daichi Okada[2], Yohei Yamamoto[2], and •Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Faculty of Pure

and Applied Sciences, University of Tsukuba, Japan

We report on the realization of spherical microresonators by self-assembly of π-conjugated copolymers. These polymers combine the features of being a dye as well as a dielectric. They also enable facile, large-scale fabrication of microspheres with excellent optical and structural properties [1]. Single microspheres were investigated by photoluminescence in the visible regime. The spectra exhibit sharp whispering gallery modes (WGMs) with Q-factors up to 10 000 [2], superimposed upon a broad luminescence background. The high Q-factors, together with the properties of the polymer spheres, make it possible to study the evolution of WGMs, both inside a single sphere, as well as between optically coupled multi-sphere arrangements [3]. Strong optical excitation leads to a slight oblate deformation of the resonators. This results in a splitting of the WGMs, as the high degeneracy of perfectly spherical confinement is lifted [2]. Using suitable polymer blends with tunable fluorescence properties, efficient, long-range unidirectional photon energy transfer ("photon one-way street") can be demonstrated [3].

[1] K. Tabata *et al.*, Sci. Rep. **4**, 5902 (2014).
[2] D. Braam *et al.*, Sci. Rep. **6**, 19635 (2016).
[3] S. Kushida *et al.*, ACS Nano **10**, 5543 (2016).

KFM 5.7 Mon 17:30 EMH 025

WGM resonator technique for condensed matter characterization — Hanna Hlukhova[1], Nataliia Naumova[1], Alexander Barannik[2], Alexey Gubin[2], Irina Protsenko[2], Nikolay Cherpak[2], and •Svetlana Vitusevich[1] — [1]Bioelectronics (ICS-8), Forschungszentrum Juelich, 52425 Juelich, Germany — [2]Usikov Institute for Radiophysics and Electronics, 61085 Kharkiv, Ukraine

WGM resonators represent a key technique in enabling material studies due to their high-quality resonant mode operation using evanescent electromagnetic fields. A very small perturbation introduced by a material under test results in a shift of resonant frequency and change in quality factor, thus reflecting the unique dielectric properties of the material. In this work, we present several developed resonators made of sapphire or quartz materials and discuss the advantages of fabricated measurement cells. WGM resonators of various geometries and materials were suggested in order to utilize the full potential of electromagnetic fields as a test wave interacting with materials, such as single-crystal Fe-pnictides and bioliquids. The resonators were studied using numerical modeling methods. Experimentally obtained quality factors are in good agreement with modeled values. It was also shown that the resonator enables the measurement of the complex permittivity of materials with an error of about 1 %. Microfluid channels combined with WGM resonators operated in the Ka band open up the possibility of contactless measurements for small volumes of biological liquids. This work is supported by DFG project: VI 456/3-1. N.N. greatly appreciates support from the Heinrich Hertz-Foundation.

KFM 5.8 Mon 17:50 EMH 025

Towards a whispering gallery mode resonator based wavemeter — •Thomas Halbauer[1,2], Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand

Macroscopic crystalline whispering gallery mode resonators (WGMR) can provide the possibility for a whispering gallery type wavemeter (WGTW) in just one monolithic device. The frequency spacings between different resonance frequencies of the WGMR represent a unique fingerprint of the frequency of the exciting laser. We use an electro-optic frequency tuning mechanism to shift the fingerprint of an unknown source with fixed frequency. The accuracy is only limited by the linewidth of resonances. In combination with our experimental resonance frequency analysis [1], this unambiguously reveals the excitation wavelength. For achieving the required temperature stability, we implement a scheme based on the differential shift between differently polarized resonance frequencies of an additional locking laser.

[1] G. Schunk *et al.*, Opt. Express **22**, 30795 (2014).