KFM 1: Whispering Gallery Mode Resonators I

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

Time: Monday 9:30–12:50 Location: EMH 025

Invited Talk KFM 1.1 Mon 9:30 EMH 025

Collective nano-optomechanics and liquids — •Ivan Favero — Université Paris Diderot, CNRS, France

We present a new technique to resonantly tune ensembles of nanophotonic/mechanical resonators. The technique builds on the recent experimental development of nano-optomechanics in the liquid-state [1]. Laser light injected into the optical mode of a first resonator immersed in a liquid triggers an etching process, leading to a fine-tuning of the resonators dimensions. The evolution of dimensions is monitored continuously by spectrally tracking the associated optical resonance. This tuning process, dubbed resonant photo-electrochemical etching, is naturally scalable to multiple resonators and has already allowed us to resonantly tune small ensembles (2 to 5 units) [2]. As a first application of this technique, we explore the resonant optical interaction of multiple and distant nano-optomechanical systems. Light flowing unidirectionally along a chain of nano-optomechanical oscillators is observed to produce their frequency-locking above a certain threshold, which represents a first example of collective phenomenon in optomechanics [3]. Our experiments are explained by a minimal semi-classical model, and set the grounds for more advanced quantum experiments.

Acknowledgements: the work presented involved contribution by E. Gil-Santos, W. Hease, A. Lemaitre, M. Labousse, C. Ciuti and G. Leo

[1] Nature Nanotech 10, 810 (2015) [2] Nature Comm 8, 14267 (2017). [3] Phys Rev Lett 118, 063605 (2017).

Invited Talk KFM 1.2 Mon 10:00 EMH 025

Whispering gallery optical parametric oscillators — •Ingo Breunig — Department of Microsystems Engineering - IMTEK, University of Freiburg, Georges-Köhler-Allee 102, 79110 Freiburg, Germany — Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstraße 8, 79110 Freiburg, Germany

Continuous-wave optical parametric oscillators (cw OPOs) combine narrow-linewidth emission with a large wavelength tuning range far beyond that of lasers. Conventionally, these devices are based on a nonlinear-optical crystal surrounded by a mirror cavity.

In whispering gallery optical parametric oscillators (WGR OPOs), light is guided by total internal reflection in a spheroidally-shaped millimeter-sized nonlinear-optical crystal. They provide oscillation thresholds in the (sub)-mW range. However, WGR OPOs are intrinsically triply-resonant. One might assume that wavelength tuning of is much more difficult to control here compared with that of conventional mirror-based singly-resonant systems.

Nevertheless, several experimental studies revealed that the output wavelengths of whispering gallery optical parametric oscillators can be tuned in well-defined steps over hundreds of nanometers by temperature variation and mode-hop-freely to MHz-wide resonances of alkali atoms. WGR OPOs are operated in a spectral range from wavelengths below 600 nm to ones beyond 8000 nm. Thus, these light sources - despite of their intrinsic triple resonance - might serve as compact and wavelength flexible devices for various applications.

KFM 1.3 Mon 10:30 EMH 025

Widely tunable polymer-based photonic devices — Tobias Siegle, •Johann Frank, Stefan Schierle, Michael Remmel, Matthias Migeot, Carolin Klusmann, and Heinz Kalt — Institute of Applied Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Whispering gallery mode (WGM) resonators have a wide range of applications such as optical sensors, lasers or filters and modulators. Using polymers as resonator material and exploiting the flexibility of elastomeric substrates enables a tunability that further enhances the functionality of photonic devices. In this contribution we demonstrate a fine, reversible and spectrally wide resonance tuning using a novel type of WGM resonators. Further we report on the realization of photonic molecules with tunable coupling. Resonance tuning is achieved using a split-disk geometry - two opposing half-disks structured with direct laser writing onto a elastomeric substrate. Calibrated straining of the substrate allows reversibly tuning the distance between the half-disks and hence the resonance wavelength. Laser emission from dye-doped split-disk resonators reveals a wide tunability of more than three times the free spectral range. Similarly, adjacent goblet-shaped resonators are structured on the elastomer using direct laser writing. Resolving the laser emission spectroscopically and spatially while reducing the coupling gap demonstrates the formation of photonic molecules. Variation of the gap width and hence the coupling strength results in tunable laser-mode intensities, in particular in super-mode formation and mode vanishing due to the Vernier effect.

KFM 1.4 Mon 10:50 EMH 025

Electrical tuning of polymer-based photonic devices on a dielectric polymer substrate — •Matthias Migeot, Tobias Siegle, Michael Remmel, and Heinz Kalt — Institute of Applied Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Whispering gallery mode (WGM) resonators are versatile photonic structures which have a great variety of applications. A prominent example is given by coupling of two or more WGM resonators to photonic molecules or coupled resonator optical waveguides (CROWs). In this context, it is desirable to dynamically and reversibly tune the coupling strength between multiple resonators as well as the individual resonance wavelengths. In contrast to commonly used semiconductor or silica-based resonators, polymers provide large flexibility to achieve the required tuning capabilities even fabricated in high-precision mass production. In this contribution we use a dielectric polymer as substrate for coupled WGM resonators. The substrate consists of a prestreched PDMS thin-film which is contacted from both sides with polymeric electrodes. If the electrodes are structured appropriately a high DC voltage can be applied to the electrodes which leads to a local relaxation of the substrate and thereby to a reduction of the distances on the substrate. We show first results on the independent control of both, the coupling strength between multiple resonators and the resonance wavelength of an individual (split-disk) resonator.

20 min break

KFM 1.5 Mon 11:30 EMH 025

Mid-infrared whispering gallery optical parametric oscillators — •Yuechen Jia[1], Kevin Hanka[1], Karsten Buse[1,2], and Ingo Breunig[1,2] — [1]Laboratory for Optical Systems, Department of Microsystems Engineering - IMTEK, University of Freiburg, Georges-Köhler-Allee 102, 79110 Freiburg, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstraße 8, 79110 Freiburg, Germany

The mid-infrared (mid-IR) spectral window is of great interest because it allows for high-resolution spectroscopy of nearly all gas molecules. Whispering-gallery-resonator (WGR)-based continuous-wave optical parametric oscillators (CW OPOs), which combine high miniaturization and large wavelength tunability, are emerging as efficient frequency-conversion devices for applications in the mid-IR. Based on traditional nonlinear optical materials such as LiNbO3 or KTP, however, CW OPOs are limited to output wavelengths shorter than 5 μm due to the onset of multi-phonon absorption. In this contribution, we report about the fabrication of high-quality-factor whispering gallery resonators made out of AgGaSe2, CdSiP2 and orientation-patterned GaP crystals, which exhibit the highest nonlinear coefficients and broadest infrared transparency ranges among all practical nonlinear optical crystals. With these WGRs, additionally, CW OPOs with low oscillation thresholds and wide tunability in the mid-IR spectral range of 2-8 μm are realized.

KFM 1.6 Mon 11:50 EMH 025

Phase transition studies using second-harmonic phonon spectroscopy — •Christopher J. Winta, Sandy Gewinner, Wieland Schöllkopf, Martin Wolf, and Alexander Paarmann — Fritz-Haber-Institut der MPG

Nonlinear optical spectroscopy constitutes a powerful tool for the investigation of crystalline solids and their structure. Apart from improved sensitivity compared to linear techniques, it offers additional experimental degrees of freedom which can be used to selectively study different symmetry components of the detected signal. The mid-infrared (MIR) spectral region is particularly interesting as it contains optical phonon resonances which themselves carry symmetry information.

Here, we demonstrate MIR second-harmonic (SH) phonon spectroscopy [1] as a symmetry-sensitive technique to investigate structural phase transitions, using the $\alpha \rightarrow \beta$ transition of quartz as a case example. A MIR free-electron laser grants access to essentially all optical phonon resonances of quartz which are selectively investigated with regard to their temperature-dependent behavior upon T_c. The data show a critical phase transition behavior of the phonon frequencies, damping rates and SH peak amplitudes. Additionally, certain phonon modes become IR-forbidden in the higher symmetry β-phase and consequently disappear from the SH spectra upon the phase transition.

Given its sensitivity to crystal structure and symmetry, our novel technique presents itself as a promising tool for the study of structural phase transitions in polar dielectrics, e.g. ferroelectrics or multiferroics.

[1] Winta et al., arXiv:1710.02097 (2017)

KFM 1.7 Mon 12:10 EMH 025

Single photon generation in a whispering gallery mode resonator — •Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Florian Sedlmeir[1,2], Alexander Otterpohl[1,2], Ulrich Vogl[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]MPL, Erlangen, Germany — [2]FAU, Erlangen, Germany — [3]University of Otago, Dunedin, New Zealand

Single photons are an important resource for quantum information processing since they are reliable long distance carriers for quantum information. The generation of high quality single photons with controllable narrow spectral bandwidths and central frequencies is key to facilitate efficient coupling of any atomic system to non-classical light fields. Here, we report on a fully tunable, narrow band and efficient source of non-classical light, in particular single photons [1,2], based on a crystalline whispering gallery mode resonator. It is made of lithium niobate and works based on spontaneous parametric down-conversion where a pump photon decays due to material nonlinearties into two single cavity modes of different wavelengths. The central wavelength of the emitted light can be tuned over hundreds of nanometers [3].

Currently, we are working on generating polarization entangled photon states with our compact and monolithic source, which opens up novel possibilities for creating the central building block for proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] G. Schunk et al., Optica 2, 773-778 (2015).

KFM 1.8 Mon 12:30 EMH 025

Generation of non-classical light in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Thomas Dirmeier[1,2], Ulrich Vogl[1,2], Gerhard Schunk[1,2], Golnoush Shafiee[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Tobias Gehring[4], Ulrik L. Andersen[4], 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 — [4]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

Macroscopic crystalline whispering gallery mode resonators (WGMR) made out of $LiNbO_3$ are a versatile source of non-classical light generated via optical parametric down-conversion [1]. This is a process where one photon is split into two photons called signal and idler. Both photons are correlated due to energy conservation, which affects the statistical fluctuations in certain measurements. We report how non-classical light can be efficiently generated and present the prospects of possible applications within the field of optomechanics [2].

[1] J. U. Fürst et al., Phys. Rev. Lett. **106**, 113901 (2011).
[2] V. Peano et al., Phys. Rev. Lett. **115**, 243603(2015).