2. NextLite DoktorandInnen-Workshop

Thursday, June 23rd - Friday, June 24th, 2016 || Graz

@Steiermarkhof
8052 Graz, Krottendorfer Straße 81

Thursday, June 23rd		
from 10.00	*Welcome Coffee*	
11.00	*Welcome / General Introduction*	*Martin Belitsch/ Marija Gasparic*
11.10	Parity-Time Symmetry and non-Hermitian Photonics with Whispering Gallery Resonators	**Şahin Kaya Özdemir** *Electrical & Systems Engineering, Washington University, St. Louis*
12.30	*Lunch*	
14.00	Studying light-matter interaction with precisely-characterized infrared and optical waveforms	**Nicholas Karpowicz** *Max-Planck-Institut für Quantenoptik*
15.00	*Coffee break*	
15.30	Combining spectroscopy and tomography in the transmission electron microscope	**Georg Haberfehlner** *TU Graz, FELMI-ZFE* *Centre for Electron Microscopy*
16.15	*Coffee break*	
16.30	Anton Paar GmbH	**Ronald Henzinger** *Anton Paar GmbH*
17:00	ams AG - Shaping the world with sensor solutions	**Franz Schrank** *ams AG*
18.00	*Dinner*	

Friday, June 24th		
09.00	*Coffee*	
09.30	Optical Quantum Memories: from free-space to all-fibered implementations	**Julien Laurat** *Laboratoire Kastler Brossel, Paris*
10.30	*Coffee break*	
11.00	Germanium mid-infrared plasmonics for sensing	**Paolo Biagioni** *Politecnico di Milano, Dipartimento di Fisica*
12.00	*Lunch*	
13.00	Two-photon 3D lithography: A versatile fabrication method for complex 3D shapes for industrial applications	**Frank Reil** *JOANNEUM RESEARCH Forschungsgesellschaft GmbH*
14.00-14.15	*Short coffee break*	
14.15	Networking Activity: [15.00] Guided Tour Schloss Eggenberg	

Abstracts

Parity-Time Symmetry and non-Hermitian Photonics with Whispering Gallery Resonators

Şahin Kaya Özdemir
Electrical & Systems Engineering, Washington University, St. Louis

Photonics has emerged as a key enabling technology providing breakthrough solutions that revolutionize our everyday experiences: from communications and healthcare to environment monitoring, energy efficiency and computing. Photonic technologies will also continue to change the ways we do computing by overcoming limitations of electronics through all-optical processors and photonic quantum technologies. In this talk, I will highlight a versatile and high-performance optical platform- whispering-gallery-mode (WGM) optical microresonators- for exploring basic science and also for developing disruptive technologies that provide solutions to challenging scientific and engineering problems. In this talk, after reviewing the physics and general applications of WGM microresonators I will focus on systems of solitary and coupled WGM resonators for on-chip control of optical processes and light propagation.

WGM resonators represent open physical systems that are characterized by non-Hermitian Hamiltonians, and thus by appropriately steering the system parameters, their complex eigenvalues and the corresponding eigenstates can be made to coalesce giving rise to a degeneracy referred to as exceptional point (EP). I will present applications enabled by driving WGM resonators through EPs. I will first show parity-time (PT) symmetry and its breaking in coupled WGM resonators with balanced loss and gain, and then discuss how this system can be utilized for nonlinearity-based nonreciprocal light transmission when it is operated in the broken-PT phase [1]. Next, I will show that modulating the loss contrast between two lossy resonators can bring the system to an EP which then leads to the counterintuitive observation of loss-induced suppression and revival of lasing in WGM microresonators [2]. This opens a new way to control loss and to benefit from loss in photonic system. Finally, I will discuss chiral modes and directional emission in WGM microresonators and microlasers enabled by EPs [3]. This has enabled a dynamic control of the rotation direction of light in a WGM resonators, and provided a new trick to tune the emission direction of a WGM microlasers on-demand. I will end the talk discussing some of the the opportunities and challenges in the WGM research, in particular within the framework of exceptional points and PT-symmetry.

[1] B. Peng *et al.*, *Parity-time-symmetric whispering-gallery microcavities*. Nat. Phys. **10**, 394-398 (2014).
[2] B. Peng *et al.*, *Loss-induced suppression and revival of lasing.* Science **346**, 328 (2014).
[3] B. Peng *et al.*, *Chiral modes and directional lasing at exceptional points. Proc. Natl. Acad. Sci. USA* Early edition on *June 6, 2016, doi:10.1073/pnas.1603318113* (2016).

Studying light-matter interaction with precisely-characterized infrared and optical waveforms

Nicholas Karpowicz
Max-Planck-Institut für Quantenoptik, Abt. für Attosekundenphysik

By measuring the exact temporal evolution of infrared and visible laser fields, we are able to reconstruct what happens when they interact with solid state materials, within an oscillation cycle of the laser field. Employing attosecond streaking and electro-optic sampling, we are able to reconstruct important observables such as the time-dependent nonlinear polarization, to provide a detailed view of energy transfer and charge dynamics with sub-femtosecond precision. The talk will comprise an overview of the key experimental techniques, and what they tell us about the fundamental physics of light-matter interaction in the attosecond regime.

Combining spectroscopy and tomography in the transmission electron microscope

Georg Haberfehlner
TU Graz, FELMI-ZFE, Centre for Electron Microscopy

The transmission electron microscope (TEM) is a versatile instrument for imaging materials structure, composition and properties at the nanoscale down to atomic resolution. In scanning TEM (STEM) mode the electron beam is focused and scanned over the sample. For each scanning position simultaneous acquisition of the high-angle annual dark field (HAADF), the electron energy-loss spectroscopy (EELS) and the energy-dispersive X-ray spectroscopy (EDX) signal is possible. While the HAADF signal provides mass-thickness contrast, both EELS and EDX allow elemental mapping. With the high energy resolution of a monochromated microscope (< 0.2 eV) EELS can additionally give information about elemental bonding and about electrical and optical materials properties. Over the last years this has been used extensively for mapping surface plasmons with high spatial resolution.
Electron tomography extends the imaging capabilities of the TEM to the third spatial dimension. 3D reconstructions are done from a tilt series of images. HAADF STEM tomography gives 3D information about sample morphology based on mass contrast and has been demonstrated at atomic resolution for very small samples. Combining EELS and EDX with tomography enables elemental identification in 3D as well as reconstruction of 3D localized spectral information.
Imaging of particle plasmon fields in three dimensions becomes possible by EELS and tomography. On one hand the 3D morphological reconstruction of metallic nanoparticles can be used as input for numerical simulations of their nanoscale photonic properties, which allows comparison of simulated and experimental EELS maps and spectra, on the other hand tilt series of EELS spectrum images can be used to directly reconstruct the photonic environment of plasmonic nanoparticles giving access to 3D nanooptic quantities such as the photonic local density of states.
In this presentation I will discuss the principles of spectroscopy and tomography in the TEM and show their application for 3D nanoscale imaging of materials with a focus on surface plasmon mapping.

Optical Quantum Memories: from free-space to all-fibered implementations

Julien Laurat
Laboratoire Kastler Brossel, Paris
(quantumnetworks.lkb.ens.fr)

In recent years, the physical implementation of quantum interfaces between light and matter has triggered a very active research, with unique applications to quantum optics and quantum information networks. A successful approach consists in coupling light with atomic ensembles. In this context, I will present recent results based on large ensemble of cold neutral atoms, in two different settings.

The first example will be the storage of multimode structured light, including twisted light and vector vortex beam, in a free-space implementation based on a large magneto-optical trap. The full structuration of light in the transverse plane holds the promise of unprecedented capabilities for applications in classical optics as well as in quantum information sciences. To extend their use to quantum networks, multimode memories have to be realized. By combining an ensemble-based memory implementation and an additional dual-rail multiplexing of the storing medium, we demonstrated a multiple-degree-of-freedom quantum register.

In a second part, I will present an experiment based on a one-dimensional nanoscale waveguide. By interfacing a nanofiber with a laser-cooled ensemble of atoms in the vicinity, we observed electromagnetically-induced transparency, slow-light and coherent storage at the single-photon level in a setting where light is tightly confined in the transverse directions. This result based on subdiffraction-limited optical mode interacting with atoms via the strong evanescent field demonstrates an alternative to free-space focusing and a new capability for information storage in an all-fibered quantum network. I will finally show recent results demonstrating in this system a large Bragg reflection for the guided light. By engineering the optical lattice in the evanescent field it is possible to control the single-photon transport properties.

Germanium mid-infrared plasmonics for sensing

Paolo Biagioni
Politecnico di Milano, Dipartimento di Fisica

The quest for novel plasmonic materials has been a lively area of research over the last few years. In the mid-infrared (mid-IR) spectral region, in particular, localized plasmon resonances in nanoparticles and nanoantennas hold promise for enhanced IR spectroscopies, with key applications in biology, medicine, and security. In this frame, the development of a CMOS-compatible plasmonic platform in the mid-IR could have disruptive effects for future technologies, allowing for cost-effective sensing devices integrated with electronics [1-2].

We report on the growth, fabrication and optical characterization of heavily-doped Ge antennas integrated on a Si substrate and we exploit them for the sensing of solid-phase and liquid-phase analytes [3-5]. Epitaxial Ge is grown on Si by plasma-enhanced chemical vapor deposition, exploiting phosphorous as the dopant and achieving plasma frequencies above 1000 cm-1. We demonstrate two-wire gap antennas fabricated by electron-beam lithography and reactive ion etching techniques, displaying localized plasmon resonances in the important 8 to 13 µm molecular fingerprint region. We target the sensing of a thin polydimethylsiloxane (PDMS) layer (thickness of about 40 nm) and demonstrate an enhancement of two orders of magnitude in the collected signal, as derived from a comparison with the results of detailed numerical simulations. We also demonstrate real-life application such as the sensing of explosive simulants in the liquid phase, which is of interest for airport security screening. Finally, we use Ge antennas to demonstrate for the first time all-optical doping, ultrafast control of antenna resonances, and plasmon-enhanced third harmonic generation in the mid-infrared.

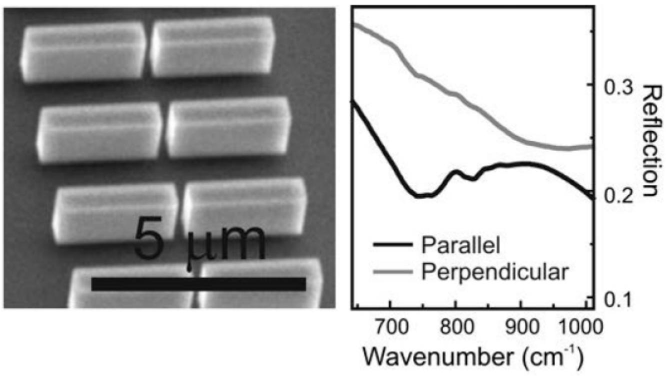

Fig. 1. A SEM image of the Ge antennas on Si (left panel) and sensing of the 800 cm^{-1} vibrational line in PDMS (right panel) for polarization parallel (black line) and perpendicular (grey line) to the antenna axis).

Our results represent a first experimental benchmark for group-IV mid-IR plasmonics and confirm that future CMOS sensing platforms could benefit significantly from plasmonic enhancements provided by integrated heavily-doped Ge-based devices. The research leading to these results has received funding from the European Union's Seventh Framework Programme under grant agreement n°613055.

References

[1] R. Soref, Nature Phot. **4**, 495-497 (2010).
[2] R. Soref, J. Hendrickson, and J.W. Cleary, Opt. Exp. **20**, 3814-3824 (2012).
[3] L. Baldassarre, E. Sakat, J. Frigerio, A. Samarelli, K. Gallacher, E. Calandrini, G. Isella, D.J. Paul, M. Ortolani, and P. Biagioni, Nano Lett. **15**, 7225-7231 (2015).
[4] P. Biagioni, J. Frigerio, A. Samarelli, K. Gallacher, L. Baldassarre, E. Sakat, E. Calandrini, R.W. Millar, V. Giliberti, G. Isella, D.J. Paul, and M. Ortolani, J. Nanophot. **9**, 093789 (2015).
[5] A. Samarelli, J. Frigerio, E. Sakat, L. Baldassarre, K. Gallacher, M. Finazzi, G. Isella, M. Ortolani, P. Biagioni, and D.J. Paul, Thin Solid Films (in press), doi:10.1016/j.tsf.2015.10.005.

Two-photon 3D lithography: A versatile fabrication method for complex 3D shapes for industrial applications

Frank Reil
JOANNEUM RESEARCH Forschungsgesellschaft mbH

Two photon processes enable true 3D writing below the diffraction limit inside a photosensitive material. This allows the fabrication of structures for a broad range of industrial applications, such as photonic crystals and optical interconnects. In this talk, we will cover the range from basic principles to state-of-the-art products and challenges with the emphasis on work performed at Joanneum Research Materials.