HL 44: Optical Properties I

Time: Wednesday 9:30–13:15 Location: H10

Invited Talk HL 44.1 Wed 9:30 H10
Rydberg excitons in cuprous oxide — •Manfred Bayer — Experimentelle Physik 2, TU Dortmund, Germany

Excitons, bound electron-hole complexes, are decisive for the optical properties of semiconductors. Thereby their description as hydrogen atom-like complexes has turned out to be extremely useful. In Rydberg atoms an electron is promoted into a state with high principal quantum number. The atom becomes a mesoscopic object then with dimensions in the micrometer-range, with which, for example, the transition from quantum to classical dynamics can be studied. Recently it has been shown that also excitons can be highly excited by observing states with principal quantum number up to n=25 in high-quality natural cuprous oxide crystals [1]. This corresponds to an average radius of more than a micrometer so that the exciton wave function is extended over more than 10 billion crystal unit cells. In this contribution similarities and differences of these Rydberg-excitons with their atomic counterparts will be addressed.

[1] T. Kazimierczuk, D. Fröhlich, S. Scheel, H. Stolz, and M. Bayer, Nature 514, 343 (2014).

HL 44.2 Wed 10:00 H10
Quantum Chaos of Rydberg Excitons in Cu_2O — •Johannes Thewes, Marc Assmann, Dietmar Fröhlich, and Manfred Bayer — Experimentelle Physik 2, Technische Universität Dortmund, D-44221 Dortmund, Germany

The yellow exciton series of Cu_2O exhibits a complex transition towards quantum chaos under the influence of an external magnetic field. The observed quadratic level repulsion in the chaotic regime indicates a non-trivial breaking of the time reversal symmetry in the system. We argue that an asymmetric scattering process with crystal phonons is the reason for the non-trivial breaking of time reversal symmetry in Cu_2O.

In a hydrogen-like system like this, the breaking of time reversal symmetry by the magnetic field itself is not sufficient to observe quadratic level repulsion. For such systems, there is still a combined symmetry operation available that leaves the system invariant. Hence, the Hamiltonian of these systems can be represented by a real and symmetric matrix which is only the prerequisite for linear level repulsion in the chaotic regime.

HL 44.3 Wed 10:15 H10
Strong coupling in a resonant inorganic/organic microcavity — •Michael Höfner[1], Sergey Sadofev[1], Björn Kobin[2], Stefan Hecht[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin — [2]Humboldt-Universität zu Berlin, Institut für Chemie, Brook-Taylor-Str. 2, 12489 Berlin

We present strong exciton photon coupling in a hybrid microcavity containing ZnO/ZnMgO quantum wells and specially synthesized ladder-type oligo-(p-phenylene) molecules. An epitaxially grown ZnMgO based Bragg reflector followed by six ZnO quantum wells and the active molecule embedded in a polymer matrix. The cavity is completed by evaporating a SiO_2/ZrO_2 based dielectric mirror. The system is investigated by low temperature angular resolved reflectivity revealing a clear anticrossing related to the Frenkel and Wannier-Mott exciton creating three polariton branches. At an angle of incidence of 35° an equal mixing of all resonances is reached [1]. Through careful adjustment of the oscillator strength of both active materials and the cavity design, we reach an equal mixing in the middle polariton branch. A hybrid exciton-polariton with equal contribution of the photon, Frenkel and Wannier-Mott resonance is created. This makes this new material combination an excellent candidate for tailoring the phonon assisted polariton relaxation and creating a polariton laser.

[1] M. Höfner, S. Sadofev, B. Kobin, S. Hecht and F. Henneberger, Hybrid polaritons in a Resonant Inorganic/Organic Semiconductor microcavity, Appl. Phys. Lett. 107, 181109, 2015.

HL 44.4 Wed 10:30 H10
Quantum Defects of Excitons in Cu_2O — Florian Schöne, •Sjard Ole Krüger, Peter Grünwald, Heinrich Stolz, and Stefan Scheel — Institut für Physik, Universität Rostock, D-18059 Rostock, Germany

Recent experiments have shown a clear deviation of the yellow exciton series in Cu_2O from an ideal (hydrogen) Rydberg series [1]. We present numerical calculations for the exciton binding energies based on the nonparabolicity of the Γ_7^+ valence band using a group theoretical band hamiltonian [2]. The momentum space Schrödinger equation has been reduced to a set of Fredholm integral equations for the radial part of the wavefunction, which could be solved numerically. Describing the deviation from a Rydberg series through quantum defects, we analyzed the influence of the valence band nonparabolicity on the exciton binding energies for angular momenta $l = 0, \ldots, 3$.

[1] T. Kazimierczuk, D. Fröhlich, S. Scheel, H. Stolz, M. Bayer, doi:10.1038/nature13832

[2] F. Schöne, S.-O. Krüger, P. Grünwald, J. Thewes, M. Aßmann, J. Heckötter, D. Fröhlich, M. Bayer, H. Stolz, and S. Scheel, arXiv:1511.05458 [cond-mat.mes-hall].

HL 44.5 Wed 10:45 H10
DIP: Organic Small Molecules for Strong Coupling — •Felix Lemke, Hartmut Fröb, and Karl Leo — Institut für Angewandte Photophysik, TU Dresden, Germany

Due to recent reports on polariton lasing with reduced threshold compared to conventional lasing, the investigation of strong coupling is of large interest. Organic molecules are promising candidates for studying light matter interaction due to their high exciton binding energy, creating a large polaritonic splitting. Since organic molecules are often unstable, there is ongoing research on small, thermally evaporable organic molecules for strong coupling.

In this work, we discuss Bu4-Ph4-DIP evaporated in between two mirrors to form a microcavity. Reflection measurements of different sample structures (one DBR/one metal mirror or two metal mirrors) are presented, showing a splitting between both polariton branches of several tens of meV. In the structure made of two metal mirrors, even a third branch arising from higher vibronic states of the molecule can be identified. The measurements are compared to calculations based on the transfer matrix algorithm.

30 min. Coffee Break

HL 44.6 Wed 11:30 H10
Exciton-Polaritons in doped semiconductor microcavities with finite hole mass — •Dimitri Pimenov[1], Oleg Yevtushenko[1], Jan von Delft[1], and Moshe Goldstein[2] — [1]Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, D-80333 München, Germany — [2]School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

As shown in recent experiments, spectral properties of exciton-polaritons in optical microcavities with an embedded semiconductor quantum well are strongly affected by doping of the semiconductor. Previous theoretical studies concerned with nonzero Fermi-energy mostly relied on the approximation of infinite valence band hole mass, which is appropriate for low-mobility samples only. For high-mobility samples, one needs to consider large but finite hole mass. We present an analytical diagrammatic approach to tackle this problem for a model of short-ranged (screened) electron-hole interaction, studying its two different regimes. In the first regime, where the Fermi-energy dominates over the exciton binding energy, one can make use of the summation of parquet diagrams introduced by Mahan and Nozières. As a trend, finite mass effects cut off the excitonic features in the polariton spectra, in qualitative agreement with the experimental findings. In the second regime of dominant binding energy, we perform a low-density summation of ladder diagrams. As opposed to the previous case, the excitonic features are enhanced by the finite mass, which can be understood based on phase-space arguments.

HL 44.7 Wed 11:45 H10
Coherent manipulation of photonic crystal microcavities with metallic electric contacts — •Wadim Quiring[1], Björn Jonas[1], Ashish Rai[2], Dirk Reuter[1], Andreas Dirk Wieck[2], and Artur Zrenner[1] — [1]Center for Optoelectronics and Photonics Paderborn (CeOPP), Universität Paderborn, Paderborn, Germany — [2]Ruhr-Universität Bochum, Bochum, Germany

We present our results of a two pulse experiment on a photonic crystal cavity (PhCC). We use MBE-grown GaAs membranes, which are designed as n-i-Schottky structures with an InGaAs wetting layer as active layer in the intrinsic region. From this we have fabricated PhCCs with narrow electrodes, which provide an electric connection to the defect and allow for photocurrent (PC) readout. The samples were first characterized by PC spectroscopy under resonant cw excitation [1]. The measured Q factors are around 5000. Double pulse excitation was realized by a 3.5 ps Ti:Sa laser followed by a Michelson interferometer. The pulse separation and relative phase could be precisely controlled over a long range. Changing the time delay we simultaneously monitored the interferogram (i) of the laser fields and (ii) of the cavity response using photocurrent detection. The excitation wavelength was chosen to be either on the cavity resonance or in defined detuning conditions. Our experiments clearly show the coherent control of the PhCC and its phase evolution with respect to the driving laser field. [1] W. Quiring et. al, Appl. Phys. Lett. 107, 041113 (2015)

HL 44.8 Wed 12:00 H10

Tailored Scattering Layers to Homogenize Light Emission from Large-Area Organic Light-Emitting Diodes — •Frederik Mayer[1], Robert Schittny[1], Amos Egel[2], Andreas Niemeyer[1], Jan Preinfalk[2], Ulrich Lemmer[2], and Martin Wegener[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — [2]Light Technology Institute and Institute of Microstructure Technology, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — [3]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

For large-area organic light-emitting diodes, the relatively high sheet resistance of the transparent electrode layer is often compensated for by adding a metallic electrode grid on top. However, these electrodes cast a shadow, leading to a spatially inhomogeneous light emission of the OLED. In this talk, based on recent findings on diffusive-light cloaking, we present a method to homogenize this light emission and thereby hide the contact grid by adding an additional light-scattering layer on top, consisting of regions with different concentrations of scattering particles. We design this light-scattering layer using Monte-Carlo simulations of light transport through multiply-scattering media and show corresponding experiments on a scaled-up model structure.

HL 44.9 Wed 12:15 H10

Circular Bragg grating cavity design for efficient sources of single photons fabricated within a deterministic technology platform — •Anna Musiał[1,2], Benjamin Wohlfeil[3], Sven Burger[3], Tobias Heuser[1], Arsenty Kaganskiy[1], Esra Yarar Tausher[1], Ronny Schmidt[1], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Faculty of Fundamental Problems of Technology, Wrocław University of Technology, Poland — [3]Computational Nano Optics, Zuse Institut Berlin, Germany

Growing interest in quantum information processing and secure communication requires realization of efficient single-photon sources (SPS). Reliable implementation of advanced quantum protocols makes deterministic fabrication technologies desirable. A further key requirement is maximizing the extraction efficiency of emission from QDs acting as single-photon emitters. To tackle these issues we propose to deterministically integrate single QDs into circular Bragg grating cavities (CBGC). We present results based on the modelling of GaAs/air CBGCs using a finite element method which allows us to optimize the cavity design parameters for maximum extraction efficiency. For this purpose, a detailed knowledge of the influence of cavity geometry on the electro-magnetic field distribution, mode energy, cavity quality factor and optimal position of the QD in the cavity is indispensable. Optimized design parameters are used to realize CBGCs that include single In(Ga)As QDs by combining cathodoluminescence spectroscopy and in-situ electron-beam lithography.

HL 44.10 Wed 12:30 H10

Nonlinear optical coefficients of III-V semiconductors measured by Raman spectroscopy — •Christian Röder, Gert Irmer, Cameliu Himcinschi, and Jens Kortus — TU Bergakademie Freiberg, Institute of Theoretical Physics, Leipziger Str. 23, D-09599 Freiberg, Germany

Applications based on nonlinear waveguides, frequency doubling, frequency mixing or phase conjugation require for design and optimization of devices an accurate knowledge of the linear and nonlinear optical response. Johnston and Kaminow [1] demonstrated for GaAs that Raman scattering can be used to determine the nonlinear optical coefficients below the bandgap. In case of wz-GaN there have been several experimental and theoretical studies with significant divergences concerning the coefficients of the second-harmonic generation (SHG) and the linear-optical effect (LEO). Due to the wurtzite structure of GaN symmetry requires three SHG and LEO coefficients to be considered independently. In the present study Raman scattering experiments were performed in order to determine all six coefficients of wz-GaN for the first time.
This work is financially supported by the European Union (European Social Fund) and by the Saxonian Government (grant no. 100231954).

[1] W.D. Johnston, Jr. and I.P. Kaminow: Phys. Rev. **188**, 1209 (1969)

Invited Talk HL 44.11 Wed 12:45 H10

From a loophole-free Bell test to a secure quantum Internet — •Ronald Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

For more than 80 years, the counterintuitive predictions of quantum theory have stimulated debate about the nature of reality. In his seminal works, John Bell showed that in any theory in which events only have local causes, the correlations between distant measurements satisfy an inequality and, moreover, that this inequality can be violated according to quantum theory. In the past decades, numerous ingenious Bell inequality tests have been reported. However, because of experimental limitations, all experiments to date required additional assumptions to obtain a contradiction with local realism, resulting in "loopholes".

In this talk I will explain our recent Bell experiment that is free of any such additional assumption [1], in which we entangle two electron spins in diamond separated by more than 1 km. I will discuss the implications of its result for possible models of nature. Furthermore, I will speculate how this result, combined with recently achieved control over individual nuclear spins in diamond [2] and teleportation between separated diamond chips [3], may lead to a quantum Internet secured through device-independent protocols - reaching the ultimate physical limits of privacy [4].

[1] B. Hensen et al., Nature 526, 682 (2015). [2] J. Cramer et al., arXiv:1508.01388 (2015). [3] W. Pfaff et al., Science 345, 532 (2014). [4] A. Ekert and R. Renner, Nature 507, 443 (2014).