HL 24: Photonic crystals II

Time: Tuesday 9:30–13:15 Location: EW 202

HL 24.1 Tue 9:30 EW 202

Direction selective filter using 3D photonic structures for ultralight trapping in solar cells — •Johannes Üpping, Andreas Bielawny, Paul T. Miclea, and Ralf Wehrspohn — Institut für Physik, Universität Halle-Wittenberg, Halle, Germany

We suggest a model to implement three dimensional photonic structures with direction-selective properties to be incorporated in solar cells. Our devices enhance the pathway of incident light within the solar cell in the spectral region of low absorption by restricting the reemission angle of the solar cell, this kind of light trapping we call ultra light trapping. Numerical studies of 3D photonic structures have been carried out with different numerical methods in order to find convenient structures. By matching photonic stop gaps of our device to the electronic bandgap of the cells semiconductor material, and with the orientation of the stop gaps high-symmetry axes around, but not in the direction of normal incidence, we inhibit the propagation of light selectively in angle and spectral distribution. At normal incidence, high transmission is provided because of another high symmetry axis of the photonic crystal. The result is a decrease in the allowed angle of reemission for the solar cell. A direction selective transmission calculation and corresponding microwave measurements show the ability of an inverted opal structure for ultra light trapping.

HL 24.2 Tue 9:45 EW 202

Coupled Bragg Pillar Cavities with Localized and Delocalized Mode Structure — •Matthias Karl[1], Shunfeng Li[1], Erich Müller[2], Dagmar Gerthsen[2], Heinz Kalt[1], and Michael Hetterich[1] — [1]Institut für Angewandte Physik and Center for Functional Nanostructures (CFN), Universität Karlsruhe (TH), 76128 Karlsruhe, Germany — [2]Laboratorium für Elektronenmikroskopie and CFN, Universität Karlsruhe (TH), 76128 Karlsruhe

In the context of a further application in quantum information processing we are investigating the optical coupling of spatially separated quantum dots (QDs) via optical microcavity modes. For this purpose we study pillar cavities with top and bottom GaAs/AlAs Bragg mirrors. InAs QDs are embedded in the middle of the lambda-thick cavity emitting at around 950 nm. Out of this molecular-beam epitaxially grown layer structure single and connected pillars are milled by means of a focused-ion beam. A micro-photoluminescence set-up with an additional spatial resolution allows to measure the intensity distribution for different modes. Depending geometrically on the diameters of the pillars and the coupling bridge between two of them it is possible to design connected pillars with the coexistence of localized and delocalized cavity modes. The design of such cavity structures is devised using a step-index fiber simulation based on the finite-element method. Experimental results confirm these predicted cavity mode structures.

HL 24.3 Tue 10:00 EW 202

Local Infiltration of Individual Pores with Optical Nonlinear Polymers in Macroporous Silicon Photonic Crystals — •Peter Nolte[1], Daniel Pergande[1], Stefan S. Schweizer[1], Ralf B. Wehrspohn[1], Markus Geuss[2], and Martin Steinhart[2] — [1]Institut für Physik, Universität Halle-Wittenberg, Halle, Germany — [2]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany

Photonic crystals (PhC) are a promising concept for new optical components. Passive devices in PhC, e.g. complex waveguides, are widely known, but for most applications active devices are required. One possible way to realize such devices is the functioning of 2D-PhC. This can be done by combining 2D-PhC with optical nonlinear (nlo) polymers. We present an experimental technique for the infiltration of individual pores which allows the realization of a broad spectrum of different designs. For the infiltration experiments we use 2D-PhC templates made of marcroporous silicon. After electrochemical deposition of a gold layer we use a focused ion beam machine and a mature infiltration technique for the infiltration of individual pores.

HL 24.4 Tue 10:15 EW 202

Simulation of Optical Nanostructures via a Fourier Modal Method — •Sabine Essig[1,2,3] and Kurt Busch[1,2,3] — [1]Institut für Theoretische Festkörperphysik, Universität Karlsruhe — [2]Karlsruhe School of Optics & Photonics (KSOP), Universität Karlsruhe — [3]DFG Forschungszentrum Center for Functional Nanostructures (CFN), Universität Karlsruhe

We present simulation results for three-dimensional periodic nanostructures via the Fourier Modal Method in combination with the Scattering-matrix approach. This method provides us with the possibility to investigate the optical properties of photonic crystals in an easy way. By carefully applying Fast Fourier Factorization rules also metallic nanostructures such as photonic metamaterials can be simulated.

In our simulations we pay particular attention to chiral metamaterials. We show calculations of transmittance and reflectance spectra as well as electric and magnetic field distributions inside these structures.

HL 24.5 Tue 10:30 EW 202

Silicon on insulator photonic crystal nanostructures for label free optical biosensing — •Thomas Zabel, Dominic F. Dorfner, Uli Rant, Gerhard Abstreiter, and Jonathan J. Finley — Walter Schottky Institut, TU Muenchen, Am Coulombwall 3, 85748 Garching

Silicon based photonic crystal (PC) nanostructures are of widespread interest for realizing optical waveguides, low-loss bends and nanoscale cavities. The mode frequencies of such cavities is highly sensitive to their local dielectric environment, making them interesting for sensitive label free optical bio-sensing. We have designed and realized 2D PC nanocavity sensors based on the biocompatible SOI material system by defining a triangular lattice of air-holes in a 300nm thick freestanding Si membrane. The 400nm lattice pitch results in a 2D PBG extending from $\sim 1.4 - 1.6\mu m$. A W1 waveguide is used to guide light into the structures and evanescently couple to point defect nanocavities defined in their immediate vicinity. Light from a tunable laser source allows measurements of cavity Q-factors and resonant frequencies by detecting radiation from the surface. Operating such structures in air and a micro-fluidic cell allow us to measure the cut-off wavelength of the PC waveguide and the cavity modes as a function of the local dielectric environment. We have optimized the cavity design and achieved Q-factors up to $\sim$ 46000 in air and observed mode shifts up to $\Delta\lambda = 50nm$ upon immersing in various solvents. These structures allow local refractive index changes of $\Delta n/n < 0.001$ to be detected. Perspectives for sensing non-specifically adsorbed proteins such as BSA will be discussed. Supported financially by the Nanosystems Initiative Munich

HL 24.6 Tue 10:45 EW 202

Time-Domain Simulations for Metallic Nano-Structures — A Krylov-Subspace Approach Beyond the Limitations of FDTD — •Michael König[1,3], Jens Niegemann[1,2,3], Lasha Tkeshelashvili[1,2,3], and Kurt Busch[1,2,3] — [1]Institut für Theoretische Festkörperphysik, Universität Karlsruhe — [2]DFG Forschungszentrum Center for Functional Nanostructures (CFN), Universität Karlsruhe — [3]Karlsruhe School of Optics & Photonics (KSOP), Universität Karlsruhe

Numerical simulations of metallic nano–structures are crucial for the efficient design of plasmonic devices. Conventional time–domain solvers such as FDTD introduce large numerical errors especially at metallic surfaces. Our approach combines a discontinuous Galerkin method on an adaptive mesh for the spatial discretisation with a Krylov-subspace technique for the time-stepping procedure. Thus, the higher-order accuracy in both time and space is supported by unconditional stability. As illustrative examples, we compare numerical results obtained with our method against analytical reference solutions and results from FDTD calculations.

HL 24.7 Tue 11:00 EW 202

Transmission Line Studies of Planar Optical Metamaterials — •Liwei Fu, Heinz Schweizer, Hongcang Guo, Na Liu, and Harald Giessen — 4. Physikalisches Institut, Universität Stuttgart, Germany

A number of recent studies have shown that optical metamaterials can be envisioned as nanocircuits in which local optical electric and magnetic fields are tailored and manipulated in the subwavelength domain [1, 2, 3, 4]. By properly arranging arrays of basic nano-scale circuit elements, stacked nano-transmission line metamaterials can be obtained to support forward or backward electromagnetic waves [2]. In this report we demonstrate transmission line circuit models for several pla-

nar optical metamaterials, which are synthesized based on retrieved nonlocal effective material parameters. Through these models, physical insight into the difference among several metamaterials can be obtained. We show further numerically that a negative index at optical frequencies with a high figure of merit (larger than 3.0 around 600 nm) can be obtained in an optimized meander structure. Most importantly, these circuit models provide the possible building blocks for 3D metamaterials.

[1] L. Fu, H. Schweizer, H. Guo, N. Liu, and H. Giessen, Appl. Phys. B 86, 425 (2007).

[2] N. Engheta, Science 317, 1698 (2007).

[3] H. Schweizer, L. Fu, H. Gräbeldinger, H. Guo, N. Liu, S. Kaiser, and H. Giessen, Phys. Stat. Sol. (b) 244, 1243 (2007).

[4] H. Schweizer, L. Fu, H. Gräbeldinger, H. Guo, N. Liu, S. Kaiser, and H. Giessen, Phys. Stat. Sol. (a) 204, 3886 (2007).

15 min. break

HL 24.8 Tue 11:30 EW 202

Bistable lasing and ultrafast mode switching in photonic crystal microcavities — •Sergei V. Zhukovsky[1], Dmitry N. Chigrin[1], Andrei V. Lavrinenko[2], and Johann Kroha[1] — [1]Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]COM-DTU, Department of Communications, Optics, and Materials, NanoDTU, TU Denmark, Bld. 345V, 2800 Kgs.Lyngby, Denmark

We show analytically and numerically that a system based on coupled microcavities can exhibit bistable lasing. Bistability occurs when microcavity modes have similar intensity distributions within the gain region. Both incoherent (hole-burning) and coherent (population-pulsation) mode interaction processes contribute to the development of bistability. Unlike the modes of most ring-laser or polarization-bistable set-ups, the modes of coupled microcavities can still have different frequencies. The phase structure of the modes remains distinct, which makes them addressable for selective lasing using a pulsed injection signal with matching symmetry [1]. We demonstrate numerically that a switching of the laser wavelength by about 20 nm at the time scale of 10 ps is possible for twin coupled defects in a 2D photonic crystal lattice [1], by far exceeding the performance of a conventional (e.g., electrooptical or micromechanical) tuning of a microcavity. The results obtained can be used in the design of integrated optical components such as multiple-wavelength microlaser sources or optical memory cells (see [2]) with nearly monochromatic control signals.

[1] S. V. Zhukovsky et al, Phys. Rev. Lett. **99**, 073902 (2007).
[2] M. Hill et al, Nature **432**, 206 (2004).

HL 24.9 Tue 11:45 EW 202

Complex Liquid Crystal Director Fields Appearing in Photonic Crystals — Heinrich Matthias and •Heinz-Siegfried Kitzerow — Faculty of Science, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

It is well known that liquid crystals can be utilized to control the optical properties of photonic crystals. The frequencies of stop band edges and the resonance frequencies of microcavities embedded in photonic crystals can be tuned by changing the temperature or applying external fields [1]. However, the complex geometry of the cavities and the anchoring of the liquid crystal orientation at interfaces cause complicated director fields [2,3] rather than an ideal, uniform alignment of the liquid crystal molecules. In addition, chirality can induce a twisted director field thereby adding an additional spatial periodicity (given by the helix pitch) to the structure. In this contribution, we describe different director fields that have been observed in the pores of photonic crystals by means of fluorescence confocal polarization microscopy. The stability conditions of topologically different director configurations are discussed.

[1] H.-S. Kitzerow, A. Lorenz, and H. Matthias: phys. stat. sol. (a) 204, 3754 (2007). [2] H. Matthias, T. Röder, S. Matthias, R. B. Wehrspohn, S. Picken and H.-S. Kitzerow: Appl. Phys. Lett. 87, 241105 (2005). [3] H. Matthias, S. L. Schweizer, R. B. Wehrspohn, and H.-S. Kitzerow: J. Opt. A: Pure Appl. Opt. 9, 389 (2007).

HL 24.10 Tue 12:00 EW 202

GaAs Micropyramids as Optical Resonators — •Torsten Beck, Matthias Karl, Frank M. Weber, Jaime Lupaca-Schomber, Shunfeng Li, Dongzhi Hu, Daniel M. Schaadt, Heinz Kalt, and Michael Hetterich — Universität Karlsruhe (TH) and Center for Functional Nanostructures (CFN), 76128 Karlsruhe, Germany

We fabricate and study GaAs micropyramids for future applications in quantum optics. Such pyramids are promising since high quality factors and small mode volumes should be feasible. The pyramidal shape is achieved by a combination of molecular-beam epitaxy, electron-beam lithography and a wet-chemical etching process. In contrast to self-assembled growth the chemical etching method allows control of the exact geometry of the pyramids especially the angle of the facets. To obtain a high optical confinement the pyramids are placed on a GaAs/AlAs distributed Bragg reflector (DBR). Besides the emission of the embedded InAs quantum dots the micro-photoluminescence spectra of the pyramidal structures show peaks of cavity modes. We investigate the mode arrangement depending on geometry. For comparison we simulate the modes with a finite-difference time-domain method. For an improvement of the optical confinement we deposite metallic films and overgrow the pyramids with DBRs. Furthermore, coupled resonator structures are fabricated.

HL 24.11 Tue 12:15 EW 202

Ethanol gas sensor based on Silicon Photonic Crystal — •Stefan L. Schweizer[1], Jürgen Wöllenstein[2], Armin Lambrecht[2], and Ralf B. Wehrspohn[1] — [1]Institut für Physik, Universität Halle-Wittenberg, 06099 Halle — [2]Fraunhofer Institut Physikalische Messtechnik, Heidenhofstr. 8, 79110 Freiburg

Gas sensors based on optical absorption are advantegous because of their sensitivity, selectivity and dynamic range. We use a 2D Photonic Crystal (PhC) based on silicon for qualitative and quantitative gas analysis of ethanol. The bandstructure of PhCs offers intriguing possibilities for the manipulation of electromagnetic waves. Taking advantage of the low group velocity and certain mode distributions for some k-points in the bandstructure of a PhC should enable the realization of very compact sensor devices for mobile applications.

We prepared sensing elements based on macroporous silicon PhCs consisting of up to 1000 of pore rows and measured the transmission with and without gas through the porous sensing element. We observed an enhancement in sensitivity of about 3 to 4 compared to a gas cell without a PhC. For further increase of the enhancement factor we optimized the photoelectrochemical etch process and switched to neutron transmutated doped silicon. Simulations predict an enhancement factor of about 30 which would allow a reduction of the setup by this factor - without loss of performance!

HL 24.12 Tue 12:30 EW 202

Simulation of Modified Radiation Dynamics using Higher-Order Methods — •Jens Niegemann[1,2,3], Lasha Tkeshlashvili[1,2,3], and Kurt Busch[1,2,3] — [1]Institut für Theoretische Festkörperphysik, Universität Karlsruhe — [2]DFG Forschungszentrum Center for Functional Nanostructures (CFN), Universität Karlsruhe — [3]Karlsruhe School of Optics & Photonics (KSOP), Universität Karlsruhe

Since the original proposal of photonic crystals, the modification of radiation dynamics was considered a feature of fundamental interest. Here, we use higher-order time-domain calculations of the coupled Maxwell-Bloch-equations in order to investigate the influence of photonic crystals on the decay of initially excited 2-level atoms. In particular, we investigate the effects of finite sample sizes as well as the influence of non-radiative transitions and dephasing. All calculations are performed through a discontinuous Galerkin finite element technique. This method allows to accuratly model complex geometries while it still maintains flexibility and reasonable performance. Thus, it is very well suited to study a large variety of experimentally relevant systems.

HL 24.13 Tue 12:45 EW 202

Analysis of metallic nanometer meander structures — •Heinz Schweizer — University Stuttgart, 4. Phys. Inst. Pfaffenwaldring 57, 70569 Stuttgart

Metallic meander structures can be regarded as basic building blocks for optical metamaterials as they show capacitive series impedance over a large bandwidth [1]. This impedance leads to a negative permeability in a homogeneous metamaterial. Meander structures are also advantageous as their impedance stays mostly isotropic with respect to the angle of incidence. We analyze the electromagnetic response on the basis of group theory and find the coupling regimes for E- and B- fields that are justified by angle-dependent optical measurements on single metamaterial layers. From optical transmission spectra we find under 20°rotation of the incident k-vector around the H-field direction only little change of the transmission spectra. The capacitive impedance spans a spectral region from 550 nm up to 665 nm. Interpreting the single layer as a thin sheet homogeneous material the impedance value corresponds to a maximum permeability value of - 4.5 at 650 nm.

[1] H. Schweizer et al., phys. stat. sol. (a) 204, 3886 (2007).

HL 24.14 Tue 13:00 EW 202

Three-dimensional photonic metamaterials at optical frequencies — •Na Liu[1], Hongcang Guo[1], Liwei Fu[1], Stefan Kaiser[2], Heinz Schweizer[1], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, 70569 Stuttgart, Germany — [2]1st Physics Institute, University of Stuttgart, 70569 Stuttgart, Germany

We present a general method to manufacture three-dimensional optical metamaterials [1] using a layer-by-layer technique. Specifically, we introduce a fabrication process involving planarization, lateral alignment, and stacking [2]. We experimentally demonstrate three-dimensional split-ring resonator metamaterials as well as fish-net metamaterials. We investigate the interaction between adjacent stacked layers using the method of plasmon hybridization [2,3] and analyze the optical properties of stacked metamaterials with respect to an increasing number of layers. Our method should pave the way towards bulk metamaterials and give new design rules for a broadband response.

[1] C. M. Soukoulis, S. Linden, and M. Wegener, Science 315, 47 (2007).

[2] N. Liu, H. C. Guo, L. W. Fu, S. Kaiser, H. Schweizer, and H. Giessen, Nat. Mater. (2007), in press.

[3] N. Liu, H. C. Guo, L. W. Fu, S. Kaiser, H. Schweizer, and H. Giessen, Adv. Mat. 19, 3628 (2007).