



Lifelong Learning Programme



# EUROPHOTONICS-POESII SPRING SCHOOL 2017

### SITGES, BARCELONA

### 22<sup>nd</sup> - 24<sup>th</sup>of March, 2017



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#### **Organizers:**

*Crina Cojocaru,* Universitat Politècnica de Catalunya Sophie Brasselet and Hugues Giovannini, Université Aix Marseille

The field of Photonics, the science of light, is booming and involves a large number of interdisciplinary activities in health, environment, energy, transport, telecommunications with significant economic and societal benefits. Optics and Photonics plays a key role in fundamental discoveries and in new technologies, with theoretical and experimental aspects. Photonics is considered by the European Commission as one of the "Key Enabling Technologies (KET)" which are increasingly driving innovation today and will continue to drive innovation in the future.

The Spring School is organized every year by **the Erasmus Mundus International Master and Doctorate programs EUROPHOTONICS**: Photonics Engineering, Biomedical Imaging, Quantum Optics, Laser Optics, Optics for Astronomy, Nanophotonics, Biophotonics (<u>http://www.europhotonics.org/wordpress/</u>), with participation of students from more than 20 different countries.

2017 edition will be held in the in **Sitges**, a small town located at half an hour drive or train ride from Barcelona's city center.

<u>CONTACTS:</u> Crina Cojocaru: <u>crina.maria.cojocaru@upc.edu</u> Alba Rubies: <u>alba.rubies@upc.edu</u>



### Sitges – Barcelona

Sitges is a Mediterranean coastal town, located in the Garraf area in the province of Barcelona, in Catalonia, Spain. Sheltered by the Garraf mountains and due to its geographical position in the Mediterranean, Sitges has a warm "micro-climate" that makes it possible to enjoy outdoor activities almost every day of the year.





### Location for the Spring School: Hotel Sunway Playa Golf

The Hotel is located on the promenade of Sitges, in front of the sea.

http://en.sunway.es/hotel-sunway-playa-golf-in-sitges/

Address: Paseo Maritimo 92-94, Sitges



### **Spring School agenda**

	Tuesday 21 <sup>st</sup> of March	Wednesday 22 <sup>nd</sup> of March	Thursday 23 <sup>rd</sup> of March	Friday 24 <sup>th</sup> of March
9.15-9.30		Opening session		
9.30-10.00		Lecture 1	Lecture 5	Lecture 12
10.00 - 10.30		(Alexander Lorenz)	(Heinz Kalt)	alt) (Ulrich Paetzold)
10.30 - 11.00		coffee break	coffee break	coffee break
11.00 - 11.30		Lecture 2	Lecture 6	Lecture 13 (Nicolas Bonod)
11.30 - 12.00		(Jordi Mompart)	(Christian Eggeling)	
12.00 - 12.30		Lecture 3	Lecture 7	Lecture 14 (Ulrich Lemmer)
12.30 - 13.00		(Heinz Kitzerow & Jörg Lindner)	(Frank Koppens)	
13.00-13.30				Closing session
13.30-14.00		lunch	lunch	
14.00 -14.30				lunch
14.30 - 15.00		Lecture 4 (Santiago Royo &	Lecture 8 (Simon Thiele)	
15.00 - 15.30		Meritxell Vilaseca)		
15.30 - 16.00		PhD talk 1	Lecture 9	
16.00 - 16.30		PhD talk 2	(Maria García Parajo)	
16.30 - 17.00		PhD talk 3	Lecture 10	
17.00 - 17.30	registration	PhD talk 4	(Romain Quidant)	
17.30 - 18.00		coffee break	coffee break	
18.00 - 18.30		PhD talk 5	Lecture 11	
18.30 - 19.00		PhD talk 6	(Niek van Hulst)	
19.00 - 19.30		Poster session	SECPhO - Light Technology Cluster (Sergio Sáez: manager)	
19.30 - 20.00			Round Table : future	
20.00 - 20.30			careers in Photonics	
20.30-10.00	dinner	dinner	dinner	

### **Invited Lectures**

INVITED TALKS	SPEAKER	TITLE	INSTITUTION
Lecture 1	Alexander Lorenz	Photopolymers and their uses in liquid crystals	Paderborn University, Germany
Lecture 2	Jordi Mompart	Optics and atoms a la de Broglie-Bohm	Optics Group, Phisics Faculty, Universitat Autónima de Barcelona
Lecture 3	Heinz Kitzerow & Jörg Lindner	Plasmonic nanostructures: spectroscopy and electron microscopy	Paderborn University, Germany
Lecture 4	Santiago Royo & Meritxell Vilaseca	CD6: Research and Innovation transfer	Centre for Sensors, Instruments and Systems Development, Universitat Politècnica de Catalunya
Lecture 5	Heinz Kalt	Tunable Polymer Photonics	Institute of Applied Physics (APH) Karlsruhe Institute of Technology (KIT), Germany
Lecture 6	Christian Eggeling	Super-resolution microscopy: Challenges and Potentials in biomedical research	Wolfson Imaging Centre Oxford, Weatherall Institute of Molecular Medicine, University of Oxford , UK
Lecture 7	Frank Koppens	Graphene quantum nano- optoelectronics: fundamentals and applications	The Institute of Photonics Sciences (ICFO), Barcelona, Spain
Lecture 8	Simon Thiele	3D printed complex microoptics	Universität Stuttgart, Institut für Technische Optik
Lecture 9	Maria Garcia Parajo	Nanophotonic approaches to investigate the spatiotemporal organization of biological membranes	The Institute of Photonics Sciences (ICFO), Barcelona, Spain
Lecture 10	Romain Quidant	Putting Nanophotonics to Work	The Institute of Photonics Sciences (ICFO), Barcelona, Spain
Lecture 11	Niek van Hulst	Tracking femtosecond dynamics at the nanoscale	The Institute of Photonics Sciences (ICFO), Barcelona, Spain
Lecture 12	Ulirich Paetzold	Perovskite Photovoltaics	Karlsruhe Institute of Technology (KIT), Germany
Lecture 13	Nicolas Bonod	Resonant interaction of light with metallic and dielectric particles	Fresnel Institute, Marseille, France
Lecture 14	Uli Lemmer	Unravelling the role of charge transfer states in polymer solar cells	Karlsruhe Institute of Technology (KIT), Germany

### **Europhotonics PhD Students**

PhD TALKS	SPEAKER	TITLE	INSTITUTION
PhD talk 1	Raju Regmi	In-plane plasmonic nano antennas explore membrane heterogeneities in living cells	Fresnel Institute (France) - ICFO (SPAIN)
PhD talk 2	Waqas Waseem Ahmed	Light propagation in PT-symmetric potentials	UPC - LENS
PhD talk 3	Dmitry Nuzhdin	Subpicosecond imaging of polymeric photonic circuits	LENS - KIT
PhD talk 4	Vikas Remesh	Observing the ultrafast processes in nanostructures	ICFO - Fresnel Institute
PhD talk 5	Pablo Marín Palomo	Chip-Scale Frequency Comb Sources for Coherent Optical Communications	KIT - ICFO
PhD talk 6	Awoke Atena Negash	Blind-SIM reconstruction techniques for fluorescence microscopy	Fresnel - ICFO

### **Round Table participants**

Name	INSTITUTION	
Sergio Sáez	Souther European Cluster in Photonics and Optics (SECPho) - Cluster Manager http://www.secpho.org/secpho/	
Martin Leahy	National University of Ireland, Galway, Scientific Director of the National Biophotonics and Imaging Platform (www.nbipireland.ie), manager of Oxford Optronix.	
Romain Quidant	The Institute of Photonics Sciences (ICFO), Barcelona, Spain	
Maria Garcia Parajo	The Institute of Photonics Sciences (ICFO), Barcelona, Spain	
Niek van Hulst	The Institute of Photonics Sciences (ICFO), Barcelona, Spain	
Heinz Kalt	Institute of Applied Physics (APH) Karlsruhe Institute of Technology (KIT), Germany	
Uli Lemmer	Light Technology Institute Karlsruhe Institute of Technology (KIT), Germany	

### Lectures

#### [Lecture-1]

#### Photopolymers and Their Uses in Liquid Crystals

#### **Alexander Lorenz**

Department of Chemistry, University of Paderborn, Germany

Use of photopolymer in hybridized liquid crystals has led to much improved hybrid materials with enhanced stability, novel kinds of responses, or enhanced responsiveness. Polymer-



(single and stack)

Fig. 1. Calamitic LCs are soft, fluid phases, which consist of rod-shaped organic molecules. Their structure can be visualized by three-dimensional arrangements of rods (director fields). Each rod represents a small volume of (on average) parallel molecules. Chirality leads to twisted director fields.

stabilized blue phase LCs [1-5], chiral nematic LCs with flexoelectro-optic response [6-8], and also copolymer network nematic LCs [9are great examples for emerging 11] technologies with high prospects for novel photonic applications. The electro-optical performance of these hybridized LCs can be impressively enhanced by use of a small fraction of in-situ generated polymer. Calamitic LCs consist of rod-shaped molecules. Due to a small amount of added chiral compounds (chiral dopants), these molecules can form helical arrangements (Fig. 1: chiral nematic helix). The pitch length inside chiral nematic LCs (N\*-LCs) is highly sensitive to both dopant concentration and temperature. If the chirality is sufficiently high, thermodynamically stable, frustrated blue phase LCs can occur in the phase

diagrams of N\*-LCs. Their otherwise delicate thermal stability can be impressively enhanced by use of tailored photopolymers [3]. In general, such polymers can be in-situ generated by photo-polymerization of suitable reactive mixtures, doped in the (non-reactive) host LC. Preferred precursors are non-mesogenic and mesogenic (reactive mesogens) precursors, which form nanostructured functional crosslinked co-polymers. After in-situ photopolymerization, the polymer obtained forms a self-assembled stabilizing support structure even for highly delicate LC arrangements.

#### References

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#### [Lecture-2]

#### Optics and Atom Optics á la de Broglie-Bohm

#### Jordi Mompart

Department of Physics, Universitat Autònoma de Barcelona, Spain

The standard formulation of quantum mechanics, through Bohr's complementarity principle and Heisenberg's uncertainty between position and momentum conjugate variables, suggests that trajectories cannot be ascribed to quantum particles. Surprisingly, in 2011 A. M. Steinberg and co-workers [1] reported the observation of average trajectories of singlephotons in a Young type double-slit experiment which reproduced those predicted by the de Broglie-Bohm formulation of quantum mechanics [2]. De Broglie-Bohm quantum mechanics provides an explanation of quantum phenomena in terms of point particles guided by wave functions. Although the de Broglie-Bohm and standard quantum theories have different formalisms, both yield exactly the same predictions for all quantum phenomena. In this talk, we will first review the de Broglie-Bohm formulation of quantum mechanics for a single nonrelativistic quantum particle to later on show that this formulation is equivalent to that of ray optics beyond the eikonal approximation [3]. Thus, the quantum potential emerging in the de Broglie-Bohm formulation of quantum mechanics relates to a wave potential in the ray optics case. Then, we will discuss two examples on the use of the de Broglie-Bohm formulation to solve practical problems in quantum mechanics: (i) quantum transport of a single cold atom in a triple well potential [4]; and (ii) photoionization of a hydrogen atom with light beams carrying orbital angular momentum [5].

#### References

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#### [Lecture-3]

#### Plasmonic nanostructures: fabrication, electron microscopy, spectroscopy

#### Jörg Lindner and Heinz Kitzerow

Center for Optoelectronics and Photonics Paderborn, University of Paderborn, Germany

Oscillations of the charge carrier density in a metal (plasmons) enable strong interaction between electromagnetic radiation and matter. This interaction can be used to manipulate light using nanostructures that exhibit feature sizes distinctly smaller than the wavelength of light. Our tutorial describes some optical properties of metal nanoparticles and metal/dielectric nanostructures (metasurfaces or metamate-rials) in the visible and infrared spectral range, emphasizing some specific aspects:

The method of nanosphere lithography uses self-assembly of colloidal particles to cover large areas with specific metal-dielectric nanostructures; this method provides a versatile tool to fabricate metasurfaces.

Tunable optical properties can be achieved, when a liquid crystal is used as the dielectric component of a metal/dielectric nanostructure.

Electron microscopy and FTIR spectroscopy/microscopy are important tools to characterize the nanostructures and their optical properties, respectively.

#### [Lecture-4]

#### **THE CD6: Research and Innovation transfer**

#### Santiago Royo and Meritxell Vilaseca

Centre for Sensors, Instruments and Systems Development, Universitat Politècnica de Catalunya, Barcelona, Spain

The CD6 is a technological innovation center located at the Campus of Terrassa (Barcelona) of the Universitat Politècnica de Catalunya (UPC), which operates in the fields of Photonics and Optical Engineering. The activity of CD6 is aimed at creating value through innovation. Applied research developed by CD6 is defined in order the new knowledge generated, reaches the market as new products or new processes.

Almost 40 people with complementary expertise (*Optics, Electronics, Mechanical* and *Software*) work at CD6. This multidisciplinary combination is necessary to develop applications with a short time-to-market. The research results achieved at CD6 have led to the creation of several spin-off companies that manufacture and market new products in different sectors.

An overview of the center will be given in this lecture as well as scientific and technological results achieved by members of CD6. Furthermore, two specific examples of projects, one related to basic research and another which led to the creation a spin-off company will be explained as examples of research and innovation.

#### [Lecture-5]

#### **Tunable Polymer Photonics**

#### <u>Heinz Kalt</u>

#### Institute of Applied Physics, Karlsruhe Institute of Technology, Germany

Polymers are versatile materials for applications in photonics. Polymeric photonic devices can be fabricated not only with high precision but also with methods suitable for mass production to realize 3D optical-circuit architectures. Such devices can be functionalized for application in bio-sensing. Optical microresonators show excellent figures of merit and can be used as passive or active cavities. Arrays of such cavities can be coupled to form photonic molecules. This talk will demonstrate the here mentioned properties for the case of polymeric whispering-gallery-mode (WGM) resonators.

Some polymers show a high mechanical elasticity. These elastomers can be used as substrate material enabling the tunability of the resonances of WGM cavities. Also the coupling gaps in photonic molecules can be tuned. I also describe the use of liquid-crystalline elastomers for resonator tuning. Such tuning capabilities are essential for matching cavity resonances in coupled arrays or to bring optical transitions of embedded quantum emitters into resonance.



#### [Lecture-6]

#### Super-resolution microscopy: Challenges and Potentials in biomedical research

#### **Christian Eggeling**

Wolfson Imaging Centre Oxford, Weatherall Institute of Molecular Medicine, University of Oxford, United Kingdom

Understanding the complex interactions of molecular processes underlying the efficient functioning of the human body is one of the main objectives of biomedical research. Scientifically, it is important that the applied observation methods do not influence the biological system during observation. The most suitable tool that can cover all of this is optical far-field fluorescence microscopy. Yet, biomedical applications often demand coverage of a large range of spatial and temporal scales, and/or long acquisition times, which can so far not all be covered by a single microscope and puts some challenges on microscope infrastructure. Taking immune cell responses and plasma membrane organization as examples, we outline these challenges but also give new insights into possible solutions and the potentials of these advanced microscopy techniques, e.g. for solving long-standing questions such as of lipid membrane rafts.

#### [Lecture-7]

#### Graphene quantum nano-optoelectronics: fundamentals and applications

#### Frank Koppens

ICFO-Institute of Photonic Sciences and ICREA- Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Optoelectronics and power conversion based on graphene and related 2d materials is one of the most rapidly developing and exciting areas with prospects for commercial applications. These materials have huge potential for an "all-in-one" solution to the challenges of future opto-electronic technologies, banking on a wide palette of unique aspects such as tuneable optical properties, broadband absorption (from UV to THz frequencies), high electrical mobility for ultrafast operation, and novel gate-tuneable plasmonic properties. In addition, graphene is an excellent host for confining and manipulating optical fields at the nanoscale, with potential for new avenues in quantum information processing, imaging, and sensing.

In this lecture, I will review both fundamentals and applications associated to the interactions of light with graphene and related 2d materials. I will show how to exploit graphene as a host for guiding, switching and manipulating light and electrons at the nanoscale. This is achieved by exploiting surface plasmons: surface waves coupled to the charge carrier excitations of the



conducting sheet. Due to the unique characteristics of graphene, light can be squeezed into extremely small volumes and thus facilitate strongly enhanced light-matter interactions, which can be tuned by electric fields. Additionally, I will discuss novel types of (hybrid) graphene photodetectors for visible and infrared frequencies, as well as the effects of carrier dynamics on photodetection performances. Finally, ongoing efforts towards applications are being discussed, addressing the fields of photodetection, optical modulation, nanophotonics, long-wavelength photonics and power conversion.

#### [Lecture-8]

#### **3D printed complex microoptics**

#### Simon Thiele

Institut für Technische Optik, Universität Stuttgart, Germany

In this talk, I will introduce femtosecond 3D direct laser writing for the manufacturing of complex microoptics. We can manufacture singlets, doublets, and triplets with freeform aspheric surfaces and diameters of down to 100  $\mu$ m. The surface roughness is below 20 nm, and the shape accuracy is below one wavelength. We achieve high-resolution imaging with reduced aberrations over very large fields of view up to 70°. We print our complex microscope objectives directly on single-mode as well as multicore fibers, directly onto CMOS image sensors, as well as onto LEDs and other substrates. Our system is well suited for novel endoscopy, compact and integrated imaging systems and sensors, as well as integrated illumination systems.

#### [Lecture-9]

### Nanophotonic approaches to investigate the spatiotemporal organization of biological membranes

#### Maria Garcia-Parajo

ICFO-Institute of Photonic Sciences, and ICREA- Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

A hot topic in cell biology is to understand the specific nanometer-scale organization and distribution of the surface machinery of living cells and its role regulating the spatiotemporal control of different cellular processes. Cell adhesion, pathogen recognition or lipid-mediated signaling, all fundamentally important processes in immunology, are governed by molecular interactions occurring at the nanoscale. From the technical point of view, the quest for optical imaging of biological processes at the nanoscale has driven in recent years a swift development of a large number of microscopy techniques based on far-field optics. These super-resolution methods are providing new capabilities for probing biology at the nanoscale by fluorescence. While these techniques conveniently use lens-based microscopy, the attainable resolution and/or localization precision severely depend on the sample fluorescence properties. True nanoscale optical resolution free from these constrains can alternatively be obtained by interacting with fluorophores in the near-field. Indeed, near-field scanning optical microscopy (NSOM) using subwavelength aperture probes is one of the earliest approaches sought to achieve nanometric optical resolution. More recently, photonic antennas have emerged as excellent alternative candidates to further improve the resolution of NSOM by amplifying electromagnetic fields into regions of space much smaller than the wavelength of light. In this lecture, I will describe our efforts towards the fabrication of different nanoantenna probe configurations as well as 2D antenna arrays for applications in nanoimaging and spectroscopy of living cells with unprecedented resolution and sensitivity. I will also discuss the combination of far-field super-resolution nanoscopy and multi-colour single particle tracking to elucidate the multi-scale spatiotemporal organisation of immune receptors on living cell membranes in relation to cell function.

#### [Lecture-10]

#### **Putting Nanophotonics to Work**

#### **Romain Quidant**

ICFO-Institute of Photonic Sciences and ICREA- Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

15 years of very active research in the field plasmonics have enabled us to considerably advance light control on the nanometer scale. Beyond the original *peak of inflated expectation*, the assets of nanoplasmonics over other technologies became clearer along with its limitations. More recently, the field has entered into the "*slope of enlightenment*" in which the actual contribution of metallic nanostructures to future technologies is better identified. In this tutorial talk, following a general introduction on the main assets of plasmonics, we will review different aspects of our research where metallic nanostructures are used as an enabling tool towards specific photonic functionalities.

#### [Lecture-11]

#### Tracking femtosecond dynamics at the nanoscale

#### <u>Niek van Hulst</u>

ICFO-Institute of Photonic Sciences and ICREA- Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

I'll present the advances of pulse control and ultrafast coherent excitation of both plasmonic nanoantennas and individual molecular systems. Essential concepts from coherent control of ultrashort broadband laser pulses are combined with nanoscale diffraction limited detection and imaging of single photon emitters; that is, the central area of this research is where *"ultrafast meets ultrasmall"*.

First, I'll discuss the critical role of dedicated pulse shaping and phase control, which is crucial to realize free of spatiotemporal coupling Fourier limited pulses inside a high numerical aperture microscope at the diffraction limited spot. Next we apply this scheme to plasmonic antennas, exploiting broadband two-photon excitation, to determine amplitude and phase of plasmonic resonances, to achieve ultrafast switching of nanoscale hotspots, and multicolor second harmonic detection for imaging applications.

Subsequently, phase-shaped pulses can equally be used to address single molecules and control the electronic state population to retrieve single molecule vibrational dynamics response. Single molecule detection generally relies on detection of fluorescence; here I'll enter into some innovative alternatives: optical antennas to enhance quantum efficiency; transient absorption on singles; detection of stimulated emission.

Finally, imaging nanoscale light transport requires local excitation and detection far beyond the diffraction limit. I'll address the use of nanoholes and scanning resonant antenna probes to confine the light field and couple effectively to single emitters on the nanoscale. The plasmonic antenna acts as a nanocavity with relative strong coupling (~100GHz), speeding up the radiative decay to picosecond time scale and allowing > GHz single photon emission.

I will conclude with an outlook of the challenges ahead and the perspectives of addressing coupled networks in real nano-space and on femtosecond timescale.

#### [Lecture-12]

#### **Promises and Challenges of Perovskite Photovoltaics**

#### **Ulrich W. Paetzold**

Institute of Microstructure Technology, Karlsruhe Institute of Technology, Germany

Organic-inorganic hybrid perovskite solar cells are the new shooting stars in the field of high efficiency thin-film photovoltaics. Today, less than 6 years after the first reported solid state perovskite solar cell, record power conversion efficiencies above 22 % have been reported, approaching the efficiencies of well-established thin-film solar cells based on cadmium telluride (CdTe) or copper indium gallium diselenide (CIGS) as well as those of the marketdominating silicon solar cells. The promises of organic-inorganic hybrid perovskites are based on their outstanding optoelectronic properties, combining long charge carrier lifetimes, very low non-radiative recombination rates and high absorption coefficients. Moreover, organic-inorganic hybrid perovskites feature the ability to vary the bandgap via stoichiometric variations which is highly desirable for building-integrated photovoltaics as well as multijunction photovoltaics. The compatibility with low-cost solution-based deposition techniques brings further advantages with regard to low costs and facile large area fabrication. Despite these promises, organic-inorganic hybrid perovskite solar cells also face key challenges related to the uncertainties about the stability of the devices, the discrepancies in measuring routines due to hysteresis, and the difficulties in replacing the toxic heavy metal lead. In order to provide an overview of the technological progress as well as the unique optoelectronic material properties, we present a review on the promises and challenges of next generation perovskite photovoltaics.

#### [Lecture-13]

#### Unravelling the role of charge transfer states in polymer solar cells

#### <u>Uli Lemmer</u>

Light Technology Institute and Institute of Microstructure Technology, Karlsruhe Institute of Technology, Germany

The mechanisms of excited state dissociation in organic semiconductors are crucial for the efficiencies in organic photovoltaics. We present a comprehensive study of the field and temperature dependence of the dissociation of singlet excitons and charge-transfer states generated across interfaces in bulk heterojunction solar cells. We investigate the dissociation of the states from 10K to room temperature and for varying electric fields with the techniques of time-resolved emission spectroscopy and luminescence quenching. Our results show a completely different behavior for the two prototype conjugated polymers P3HT and PTB7 often used as absorber materials in polymer solar cells [1,2]. To draw quantitative conclusions from our data, we use an analytical field-assisted hopping model. The data also imply that a strong reduction of the Coulomb binding energy at the interface facilitates their separation.

#### References

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#### [Lecture-14]

#### Resonant interaction of light with metallic and dielectric particles

#### Nicolas Bonod

#### CNRS, Centrale Marseille, Fresnel Institute, Aix-Marseille University, France

The resonant interaction of light with optical scatterers is due to the excitation of photonic resonances hosted by dielectric and metallic particles. The optical properties of scatterers can be studied through the calculation of their polarizability. In the case of metallic particles characterized by a negative real part of the dielectric permittivity, the resonant interaction is due to the excitation of localized surface plasmons [1]. In the case of dielectric particles with positive dielectric permittivities, the resonant interaction is due to the excitation of morphologic resonances, also called Mie resonances [2]. In both cases, the resonant interaction leads to electric field intensities enhanced in the vicinity of the particle and to an enhanced scattered field. It was recently proved that the fields yielded by metallic particles excited at their plasmonic resonance can be accurately reproduced by positive dielectric particles (without free electrons: positive dielectric permittivity)[3]. The large dielectric permittivities required to get this result can be found in hyperfrequencies.

Dielectric nanoparticles are very attractive to design optical scatterers that resonantly interact withelectromagnetic waves [4]. In the visible spectrum, silicon particles feature electric and magnetic low order Mie resonances that can play a key role to enhance light matter interaction. (i) The enhancement of the far field scattering can be used to create a palette of structural colours [5]. The structural color is tuned by modifying the shape and the size of the particles. The high quality factor and the richness of the scattering spectrum offer plenty of opportunities to create structural colours of high purity, with applications in printing technology orspectral filtering [5]. (ii) The enhancement of the near field intensities can be used to enhance interaction of light with quantum emitters. The Mie resonances hosted by dielectric particles permit to enhance either the electric or magnetic decay rates of quantum emitters [6]. Importantly, in the case of dielectric particles, quantum emitters can be placed inside the particles which form novel photonic cavities associated with high Purcell factors [7]. Coupling different silicon particles can further enhance the electric field intensity in the vicinity of particles. It was recently proved that the nanogap separating two particles was behaves as an efficient platform to probe individual fluorescent molecules [8].

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### PhD Talks

#### [PhD talk-1]

### In-plane plasmonic nano antennas explore membrane heterogeneities in living cells

#### <u>Raju Regmi</u>

Fresnel Institute, Marseille, France and ICFO-Institute of Photonic Sciences, Barcelona, Spain

The spatiotemporal architecture of the cell membrane and diffusion dynamics of its constituents (lipids and proteins) are fundamentally important to understand cellular processes such as signaling and trafficking. Sub-diffraction photonics based on plasmonics offer opportunities to follow single molecule events as they can confine electric fields in nanoscale hotspots with spatial dimensions comparable to single molecules (~5 nm). In this work, we propose plasmonic antenna arrays with surface nanogaps to study the diffusion characteristics of phosphoethanolamine and sphingomyelin in membranes of living cells. The findings are important to understand the heterogeneous organization of membrane lipids at the nanoscale which are otherwise hidden in the confocal ensemble.

#### [PhD talk-2]

#### Light propagation in PT-symmetric potentials

#### Waqas Waseem Ahmed

European Laboratory for Non-linear Spectroscopy, University of Florence, Italy and Universitat Politècnica de Catalunya, Barcelona, Spain

Optical Parity-Time (PT-) symmetric potentials support unusual properties when the symmetric coupling between internal modes is broken. We explore such optical potentials in 1D and 2D combining gain-loss and index modulations for field localization, enhancement and self-collimation, which could have actual realizations in micro and nanophotonic structures. As a direct application, we show how to render a broad aperture VCSEL into a bright and narrow beam source.

#### [PhD talk-3]

#### Sub picosecond imaging of polymeric photonic circuits

#### **Dmitry Nuzhdin**

European Laboratory for Non-linear Spectroscopy, University of Florence, Italy and Karlsruhe Institute of Technology, Germany

Integrated photonic circuits have become a vital part of modern photonics. In spite of all the technological developments, fabrication procedures leave numerous uncertainties in the final parameters of the system. We report a novel non invasive far-field method of diagnostics of photonic devices, based on time-resolved optical gating. The optical scheme designed to resolve light propagation in space and time is based on cross-correlation optical gating technique. Two synchronous probe and gate femtosecond pulses ( $\approx 120 \ fs$ ) propagate

collimated in order to overlap spatially and temporally in the non-linear crystal that would generate a sum-frequency signal. The sum-frequency signal, in its turn, is collected by photomultiplier tube or CCD camera. Translation stage allows to change a delay of gate pulse which defines one temporal frame. Including optical imaging components it is possible to retrieve a spatial distribution information from the probe beam that would give an optical image of the sample resolved in time. Thus the crystal would produce a sum-frequency signal with spatial profile of the probe beam, although with lower resolution.

#### [PhD talk-4]

#### Observing the ultrafast processes at the nanoscale

#### Vikas Remesh

ICFO-Institute of Photonic Sciences, Barcelona, Spain and Fresnel Institute, Marseille, France

Observing the light- matter interactions provides fascinating insights on various processes that are unknown so far. The advancement in nanofabrication and ultrafast lasers have allowed us to merge two powerful tools and thus enabling us to investigate interesting processes at the nanoscale. Metal nanoantennas are known to sustain collective electron oscillations called plasmons within them, on excitation with resonant light. Although surface plasmon effect has been exploited for various interesting applications, little has been known about their coherent response, and the possibility of exerting a true coherent control on plasmons has not been tested so far experimentally. In this talk, I would walk you through our recent attempts in understanding the coherent response of plasmons in three different metals: Gold, Silver and Aluminium.

#### [PhD talk-5]

#### **Chip-Scale Frequency Comb Sources for Coherent Optical Communications**

#### Pablo Marin Palomo

Karlsruhe Institute of Technology, Germany and ICFO-Institute of Photonic Sciences, Barcelona, Spain

The present capacity increase of optical networks relies mainly on wavelength division multiplexing (WDM) and coherent transmission. The associated transceiver systems need to be cost-efficient and compact while featuring low power consumption. These requirements can be partially fulfilled by high-density integration of IQ modulators and coherent receivers, e.g., on the silicon photonic platform. Scalability of the associated optical sources, however, is still an issue, notably for transmission of tens of *Tbit/s*, where hundreds of individually stabilized lasers are usually used. Optical frequency combs are a promising candidate to realize compact and power-efficient optical sources for next generation high-speed WDM links. In this talk I will review different techniques that have been used to generate frequency combs for data transmission and I will present the frequency comb sources we have investigated so far for such purpose. In particular, using dissipative Kerr soliton frequency combs, we have achieved record high data transmission with an integrated comb source.

#### [PhD talk-6]

#### Blind-SIM reconstruction techniques for fluorescence microscopy

#### Awoke Atena Negash

Fresnel Institute, Marseille, France and ICFO-Institute of Photonic Sciences, Barcelona, Spain

Using multiple non-uniform illuminations, classical harmonic structures or random speckle patterns, permit to retrieve the sample information beyond the frequency support of the optical transfer function of the microscope. Yet, a reconstruction procedure must be used to restore the high-resolution sample image from the low-resolution data obtained under multiple illuminations. For algorithms that require a prior knowledge of the illumination pattern such as classical SIM, precise control of the illuminations is achieved at the expense of instrumental constraints. In random speckle illuminations the control of the illuminations is not even physically possible. Therefore, it is desirable to have a reconstruction mechanism that require a little prior knowledge on the illuminations. We present the blind-reconstruction mechanisms that retrieve transverse and axial resolutions without requiring the information of individual non-uniform illumination patterns. The approach only assumes that the temporal average of the illumination intensity patterns over the sample is homogeneous. The reconstruction mechanisms are illustrated on synthetically-generated, standard-calibrated and biological samples.

### Posters

#### [Poster-1]

#### Enhancement of second harmonic generation by plasmonic nanoantennas

#### Nils Weber, Thomas Zentgraf, and Cedrik Meier Experimental Physics & CeOPP, University of Paderborn, Germany

The light-matter interaction for nonlinear processes is known to be rather weak. Consequently, high excitation powers are required for efficient second harmonic generation (SHG). Plasmonic nanostructures are a promising approach to achieve strong near-field enhancement. This work focuses on the investigation of resonances of nanorod antennas with respect to lattice periodicity and geometry, as well as their efficiency for second harmonic generation of light.

Optimized plasmonic nanostructures result in highly amplified electromagnetic fields and sharp plasmonic resonances. Two major absorbance peaks can be identified from the transmission spectra, resulting from the excitation of localized surface plasmon polaritons (LSPPs) and from the lattice diffraction, which is given by the periodical arrangement of the antennas within each array. For a superposition of both peaks, the local electric field is strongly enhanced, which is due to the light being diffracted by the grating like antenna array within the dielectric surface.

This effect can be utilized to increase the efficiency of second harmonic generation from the substrate. Since SHG is mostly generated at the surface of the substrate, thin ZnO films with periodically arranged nanoantennas show highly amplified SHG signals. This effect can be further increased by using double resonant nanoantennas with a second plasmonic resonance for the SHG signal, resulting in a strongly improved far field interaction.

#### [Poster-2]

#### Methyl red doped liquid crystals and their combination with metamaterials

#### Bernhard Atorf and Heinz-Siegfried Kitzerow

Department of Chemistry and Center of Optoelectronics and Photonics, University of Paderborn, Germany

Optical metamaterials composed of metal nanostructures can exhibit very unusual optical properties[1] owing to the interaction of electromagnetic waves with plasmonic resonances. If the size of the optically active structures composing the metamaterial is in the range of a few 100 nm, these resonances appear in the infrared (IR) spectral range and are typically investigated in IR microscope connected to a spectrometer. Combination with a liquid crystal yields tuneable properties: The wavenumbers of the resonant modes are shifted by an applied electrical field due to the director reorientation[2].

In principle, the optical resonances could also be shifted through the nonlinear response of a dye-doped liquid crystal. For example, the refractive index of methyl red-doped liquid crystals is known to be extremely sensitive to optical radiation owing to the colossal optical nonlinear effect[3]. This effect is based on a surface induced reorientation of the liquid crystalline director[4]. To study the huge nonlinear response and to measure the influence on the optical resonances of the metamaterial we couple a green laser beam into the path of an

IR microscope-spectrometer setup (Fig. 1). If a homeotropic cell (filled with a methyl reddoped liquid crystal) is illuminated with a green laser beam, which is linearly polarized at an azimuthal angle of  $45^{\circ}$  with respect to the polarization of the infrared radiation, the liquid crystal tends to align along the polarization of the laser beam (Fig. 2). We discuss different strategies to use the huge nonlinear response in combination with metamaterials.





Fig. 1: Adjustment in the IR-spectrometer for the coupling of the green laser.

Fig. 2: Effect of a green cw laser on a methyl red-doped liquid crystal in a homeotropic cell: Deviation  $(\Delta \phi)$  of the azimuthal angle of the director from the plane of polarization of the laser light versus illumination time.

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#### [Poster-3]

#### **Directional Emission from Dielectric Leaky-Wave Nanoantennas**

A. Hildebrandt<sup>1</sup>, M. Peter<sup>2</sup>, C. Schlickriege<sup>3</sup>, K. Gharib<sup>2</sup>, T. Zentgraf<sup>3</sup>, S. Linden<sup>2</sup>, and J.

Förstner<sup>1</sup>

<sup>1</sup>Department of Electrical Engineering, University of Paderborn, Germany <sup>2</sup> Physikalisches InsKtut, University of Bonn, Germany <sup>3</sup>Department of Physics, University of Paderborn, Germany

Useful for innovations in nanophotonics is the idea to scale down known devices from the radio frequency (RF) regime to optical frequencies. A prominent example is the metallic Yagi-Uda antenna, which employs plasmonic resonances to couple localized emitters to selected far field modes. The two most pronounced differences compared to the RF regime are firstly the ratio of the skin depth of electromagnetic fields and the dimensions of the antenna, which means that plasmonic resonances and thus high intrinsic losses occur. Secondly such nanoantennas are deposited on a substrate, which acts as a parasitic impedance and thus changes the radiation pattern and the performance of such antennas significantly. In order to overcome both problems, we use a pure dielectric, leaky waveguide with finite size, where the leaking fields interfere resulting in useful radiation patterns.

#### [Poster-4]

#### Metallic nanoparticles created by double angle controlled nanosphere lithography investigated by transmission electron microscopy

C. Brodehl, S. Greulich-Weber, and J. K. N. Lindner Center for Optoelectronics and Photonics, University of Paderborn, Germany

Metallic nanoparticles show interesting optical properties due to electromagnetic resonances. These resonances originate from a collective oscillations of the metal's conduction electrons. Beside material properties, also the shape and microscopic structure of the nanoparticles influences their response to an external stimulation. Since manufacturing of tailored metallic nanoparticles has become possible, the research on plasmon based optics grows and reveals e.g. the development of interesting new optical devices like flat lenses. While optical experiments often provide information of an ensemble of plasmonic particles, transmission electron microscopy (TEM) allows to measure shape, dimension and microscopic particle structure locally for individual particles. In addition, the electron beam of the microscope can be used to induce plasmon oscillations in the nanoparticle, which can be monitored by analyzing the energy loss of the transmitted electrons in energy filtered TEM or by electron energy loss spectroscopic imaging in scanning TEM. The obtained energy loss maps can be compared to theoretical predictions and reveals spatially and energy resolved information of the plasmon resonance of single particles. Here we present our first results of transmission electron microscopy analysis of gold nanoparticles of different shapes and dimensions. The tailored particles were fabricated via an expanded angle deposition nanosphere lithography technique.

#### [Poster-5]

### Strongly localized second harmonic generation observed in 3C-SiC films on silicon

#### M. Rüsing, S. Blumenthal, K. Spychala, P. Mackwitz, G. Berth, D. J. As, and A. Zrenner Department of Physics, University of Paderborn, Germany

In this work we study zinc-blende structure SiC (3C-SiC) films grown on silicon wafers with confocal second harmonic microscopy. Second harmonic microscopy is a powerful tool for imaging and material analysis and allows for the study of material symmetry and properties. In the 3C-SiC films we find localized hot spots of extremely intense second harmonic generation with intensities up to ten times larger than in the surrounding medium. The statistical distribution of the intensities shows similarities to signatures otherwise observed in randomly disordered media and may be interpreted as a result of Anderson localization. By a depth resolved analysis we can distinguish different layers in the material with specific second harmonic signatures and different statistical distributions. The analysis shows, that signs for highly localized modes can only be observed in a certain depth. The depth dependence maybe suggest a connection to the dislocation density, because the dislocation density decreases with layer thickness. The dislocation density and surrounding bound charges may act as scattering centers offering ideal conditions in a certain depth. A comparison to a bulk 3C-SiC wafer, the silicon substrate and wurtzite gallium nitride show no comparable signatures, giving further hints that the observed effect is specific to this 3C-SiC films.

#### [Poster-6]

#### Numerical simulations of one refractive and one diffractive liquid crystal test cell

#### Atefeh Habibpourmoghadam, and Alexander Lorenz Department of Physical Chemistry, University of Paderborn, Germany

A liquid crystal test cell is a test device, designed to experimentally exploit the electro-optical responses of a LC or polymer enhanced [1,2] LC in a straight-forward and highly efficient way: A thin layer (a slab) of liquid crystalline material of a few micron in thickness is assembled in-between glass plates. In order to address the LC with electric fields, various kinds of electrode-setups can be used. In a simple LC test cell, planar electrodes are used, usually made of sputtered transparent indium tin oxide, often coated with additional alignment layers to carefully predefine the initial LC alignment inside the test device. Although a neat LC is designed to be a forgiving, useful, and sometimes maybe even cosy optical medium (rather forgiving for field inhomogeneity or misalignments in the LC test cells), LCs can be dramatically pushed by adding polymer [1,2]. If so, field-inhomogeneity can have drastic impact on the optical properties of a LC test cell.

We have conducted numerical simulations to track down and explain the impact of polymer in a LC by considering a Q-tensor approach [3-5] to describe the local field induced reorientation of the LC. Polymer beads were modelled to provide additional anchoring of the LCs. Our result show how test cells with on-purpose created field non-uniformities can be used to modify the optical properties of refractive (wedge) and diffractive (patterned electrodes) test cells and convert them into novel kinds of switches and beam splitters.

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#### [Poster-7]

### Electrode patterning by nanosphere lithography for switchable 2D blue phase gratingsfilms on silicon

Markus Wahle<sup>1,2</sup>, Katharina Brassat<sup>2,3</sup>, Justus Ebel<sup>1,2</sup>, Julius Bürger<sup>2,3</sup>, Jörg K. N. Lindner<sup>2,3</sup>, and Heinz-Siegfried Kitzerow<sup>1,2</sup>

<sup>1</sup>Department of Chemistry, University of Paderborn, Germany <sup>2</sup>Center for Optoelectronics and Photonics Paderborn CeOPP, University of Paderborn, Germany <sup>3</sup>Department of Physics, University of Paderborn, Germany.

In this contribution, we propose nanosphere lithography (NSL) as a self-assembly technique for the fabrication of 2D structured electrodes. We use these electrodes to manufacture an electrically switchable blue phase grating.

NSL is based on the self-assembly of nano- or micrometer sized spheres into hexagonally closed packed monolayers [Fig. 1(a)]. This allows for cost effective and fast structuring of large areas (~cm2). Shrinking the spheres [Fig. 1(b)] and subsequent metal deposition [Fig. 1(c)] yield structured metal thin films [1].

The prepared electrodes provide a versatile basis for liquid crystal (LC) gratings. Usually, LC gratings rely on electrodes structured by standard techniques, which are limited to periodicities of  $\geq 5 \ \mu m.[2]$  This leads to low diffraction angles, which impairs the applicability of these gratings. Most methods to produce smaller structures are cost and time consuming. NSL therefore provides a superior alternative.

We combine the NSL-structured electrode with polymer-stabilized blue phases to achieve sub-millisecond switching and polarization independence. The prepared samples show a high diffraction angle [Fig. 1(d)] and a tunable diffraction efficiency [Fig. 1(e)]. The blue phase device can be easily and accurately modelled using the finite element technique [Fig. 1(f)].



Fig. 1: (a)-(b) SEM images of (a) a self-assembled monolayer of 2  $\mu$ m spheres, (b) spheres after shrinking by reactive ion etching (RIE). (c) AFM images of the structured electrodes after metal deposition and sphere removal. (d) Diffraction pattern of the LC cell. (e) Diffraction efficiency versus voltage. (f) Simulated diffraction pattern at 76 V (maximum efficiency).

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#### [Poster-8]

### Photoinduced formation of silver nanoparticles in DNA-containing lyotropic liquid crystals

Dmitry Kushnikovskiy<sup>1</sup>, Azat Bilalov<sup>2</sup> and Claudia Schmidt<sup>1</sup> <sup>1</sup> Department of Chemistry, Paderborn University, Germany <sup>2</sup> Physical and Colloid Chemistry, Kazan National Research Technological University, Russia

Metal nanoparticles have attracted a lot of attention in the field of colloidal and material science due to their unique electronic and optical properties. Because of the broad field of potential applications, there is also a growing interest in developing new green methods for the controlled synthesis of nanomaterials. Due to the rich polymorphism, lyotropic liquid crystals formed by amphiphilic molecules are particularly interesting templates to control size and morphology of nanoparticles.

Both DNA and surfactants have been successfully used for the synthesis of silver nanoparticles. However, the templating properties of DNA-cationic surfactant complexes are almost unknown. In this contribution, we report the photochemical synthesis of silver nanoparticles in various lyotropic liquid crystalline phases formed by the dodecyltrimethylammonium-DNA complex in the presence of an aqueous solution of 2hydroxypropyl-\beta-cyclodextrin [1]. Silver nanoparticles were synthesized via photoreduction of the DNA-Ag+ complexes where the Ag+ ions are embedded in the DNA helical structure [2]. The reported method does not require any external reducing or stabilizing agents since DNA acts as a photosensitizing agent and a template for the nanoparticle formation. Size and morphology of the resulting nanoparticles can be controlled by the Ag+/DNA ratio and the structure of the liquid crystalline phase.

The effect of the formation of silver nanoparticles on the lyotropic liquid crystalline phase was investigated by small angle x-ray scattering, <sup>2</sup>H and <sup>31</sup>P NMR spectroscopy. The influence of the template mesophase on the formation rate and nanoparticle size and morphology was studied using UV-spectroscopy, TEM and AFM.



Fig. 1. AFM (A) and TEM (B) images showing the formation of particles in DNA and TEM image of nanoparticles synthesized in tetragonal phase (C).

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#### [Poster-9]

#### DNA nanostructures and chromonic liquid

#### Bingru Zhang, and Heinz-S Kitzerow

#### Department of Chemistry and Center for Optoelectronics and Photonics, University of Paderborn, Germany

Liquid crystals have found increasing interest in the field of photonics and metamaterials research [1]. Liquid crystals may not only serve as a tunable dielectric component, but can also be used to control the position of colloidal particles. For example, colloidal particles were observed to form linear chains in the columnar phase of the lyotropic chromonic liquid crystal disodium cromoglycate (DSCG) [2] (Fig. 1a). During the last years, it is confirmed, plasmonic DNA-origami nanostructure can be dissolved in lyotropic chromonic liquid crystals [3]. In addition to these finding, the poster describes the synthesis of 18-helix-bundle DNA-origami, the hybridization with Gold-nanorod (Fig. 1b) and some important parameters

for embedding the DNA nanostructure in DSCG solution, for example, the influence of pH-value and cation concentration on the phase diagram of DSCG.



Fig.1 a: Columnar phase of a DSCG-water mixtures with embedded colloidal particles Figure b: Transmission electron micrograph of a DNA origami nanostructure decorated with a gold nanorod.

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#### [Poster-10]

#### Structural and optical properties of stacked cubic GaN quantum dots

S. Blumenthal<sup>1</sup>, T. Rieger<sup>2</sup>, D. Meertens<sup>3</sup>, A. Pawlis<sup>2</sup>, D. Reuter<sup>1</sup>, and D. J. As<sup>1</sup> <sup>1</sup>Department of Physics, University of Paderborn, Germany <sup>2</sup>Peter Grünberg Institut, Forschungszentrum Jülich, Germany <sup>3</sup>Ernst Ruska Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, Germany

Group III-nitrides attracted much attention in the development of optical and quantum optical devices, operating in the UV spectral range. Especially, quantum dots (QDs) can be efficient light emitters because of their reduced dimensionality, whereby stacking of QDs is an appropriate way to increase the number of QDs in the active region. In the last years stacked hexagonal GaN QDs have already been realized. An internal electrical field in the hexagonal phase causes a reduced recombination probability. This may be overcome by using cubic GaN (c-GaN) where no polarization fields in (001) growth direction exist [1]. Vertical stacking of QDs with a thin spacer layer leads to a vertical alignment of the QDs. Our samples were grown by plasma assisted molecular beam epitaxy on 10 µm thick 3C-SiC on top of a Si (001) substrate. The samples were topographically characterized by atomic force microscopy (AFM) measurements, transmission electron microscopy (TEM) and optically by photoluminescence (PL) spectroscopy.

The samples consist of c-GaN QDs in a c-AlN matrix. We realized samples with 1, 5, 8, 10 and 13 layers of QDs to study the influence of the number of stacks on the optical properties. Cross-sectional TEM measurements show that the QDs are vertically aligned along the growth direction. The PL measurements were performed with a 266 nm laser at room-temperature. The spectra (see Fig.1) show a superlinear increase in emission intensity and a blue-shift of the emission energy with increasing number of stacks. In our QDs the main

confining dimension is the height [2]. Since AFM measurements confirm that there is no change in the diameter of the QDs, we assume that the blue-shift of the emission energy is due to a decrease of the QD height. The samples with a larger number of stacked QD layers are promising candidates for applications in highly efficient UV light emitters.



Fig. 1: PL intensity of the stacked QDs at room temperature. The emission energy and the intensity increases with increasing number of stacks.

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#### [Poster-11]

#### Joining self-assembly techniques: A route to hierarchical nanopores

K. Brassat<sup>1,2</sup>, D. Kool<sup>1,2</sup>, and J. K. N. Lindner<sup>1,2</sup>

<sup>1</sup>Neanostructuring, Nanoanalysis and Photonic Materials NNP Group, Dept. of Physics, University of Paderborn, Germany

<sup>2</sup>Center for Optoelectronics and Photonics Paderborn CeOPP, University of Paderborn, Germany

Self-assembly techniques allow for the nanopatterning of surfaces with regular patterns on large areas. We introduce the nanosphere lithography (NSL) and block copolymer (BCP) lithography as two possibilities for the self-organized creation of hexagonally arranged pores in material thin films.

In a hierarchical approach, more sophisticated patterns can be created by step-wise application of different self-assembly techniques. By combining the NSL and BCP lithography, we create hierarchical nanopores (Fig. 1). This is possible as our techniques act on different size-scales.

We show how we created pores with diameters of few hundred nanometers in metal thin films by NSL. To this, colloidal polymer beads are arranged into hexagonally close-packed monolayers by convective self-assembly. We use such sphere monolayers as shadow mask in a material deposition step. BCP lithography is based on the microphase separation behavior of block copolymers, e.g. into hexagonally arranged PMMA cylinder in a PS matrix. After selective removal of the PMMA, we obtain nanopores with diameters of 17 nm in a polymer matrix.

We investigate the influence of the NSL prepatterning on the BCP phase-separation behavior and bring the occurring effects in context with the wetting behavior of polymers on patterned material thin films. The created hierarchical nanopores could find application as backsidesupported membranes for the filtration of nanoobjects or as nanosized batches in nanochemistry.



Fig. 1: SEM image of hierarchical nanopores created by nanosphere lithography and block copolymer lithography.

#### [Poster-12]

### Spectroscopic and Liquid Crystalline Properties of Distorted Arene Cores nanopores

Joachim Vollbrecht<sup>1,2</sup>, Christian Wiebeler<sup>2,3</sup>, Adam Neuba<sup>4</sup>, Harald Bock<sup>5</sup>, Stefan Schumacher<sup>2,3</sup> and Heinz Kitzerow<sup>1,2</sup>

<sup>1</sup>Department of Chemistry, Physical Chemistry, University of Paderborn, Germany <sup>2</sup>Center for Optoelectronics and Photonics Paderborn, University of Paderborn, Germany <sup>3</sup>Department of Physics, Theoretical Physics, University of Paderborn, Germany <sup>4</sup>Department of Chemistry, Inorganic and Analytical Chemistry, University of Paderbon, Germany <sup>5</sup>Centre de Recherche Paul Pascal, CNRS, Université Bordeaux, Pessac, France

Designing displays on flexible substrates with high energy conversion, brilliance, and chemical stability at low production costs are goals which require the investigation of new classes of organic semiconductors. Discotic and calamitic liquid crystals with semiconducting properties exhibit high potential to enhance the performance of organic electronics owing to their self-organizing properties[1].

In this study we focus on compounds with distorted arene cores, namely perylene esters (1) and *bay*-extended derivatives with either a phenanthroperylene- (2) or dinaphthocoronenecore (3) (Figure 1 (a)).[2-5] The distortions of the cores induce columnar liquid crystalline mesophases, even if the compounds have relatively short side chains. At the same time the spectroscopic properties change unexpectedly with each extension of the core. Not only the absorption in the ultraviolet region is enhanced, but also the fluorescent behavior is altered.

Furthermore, the luminescent emission of the compounds in the solid state is influenced by the distortions, which is of significant importance for the application of these compounds as emitter materials in electroluminescent devices (Fig. 1 (b))[6].

These results were obtained by employing UV-Vis spectroscopy, fluorescent spectroscopy, xray diffraction (XRD), cyclic voltammetry and differential scanning calorimetry. Prototype OLEDs were also manufactured and characterized. Additionally, the experimental data is supported by calculations based on time-dependent density functional theory.



Fig. 1. (a) Chemical structure of esters with a perylene- (1), phenanthro [1,2,3,4,ghi] perylene- (2), and dinaphtho [1,2-a:1',2'-j] coronene-core (3). (b) Electroluminescence spectra of compounds 1-3.

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#### [Poster-13]

#### Subwavelength Pancharatnam-Berry phase controlled metasurface for imaging with instantaneous SHG

Christian Schlickriede, Guixin Li, Shuang Zhang, and Thomas Zentgraf Experimental Physics & CeOPP, University of Paderborn, Germany

We design and experimentally investigate a new plasmonic metasurface, which is able to work as a lens for nonlinear imaging with simultaneous frequency conversion for the incident near-infrared light. With our approach, we take advantage of the nonlinear Pancharatnam-Berry phase originating from the arrangement of meta-atoms with threefold rotational geometry. Due to the strong light-matter interaction of the plasmonic antennas, the lenses have only a thickness of 30 nm. Furthermore, the nonlinear metalens shows different operation modes, which depend on the spin angular momentum of light. By using a particular polarization state, the nonlinear lens can either work as a focusing or defocusing lens while simultaneously converting the illumination light to SHG light. We investigate the beam propagation of our nonlinear metalens and determine the evolution of the real and virtual focal planes for illumination with Gaussian beams. To underline the strength and the design flexibility we fabricated and analyzed different types of more complex nonlinear devices featured by different focusing abilities. On top of that, we present intriguing spin angular momentum depending nonlinear imaging abilities giving rise to real and virtual SHG images of real objects as well as nonlinear Fourier transformations. The images are thereby generated at visible wavelength, which enables this device for revealing new avenues in integrated nano-optoelectronics, quantum communication technologies or other future device applications.

#### [Poster-14]

#### Towards a PDC source at NIR wavelengths with a single mode Rb:PPKTP waveguide

Atefeh Christof Eigner, Laura Padberg, Matteo Santandrea, Helge Rütz, and Christine Silberhorn Integrated Quantum Optics, University of Paderborn, Germany

Parametric down conversion (PDC) is a well-established process for the generation of nonclassical states and single photons. Moreover, a PDC source in the visible is attractive for quantum cryptography, as it has the advantage of a low cost detection in Si-APDs as well as coupling to ionic traps. Realising such a source in potassium titanyl phosphate (KTP) offers the advantage of high pump intensities because of the low photo refraction and the high damage resistance of the material. We produce periodically poled rubidium exchanged waveguides in KTP (Rb:PPKTP) by ourselves. This allows us to specifically tailor the dispersive properties of KTP with the potential of integrated optical circuitry. Here, we discuss our approach in manufacturing single mode waveguides in KTP at 800 nm. Moreover, we present the current status of fabricating PDC sources for the generation of photon pairs around 800 nm.

#### [Poster-15]

#### Multiphoton $\pi$ -pulse excitation for ultrafast population inversion of alkali atoms

#### Iduabo John Afa and Carles Serrat Department de Fisica, Universitat Politècnica de Catalunya, Terrassa, Spain

A comprehensive study shows that nearly complete population inversion of hydrogen-like alkali atoms can be achieved with tailored multiphoton  $\pi$ -pulse excitation with a carefully selected set of pulse areas. We demonstrate optimal population inversion in a four level system with resonant ultrashort laser pulses, considering atomic sodium (Na) and rubidium (Rb) atoms as case studies. We investigate density matrix equations beyond the rotating wave approximation and study the effects of detuning and chirp of the driving laser pulses. Selective population of low-lying Rydberg states in Rb atoms is achieved, with potential applications in fast quantum gates, mesoscopic entanglement, and high precision spectroscopy.