Institut
"Jožef Stefan"
Ljubljana, Slovenija

University *of Ljubljana*
Faculty *of Mathematics and Physics*

# 6th Workshop on Liquid Crystals for Photonics

Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia
14 – 16 September 2016
http://wlcp2016.fmf.uni-lj.si/
wlcp2016@fmf.uni-lj.si

**Mission:**

The aim of the Workshop on Liquid Crystals for Photonics (WLCP) is to bring together a forum of world first class scientists, in particular physicists, chemists and engineers, involved in photonic applications of liquid crystals. The workshop will combine invited talks, contributed talks and poster presentations to encompass the state of the art in photonics using liquid crystals and composite materials.

**Main topics of the workshop include:**

- Nanostructured liquid crystalline metamaterials
- Modelling and numerical simulation techniques of LC photonic devices
- Liquid crystal lasers
- Linear and nonlinear propagation phenomena in liquid crystals
- Holography and 3D image systems
- Novel self-organized composite liquid crystal materials
- Modulated liquid crystal structures
- Design of modulated surfaces including photoalignment and photopatterning
- LC-related biophotonics
- Light manipulation for integrated optics
- Optical trapping and manipulation with light

**Previous editions of WLCP were successfully held in:**

- Erice (Italy) in 2014
- Hong Kong (China) in 2012
- Elche (Spain) in 2010
- Cambridge (UK) in 2008
- Ghent (Belgium) in 2006

**Organizing Institutions:**

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University of Ljubljana, Faculty of Mathematics and Physics

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**Venue:**

WLCP 2016 will be held at the Jožef Stefan Institute (Jamova cesta 39, Ljubljana) in the Main institute lecture hall.

**How to Reach the Venue:**

**Walking:** It is a 20-30 minute walk from the city center (Prešeren Square) to the Jožef Stefan Institute.
**City bus:** Bus number 1 stops next to the side entrance of the Institute (bus stop name Jadranska). Note that you need the Urbana card to use the bus. You can purchase the card at ticket vending machines and newspaper kiosks on major bus stops.

**WiFi at Jožef Stefan Institute:**

network: xxxx
password: xxxx

**Lunch:**

Lunch is not included in the conference fee. However, as probably optimal suggestion, reservations of tables for lunch are made at the nearby restaurant Rožna Hiša (Rožna dolina, Cesta II/3, 1000 Ljubljana, see also the map of nearby restaurants at the end of the Abstract Book).

**WiFi in Ljubljana City Centre:**

There is free WiFi provided in Ljubljana city centre: WiFreeLjubljana (one hour/day, activation via SMS code). For more follow http://www.wifreeljubljana.si/en

**Social Activities:**

The conference dinner is included in the registration fee. It is organized on Thursday, 15 September, at 19:30 at the Ljubljana Castle (restaurant Gostilna Na Gradu). We meet at 18:45 at Preseren Square and go to together the restaurant (either walking or by funicular).

Post-conference trips will be suggested for the weekend after the conference. You are welcome to view and reserve tours via Visit Ljubljana. There are many sightseeing or recreational activities available in Slovenia, see the Official Travel Guide at http://www.slovenia.info/?lng=2 for ideas.

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# Abstracts

Plenary Talks – P
Invited Talks – I
Contributed Talks – O
Posters – PO

# Silicon photonics and its applications in communications and in sensing

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[2] *Center for Nano- and Biophotonics*, Ghent University, Ghent, Belgium

Silicon photonics is rapidly emerging as a mature technology platform for the fabrication of photonic integrated circuits. It builds on the technology base of the CMOS-world and allows to implement advanced photonic functions on a small footprint chip with high accuracy and yield. The main driver for silicon photonics is the implementation of high speed optical transceivers for the telecom and datacom field, but there is also a rapid emergence of applications in sensing, especially in a life science context. The combination of silicon photonics with liquid crystals holds considerable value since it allows to implement integrated optical phase modulators with low footprint and very low power consumption.

PL2

# Biophotonics

S.-H. A. Yun[1,2]

[1] Wellman Center for Photomedicine and Harvard Medical School,
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Light, spanning the electromagnetic spectrum from far blue to near infrared, offers versatile approaches to visualize biological specimens, detect diseases and treat health problems. Here, I revisit the fundamental advantages of light and summarize the principles of operation including photothermal and photochemical effects, overview the successful clinical utilities of light, and discuss the promises of new technologies such as cell lasers.

# Electro-optics of chiral nematics formed by molecular dimers

Oleg D. Lavrentovich

*Liquid Crystal Institute, Kent State University, Kent, OH 44242 USA*

Electrically induced reorientation of liquid crystal (LC) director caused by dielectric anisotropy is a fundamental phenomenon widely used in modern technologies. We demonstrate an electrooptic effect in a chiral nematic LC with a distinct oblique-helicoidal director deformation. The effect, predicted theoretically in late 1960-ies by R.B. Meyer and P.G. de Gennes, is observed in a chiral nematic (cholesteric) in which the ground field-free state of the director is a right-angle helicoid. In the electric field, the director forms an oblique helicoid with the pitch and cone angle controlld by the field. The effect is observed in a dimer nematic material in which the bend elastic constant is much smaller than its twist counterpart. With in-plane electrodes geometry, the heliconical structure can be used in tunable grating application; and in top-down electrodes geometry, the heliconical structure can find applications in reflective display, tunable color filter and laser, with the features of wide tunable spectrum range. The work is supported by NSF grant DMR-1410378.

# Optical vortex coronagraphy from liquid crystal topological defects

Artur Aleksanyan[1,2] and Etienne Brasselet[1,2]

[1]*Université Bordeaux, LOMA, UMR 5798, F-33400 Talence, France*
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During the last few years, liquid crystal topological defects have been unveiled as very effective optical elements that enable topological shaping of the light. In contrast to artificially structured singular optical elements produced for instance by liquid crystal photo-alignment or lithographic techniques, the use of natural liquid crystal defects does not require any machining step. We propose to use such self-engineered topological phase masks for optical vortex coronagraphy, which allows the observation of dim objects nearby a bright source of light by use of an appropriately chosen vortex phase mask acting as an efficient angular filter. Since its introduction, its successful experimental implementation has been reported both in laboratory and real conditions. Here we report on the first-time experimental demonstration of optical vortex coronagraphy based on liquid crystal topological defects. The figure of merits of our approach will be reviewed and discussed.

# Lasing from dye doped liquid crystal devices

Kristiaan Neyts, Inge Nys, Mohammad Mohammadimasoudi, Tigran Dadalyan, Serena Bolis, Jeroen Beeckman

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Elongated dye molecules emit light in a similar way as an elementary dipole antenna. When dye molecules are embedded in a homogenous nematic liquid crystal (LC), their long axis aligns with the LC director of the liquid crystal phase and the luminescence is (mainly) linearly polarized, with the electric field in the plane spanned by the LC director and the propagation vector. The optical environment plays an important role in the spontaneous emission characteristics of a dipole emitter. The spectral dependency (Fig.1, left), the angle dependency and the decay rate all change when the dye molecule is placed in another optical environment [1]. When dye molecules are excited by a short laser pulse with sufficient intensity, also light amplification by other excited dye molecules becomes important.

In this work we present new results on lasing from dye-doped liquid crystal devices. We consider 1-dimensional (layered) structures [2, 3, 4], two-dimensional structures (the lying helix of Fig.1, right), based on nematic or chiral nematic liquid crystal. In the lasing experiments the threshold energy, the slope efficiency, the lasing wavelength and the lasing angle are measured. In addition numerical simulations are performed to estimate the lasing behavior for the condition that meets the round trip gain equal to unity [5]. In liquid crystal based devices, lasing can be obtained with a low pulse energy threshold and a good slope efficiency.

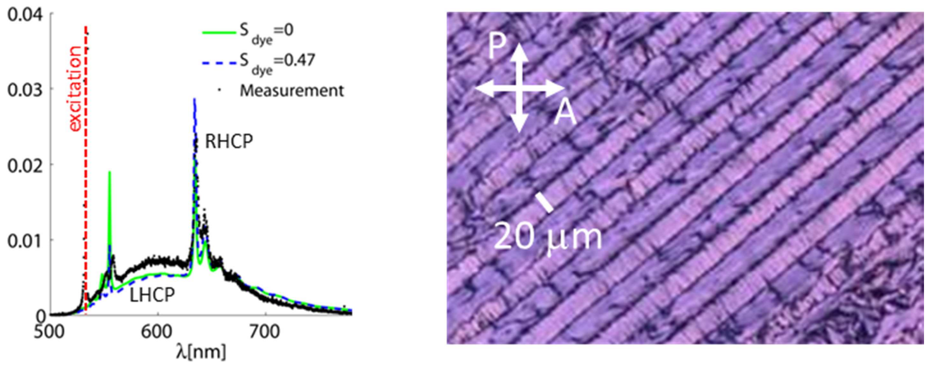


Figure 1. Left: spontaneous emission spectrum by a planar 1D CLC layer (measurement and simulations). Right: 2D lying helix CLC between electrodes with 20µm gap, for in-plane lasing.

1. L. Penninck, *et al.*, *Optics Express,* vol. 19, p. 18558, 2011.
2. L. Penninck, *et al.*, *Physical Review E,* vol. 85, 2012.
3. I. Nys, *et al.*, *Journal of the Optical Society of America B-Optical Physics,* vol. 31, p. 1516, 2014.
4. T. Dadalyan, *et al., accepted for publication in Liquid Crystals*
5. L. Penninck, *et al.*, *Journal of Applied Physics,* vol. 113, 2013.

# OPTICAL SENSING AND PHASE MODULATION DETECTION WITH PHOTO-ADDRESSED LIQUID CRYSTAL MEDIA

Umberto Bortolozzo[1], Daniel Dolfi[2], Jean-Pierre Huignard[3], Stéphanie Molin[2], Arnaud Peigné[1, 2, 4] Stefania Residori[1]

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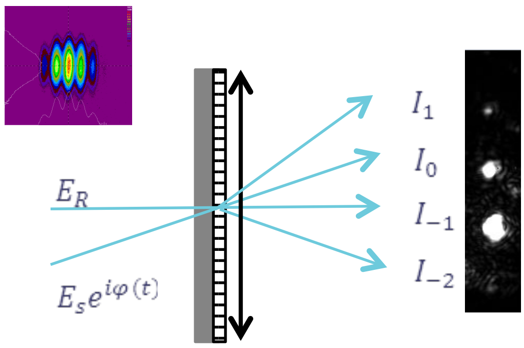
Photo-addressed liquid crystal media allow realizing optical phase and amplitude modulation detection as well as sensing applications based on self-adaptive holographic processes. We report examples of optical modulation and adaptive holographic systems based on this kind of liquid crystal media, as optically addressed spatial light modulator [1] and digital holography [2]. We show that these methods permit measuring small phase modulations even in noisy environments and with distorted and speckled wavefronts [3].




Adaptive holography with optically addressed liquid crystal spatial light modulator. In the upper inset: interference fringes on the photosensitive layer of the liquid crystal cell. Right side: an example picture of diffracted orders.

[1] A. Peigné, U. Bortolozzo, S. Residori, S. Molin, P. Nouchi, D. Dolfi, J.P. Huignard, Opt. Lett. 40, 5482 (2015).

[2] U. Bortolozzo, D. Dolfi, J.P. Huignard, S. Molin, A. Peigné, S. Residori, Opt. Lett. 40, 1302 (2015).

[3] A. Peigné, U. Bortolozzo, S. Residori, S. Molin, V. Billault, P. Nouchi, D. Dolfi, J.P. Huignard, J. of Lightwave Technology Vol. PP, n. 99, 1 (2016).

# FLAT OPTICS WITH SPACIAL PHASE MODULATION BASED ON PATTERNED CHOLESTERIC HELIX

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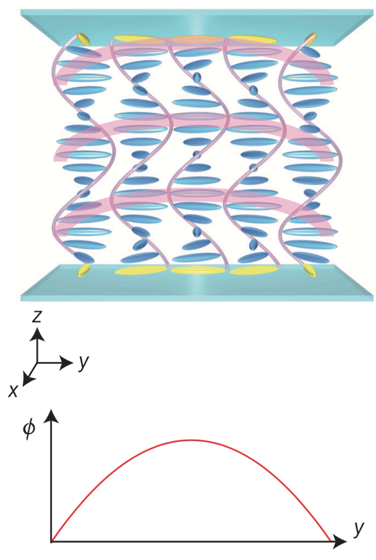
Conventional optical components such as lenses and waveplates are based on light propagation over distances much larger than the wavelength to shape wavefronts. Recently, flat thin optical components so-called “metasurfaces” based on metallic and dielectric nano-scaled resonators have attracted considerable attention, which produce abrupt changes in the phase, amplitude and/or polarization of a light beam. Metasurfaces are generally fabricated by assembling arrays of miniature resonators such as optical antennas with subwavelength resolution and the fabrication of such elements for the visible range is challenging.

Here, we demonstrate metasurface in the visible region based on patterned cholesteric liquid crystals (ChLCs). The phase of light reflected from the ChLC helix can be controlled over 0–2π depending on the spatial phase of the helix. Planar elements with arbitrary reflected wavefronts can be realized by designing the spacial pattern of helix phase that can be defined as the orientation of the director at the substrate surface as shown in the figure.

For the application of the proposed flat optics, we also demonstrate generation of polychromatic Laguerre-Gaussian (LG) beam, optical vortices. The distribution of the spatial phase of the helix is designed such that it contains a phase singularity around which the phase changes by an integral multiple of $\pi$. Reflecting the spatial phase distribution on the substrate surface, the reflected light possesses a helical wavefront at multiple wavelengths.




[1] J. Kobashi, H. Yoshida, and M. Ozaki, “Planar optics with patterned chiral liquid crystal”, *Nature Photon.* vol.10, pp.389-392 (2016).

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# NANOPARTICLES-BASED LIQUID CRYSTALS FOR INFILTRATING PHOTONIC CRYSTAL FIBERS

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Liquid crystals (LCs) are materials with an inceasing interest, because of their unique properties as: electric field-induced director axis reorientation or relatively a vast range of optical anisotropies. All these properties made LCs to be widely used in electro-optical applications as e.g. LC display devices. However, these devices still need an improvement of their electro-optical response times, which are relatively slow compared to electroluminescent devices. Over the last years, research efforts have been made to improve properties of LCs by doping them with different materials as: polymers, dyes, or carbon nanotubes.

Recently, there has been a growing interest in dispersing nanoparticles (NPs) in LCs. Metal NPs can adopt a vast number of structural geometries with an electronic structure. Even a small amount of metallic NPs should be sufficient to influence both the dielectric anisotropy as well threshold voltage of LCs and the most common dopants are gold and silver NPs [1]. Both have been shown to improve electro-optical properties and increased thermal stability of LC.

One of the promising ideas is to integrate NPs-doped LCs with photonic crystal fibers (PCFs) that may result in significant improved efficiency of electric field tuning. Propagation of light can be governed by one of two principal guiding mechanisms responsible for light trapping within the core, and can be dynamically changed by introducing NP-doped LCs into the air-channels broadening the applicability of PCFs. This kind of photonic structures are referred as a photonic liquid crystal fiber (PLCF) with highly improved spectral, polarization, and guiding tuning properties was proposed more than 10 years ago [2]. It appeared that the use of LCs as an infiltrating material greatly improved optical properties of PCFs, also doped with NPs [3].

The paper presence the latest experimental results of PCFs infiltrated with nematic LCs doped with metallic NPs. Two types of NPs: Titanium NPs and Gold NPs and two types of LCs: 6CHBT and 5CB LCs were used to compare an influence of the doping on propagation parameters of the PLCFs and their electro-optical response to external electric field. Such a combination of nanoparticles-based liquid crystals and photonic crystal fibers can be considered as a next milestone in developing a new class of fiber-based optofluidic systems.

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3. L. Scolari, S. Gauza, H. Xianyu, L. Zhai, L. Eskildsen, T.T. Alkeskjold, S.-T. Wu, A. Bjarklev, Opt. Express **17**, 3754 (2009).

# Electro-optical memory of a nano-engineered amorphous blue phase III scaffold

Sahil Sandesh Gandhi[1], Min Su Kim[1], Jeoung-Yeon Hwang[1,2] and Liang-Chy Chien[1]*

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The amorphous blue phase III (BPIII) of cholesteric liquid crystals (LCs) has remained a subject for mostly theoretical investigations for the past several decades due to its occurrence in a narrow temperature range[1–5]. Recent experimental studies indicate that it is a promising candidate for a wide range of electro-optical (EO) applications due to its sub-millisecond switching time, and no Bragg reflection in the visible spectrum[6,7].

Here, we report the fabrication of a porous polymer scaffold that mimicks the complex three-dimensional (3D) structure of BPIII at nanoscale by imprinting a reactive mesogen polymer network along topological defects in BPIII. The polymer replica of BPIII provides the first direct observation of the structure of BP III and retains the sub-millisecond EO switching behavior, that is, "EO-memory" of the original BPIII even after removal of the cholesteric BPLC and subsequent refilling with different nematic LCs. We also fabricate scaffolds mimicking the isotropic phase and BPI to demonstrate the versatility of our material system to nano-engineer EO-memory scaffolds of various structures.

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3. R. Hornreich, & S. Shtrikman, Broken icosahedral symmetry: A quasicrystalline structure for cholesteric blue phase III. *Phys. Rev. Lett.* **56,** 1723–1726 (1986).
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# MORPHING DYNAMICS IN LIGHT-TRIGGERED LIQUID CRYSTAL NETWORK COATINGS


Dirk J. Broer and Danqing Liu

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*Dept. Functional organic materials and Devices*
*Eindhoven University of Technology*


Polymers that perform a programmed and reversible shape change have a wide application potential varying from micro-robotics to surface controlled optics. The mechanism is often based on a triggered and controlled change of the degree of order in liquid crystal polymer systems. We are utilizing similar techniques to change the topography of surfaces. This can be in the form of responsive cilia integrated in surfaces and can be utilized for transport of species along the surface. But it can also be a triggered change of the topography of the surface of interest for haptic applications. We developed morphing principles based on liquid crystal networks. As with programmed shape changes, the underlying mechanism is a change of order parameter. In addition, free volume can be created controlling the oscillating dynamics of triggered species in the liquid crystal network. Free volume leads to temporary volume increase localized by liquid crystal director patterns. The triggers are temperature, light, pH, changes in environment or electrical fields. The focus of the lecture is on UV actuation.

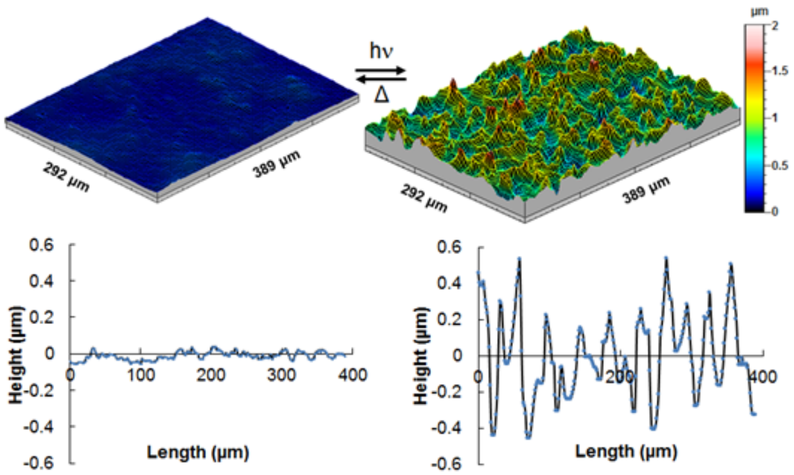


Figure 1. Interference microscope images and the corresponding surface profiles of polydomain liquid crystal polymer surfaces measured in the dark (left) and under illumination (right) [1,2].


[1] D. Liu, L. Liu, P. Onck, D.J. Broer, *PNAS* **2015**, 112, 3880.

[2] D. Liu, D.J. Broer, *Nature Communications* **2015**, **6**, 8334.

# Augmented reality with image registration, vision correction and sunlight readability via liquid crystal devices

Yi-Hsin Lin [1], Po-Ju Chen[1], and Yu-Jen Wang[1],

[1] *Department of Photonics, National Chiao Tung University, Hsinchu, Taiwan*

When human lifespan increases, people would naturally increase a great demand for high quality of life during old age as well as a desire to live healthier for longer. However, people face the descending problems physiologically and mentally as people get old. To extend mobility and fight diseases of old age, "bionic people" defined as people with augmented electronics is a trend and many electronic devices are developing to augment hearing, memory, vision or other human faculties. Augmented reality (AR), which use computer-aided projected information to augment our sense, has important impact on human life, especially for the elder people. However, there are three major problems regarding the optical system in the AR system, which are registration, vision correction, and readability under strong ambient light. Here, we solve these problems simultaneously using two liquid crystal (LC) lenses and polarizer-free attenuator integrated in optical-see-through AR system. One of the LC lens is used to electrically adjust the position of the projected virtual image which is so-called registration. The other LC lens with larger aperture and polarization independent characteristic is in charge of vision correction, such as myopia and presbyopia. The readability of virtual images under strong ambient light is solved by electrically switchable transmittance of the LC attenuator. The impact of this study is to solve three main problems of AR system and possible to develop AR system for bionic people with augmented vision and memory. The concept demonstrate in this paper could be further extended to other electro-optical devices as long as the devices exhibit the capability of phase modulations and amplitude modulations.

# LIQUID CRYSTAL NANOPHOTONIC HOLOGRAPHY

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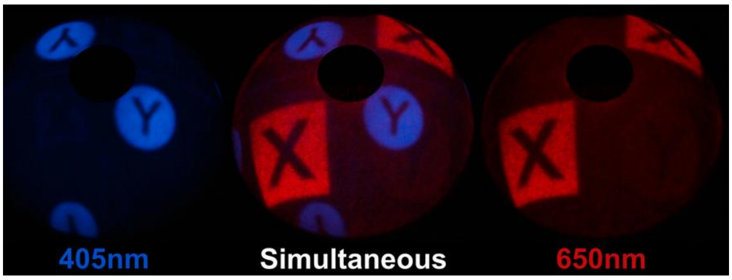
[1] *Cambridge University, Electrical Engineering,*
*9 JJ Thomson Av, Cambridge, CB3 0FA*

Advances in nanoscale fabrication allow for the realization of artificial materials with properties such as metamaterials. They are composed of subwavelength electromagnetic structures, placed at close proximity to each other. Due to mutual coupling (plasmonic resonance) between individual structures, they present properties to incident electromagnetic radiation that are different from those associated with the material from which the structures are comprised of. In this paper we demonstrate the use of silver nano-rods as shown in Fig 1, as subwavelength holographic structures to produce optical metamaterials that exhibit artificial dielectric properties, polarisation[1] and wavelength[2] control through band gaps within the optical regime. Furthermore, if a liquid crystal (LC) material is added to this geometry [3] it provides a variable refractive index pathway between the resonant elements and alters the plasmonic frequency in a complex way. This is not a simple process to model or measure as the interaction at the surface of the plasmonic element with the liquid crystal has a dominant effect in this geometry and is very difficult to observe experimentally especailly in self-assembled metatmaterials such as gold gyroids[4], however the addition of the LC materials allow us to electrically tune the properties of the metamaterials.



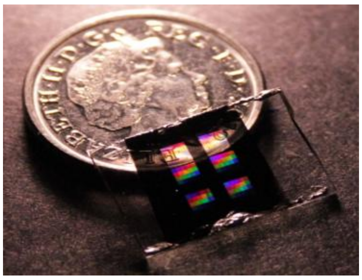



Figure 1. Plasmonic nano-holograms. a) Replay field from aN Ag nano-rod hologram at different wavelengths[2]. b) Tranparent plasmonic nanorods on a glass substrate.

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[3] Williams C, Montelongo Y, Tenorio-Pearl JO, Cabrero-Vilatela A, Hofmann S, Milne WI, Wilkinson TD, *Physica Status Solidi - Rapid Research Letters*, 9(2):125-129 01 Feb 2015
[4] Dolan JA, Wilts BD, Vignolini S, Baumberg JJ, Steiner U, Wilkinson TD. *Advanced Optical Materials* 3(1):12-32 01 Jan 2015.

# BOTTOM UP SIMULATIONS OF LIQUID CRYSTAL SURFACE ALIGNMENT AND ANISOTROPIC WETTING

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[1] *Dipartimento di Chimica Industriale "Toso Montanari", Viale Risorgimento 4, 40136 Bologna, ITALY*

The progress in computer simulation methodologies and the impressive increase in computer power have contributed greatly to improving our understanding of the alignment of liquid crystals in the thin films typically used in devices, for instance allowing the first atomistic molecular dynamics (MD) predictions of orientational anchoring for nematics on various surfaces. Various types of essentially planar anchoring (uniform, degenerate, slightly tilted) have been obtained in atomistic simulations for 5CB on realistic silicon [1] and silica substrates either crystalline or with a certain roughness [2] and on PMMA and Polystyrene polymer surfaces [3]. However, obtaining an alignment perpendicular to the confining surface, easy to spontaneously observe at the liquid crystal-air interface [1,2,4], is difficult to realize at a solid surface. Like for real systems, it can be expedient to employ Self Assembled Monolayers (SAM) to modify the substrate surface [5] and, following this strategy, we have now obtained [6] homeotropic alignment of 5CB on octadecyltrichlorosilane (OTS) and hexyltrichlorosilane (OC6) SAM coated silica. We show that this alignment is only realized when surface coverage is not complete or when a mixture of short and long chains is employed, but that full coverage SAMs induce instead planar alignment.

While atomistic simulations are unveiling details of anchoring at this chemically specific level, phenomena like surface wetting still require to be understood at generic, molecular resolution level and of moving towards the larger scale of at least submicron size droplets. Here we show, using Gay-Berne models, that nematic nanodroplets deposited on a flat (crystalline or amorphous) surface are, in general, elongated and that the contact angle changes around the droplet contour [7]. Simulations for a crystalline substrate show that the angle of contact turns reversibly from anisotropic to isotropic when crossing the clearing transition.

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# SLIPPERY INTERFACES

## - Lubrication of director and helix rotation motions -

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Anchoring effects on the polymer films in the liquid crystal (LC) display devices plays key role to create the restoring force to the black state for any types of display modes, such as IPS, STN, VA and OCB etc, However, the chiral materials with spontaneous helix, such as deformed helix mode in SmC* (DH-FLC) or the polymer stabilized blue phase (PSChBP), can recover black state by uniformly rewinding helix itself.

We have invented the principle and design of slippery interfaces, which has zero anchoring force for attached LC molecules on the interfaces, and confirmed the drastic redusction of driving voltage in DH-FLC mode of SmC* (<1 order) keeping the fast swithcing response (<few 10 micro second).

On the contrary to the SmC*, in order to reduce the driving voltage of PSChBP, the new mechanism is essential to cover slippery interfaces automatically on the polymer rods in PSChBP, because the nano-scale interfaces are entirely embedded in the ChBP. We propose new principle for designing the spontaneous slippery interfaces based on the disorder effect near the interfaces. Isotropic liquid phase wetted on the interfaces can be produced by the localized surface melting due to doping the impurities with the affinity to the interface

Finally, we design and experimetally confirm the anchoring-slippery switchable interfaces controlled by tran-cis isomerization induced by shining the UV light. The design can be applicable to both on the macroscopic (ex. glass substrates etc.) or microscopic (ex. polymer rods in PSChBP etc.) interfaces. Original interfaces are permanently covered by thin layer consist of azo-dye contraining gel like LC polymer. Trans-cis isomerization of azo-dyes localized in wetting layers produces the disorder effect to the sorrounding liquid crystal phase (SmC* or BP etc.), then wetted liquid layer appears and play role of the slippery interfaces. We also confirmed the reduction of the driving voltage of PSChBP by introducing the slippery inteface after shinning the UV light.

# Bifurcation and optical bistability with Nematicons

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Exploiting the reorientational response of nematic liquid crystals in order to generate self-confined spatial optical solitons, i.e. Nematicons [1], we demonstrate simultaneous topological and optical spontaneous symmetry breaking in planar cells with molecular director along the wavevector of intense light beams [2]. In this highly birefringent nonlinear material, nonlinear light localization can be accompanied not only by a power controlled transition from standard to negative refraction, but also by hysteresis versus angle of incidence as well as light-/voltage-driven optical bistability between diffracting and self-trapped beam states [3-5].

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# COMBINING LIQUID CRYSTALS AND POLYMERS TO FORM NOVEL STRUCTURES AND PHOTONIC DEVICES

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In this presentation, I will consider three different fabrication methodologies that can be used to form liquid crystal-polymer composites and discuss how these materials can be used to enhance ceratin electro-optic effects or even generate new topological structures. Specifically, the techniques that I will focus on include forming polymer templates of a variety of different liquid crystalline phases, two-photon laser writing of micron-scale polymer structures directly within a liquid crystal (LC) device, and drop-on-demand inkjet printing.

For the polymer templates, I will describe research that has been carried out to form polymer scaffolds of the chiral nematic, blue phase, and smectic A phases and show how these structures can be imprinted on to nematic LCs. In each of these polymer 'templated' examples, we find that the electro-optic behaviour is notably different from that observed for either the initial host phase that is used to form the polymer scaffold or the nematic phase. As a specific example, it is found that the electric field-induced wavelength tuning range of the reflection band for the achiral nematic LC that is filled into a chiral polymer scaffold is more than a factor of 2 greater than that observed for a conventional polymer-stabilized chiral nematic LC. Alternatively, for the case of the 'templated' blue phase, a linear electro-optic effect is observed that appears to contradict the cubic symmetry of the structure.

Using direct laser writing in combination with adaptive optics it is now possible to create sub-micron, 3-dimensional polymer structures directly within an LC device that consists of reactive mesogens. Upon exposure of the material to the ultrafast laser, it is possible to create a polymer network that is localised to a small volume within the device and by scanning the beam it is then possible to build up complex macroscopic polymer structures. Furthermore, by correcting for aberrations, these networks can be formed in the presence of an electric field so as to change the orientation of the LC, leading to a range of interesting structures. Finally, I will conclude the presentation with some discussion about using drop-on-demand printing to form LC-polymer composites and the challenges that are involved in printing these complex fluids.

# LC:PDMS optical waveguides: a new proposal for flexible photonics

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We demonstrated optical waveguides made of polydimethylsiloxane (PDMS) channels filled with nematic liquid crystals (LC), referred as LC:PDMS waveguides [1], inspired by optofluidic devices demonstrated by Psaltis et al. [2]. PDMS is in fact largely used in microfluidics to fabricate microsystems by means of soft lithography. Standard cast and molding technique allows to easily make passive optical waveguides by combining different kinds of PDMS for effective packaging of flexible photonic chips [3]. In this paper we propose electro-optic integrated devices based on LC:PDMS waveguides such as optical switches based on sub-micron long directional couplers for flexible low power photonic chips. Design and fabrication of LC:PDMS waveguides and devices will be presented operating at the fiber optic communication wavelength of 1550 nm. Montecarlo simulations of a lattice model will be also reported to show the molecular reorientations in a LC:PDMS with an applied electric field in an in-plane switching electrode configuration and how this affects directional coupler behavior to obtain electro-optical LC:PDMS switches.

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# COLLOIDAL DISPERSIONS OF NANOPARTICLES IN LIQUID CRYSTALS FOR PHOTONICS APPLICATIONS

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Tunable composite materials with novel physical behavior can be designed through integrating unique optical properties of solid nanostructures with the facile responses of soft matter to weak external stimuli, but this approach remains challenged by their poorly controlled co-assembly at the mesoscale. Using scalable wet chemical synthesis procedures, we fabricated anisotropic photon-upconverting, plasmonic, and gold-silica-dye colloidal nanostructures and then organized them into the device-scale electrically tunable composites by simultaneously invoking molecular and colloidal self-assembly [1-5]. We show that the ensuing ordered colloidal dispersions of shape-anisotropic nanostructures exhibit tunable properties, such as the fluorescence decay rates and emission intensity. We characterize how these properties depend on low-voltage fields and polarization of both the excitation and emission light, demonstrating a great potential for the practical realization of an interesting breed of nanostructured photonic composites.

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# LIQUID-CRYSTAL SPATIAL LIGHT MODULATOR BASED OPTICAL ARQUITECTURE FOR THE FULL POLARIZATION MODULATION – APPLICATION TO ENCODE OPTICAL POLARIZATION DEVICES

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In this presentation we will review our recent advances in the generation of different polarization components generated with liquid crystal spatial light modulators (LC-SLM). In particular we will present an optical system in a reflective geometry which, by uinsg a single parallel-aligned nematic liquid crystal SLM permits to independently modulate the phase of two orthogonal polarization components of the incoming beam [1].

Then, this sytsem is applied to generate a variety of different polarization optical elements, namely: a) Q-plate devices for the generation of vector beams [2], b) polarization diffraction gratings that generate a number of diffraction ordes with a desired state of polarization [3], or c) polarization axicon lenses that generate non-diffracting Bessel beams with a state of polarization that changes along hte propagation [4,5].

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I18

## Calculation of confocal microscope images of cholestetric blue phases

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Cholesteric blue phases [1] are interesting examples of three-dimensional non-trivial ordering in soft materials. They are composed of so-called double-twist cylinders of orientational ordering, and disclination lines that inevitably appear as a result of frustrations [1]. Two of the cholesteric blue phases, BP I and BP II, are of cubic symmetry (The third, BP III, is believed to be amorphous), and their typical lattice constant is a few hunderd nanometers, on the order of or smaller than the wavelength of visible light. Therefore real-space observation of the structures of cholesteric blue phases by optical means is challenging, although desirable in that it is a non-destructuve method. Higashiguchi *et al.* [2] reported a successful observation of the periodic structures of cholesteric blue phases by a confocal microscope. This observation was surprising because confocal microscopy was not commonly used for such small-scale structures. We also note that no fluorescent dye was used there and the confocal images arose purely from light reflected from the blue phase structures. However, there has been no theoretical attempt to interpret the confocal-microscope images; geometrical optics routinely used to explain the principle of confocal microscopy is totally useless for cholesteric blue phases.

We present our attempt to calculate confocal microscope images of cholesteric blue phases directly from their orientational ordering [3]. We solve the Maxwell equations for electric and magnetic fields to evaluate the reflected light for incident light with given wavevector, and make an appropriate superposition of results for different wavevectors of incident light. We show that the confocal images crucially depend on the wavelength and the polarization of the incident light. The calculated images agree qualitatively with experimental ones in that the symmetry of images is consistent with that of bulk blue phase ordering. Our work will give a firm theoretical ground to extend the applicability of confocal microscopy and other optical measures for real-space observations towards submicron scales.

This work is supported by the Cooperative Program of »Network Joint Research Center for Materials and Devices.«

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# USE OF LIQUID CRYSTAL CELLS TO CONTROL POLARIZATION STATE AND DEGREE OF POLARIZATION

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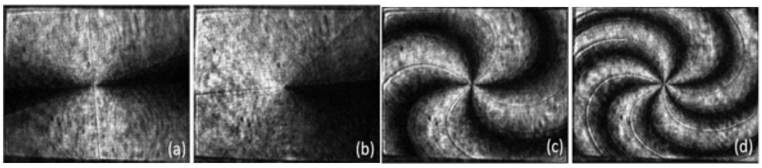
An accurate polarimetric metrology, including depolarization data, is crucial in a large number of applications. Therefore the possibility to generate SoPs with a controlled degree of polarization (DoP) results in an interesting tool for testing Stokes-Mueller polarimeters, a crucial element for these kinds of applications. In this paper we present several methods [1, 2, 3] to generate beams with uniform polarization state and degree of polarization and to generate beams with arbitrary polarization distributions.

First, a method based on time multiplexing two orthogonal polarization states is shown. The two orthogonal states are obtained sequencially by means of a ferroelectric liquid crystal cell. By static polaricing devices we can change the linear polarization into any two orthogonal elliptical polarization states. The second method is based on the superposition of two incoherent beams with two orthogonal linear polarization states, that can be changed to elliptical states as above mentioned.

Finally we present a method to generate a beam with any polarization distribution by using a parallel aligned LcoS Spatial Light Modulator (SLM). The beam impinges two times at different halves of the SLM. By means of two half wave plates rotated 22.5 degrees between them, the polarization state is rotated 45 degrees, between the two reflexions. By changing the corresponding phases at the two corresponding pixels any polarization state can be generated as shown in the next figure.

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We acknowledge the financial support of the Spanish Ministerio de Economía y Competitividad and Fondos FEDER FIS2015-66328-C3-1-R.

**The development of Liquid Crystal Display technology through Partnerships.**

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Since the first discovery of Liquid Crystal materials more than 100 years ago, to the very latest materials used in mass-produced TFT LCD's, the success of today's liquid crystal displays has been achieved through partnerships.

The development of stable, high-performing liquid crystal molecules and mixtures has been a fascinating scientific journey, and still continues with remarkable speed. We review some highlights from the history of earlier commercial materials, through to the current 'state of the art' display technologies of PS-VA and UB-FFS.

The future of liquid crystals in new displays and new applications will continue to drive liquid crystal research and partnerships will play a key role in their success.

# Bridging the electrode gap with ferroelectric thin films

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Close to the edges of electrodes, strong electric fields are present which often give rise to unwanted effects in liquid crystal behavior. In liquid crystal microdisplays for projector applications, the gap between electrodes should be as small as possible and the liquid crystal orientation should vary sharply from one pixel to the other in order to achieve the highest possible resolution. In other applications however, a smooth variation in the liquid crystal orientation is desirable and fringe field effects are highly unwanted. Electrode based tunable lenses or beam steering devices are examples in which fringe fields should be suppressed as much as possible.

A common way to alleviate the fringe field problem and to smoothen out the spatial variation of liquid crystal orientation is to deposit weakly conductive layers on top of the highly conductive electrodes. In such devices there is a trade-off between high electrical power consumption (high conductivity) and reduced smoothing effect (low conductivity). Also, it is technologically not always straightforward to obtain layers with the desired sheet conductivity. In this work, we demonstrate a new technique exploiting the extremely high dielectric permittivity of ferroelectric thin films based on lead zirconate titanate ($PbZr_xTi_{1-x}O_3$, PZT). The high dielectric permittivity of the layer leads to similar effects as the conductivity of a weak conductor. The smoothening and spreading of the electrical field lines between two electrodes is clearly demonstrated in figure 1. At the same time we also prove the excellent reduction of fringe fields near electrode edges. Using multi-electrode designs with a PZT top layer, tunable lenses with high optical quality are demonstrated [1]. Also one-dimensional beam steering is demonstrated. In both cases a reference device was fabricated without PZT layer. The benefit of using a PZT layer is obvious when comparing the PZT and non-PZT devices.

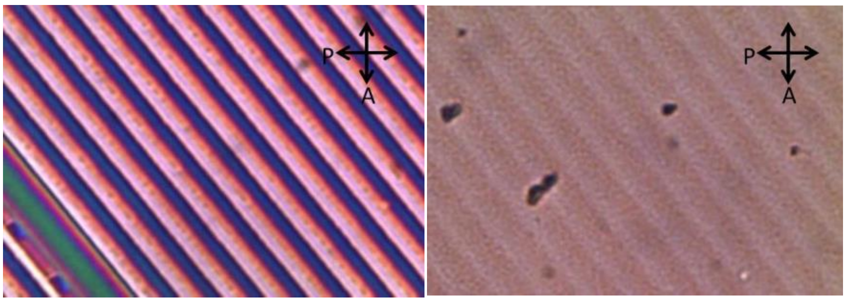


Figure 1. Liquid crystal observed under polarization microscope without PZT layer (left) and with PZT layer (right).

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# LIQUID CRYSTALLINE PERIODIC WAVEGUIDING STRUCTURES

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Liquid crystals (LCs) play an important role in modern science and technology. Specifically, LC-based optics and optoelectronics is a subject to many advanced areas of engineering. Fluid nature of LCs, their unique optical properties, much easier reconfiguration than that offered by solid-state materials and their compatibility with most optoelectronic and organic materials cause that apart to LCD applications, a significant number of LC-based functional photonic devices have been successfully demonstrated in the area of integrated optics systems [1-3].

In this work periodic liquid crystalline structures exhibiting special properties dedicated to photonic waveguiding structures will be shown. For instant methods based on photo-orientation and photo-polymerization will be presented as ones to be applied to form liquid crystalline structures with particular spatial distribution of refractive index. The latter can be in principle applied to obtain functional photonic elements for integrated optics (e.g. waveguides of different shape, switches, couplers, etc.). Such a solution allows for further miniaturization and simplification of the design, as well as its independence of external electric bias which was strongly required in our previous works regarding waveguide arrays for study of discrete light propagation [4]. It means that in comparison to existing technologies, our schemes allows for excluding electrodes and wiring from design and thus to be e.g. used in harsh and hazardous conditions.

It will be also presented that proposed LC structures may lead to the innovative solutions for all-optical steering and switching functional elements that require low-power, low losses and safety for operation rather than fast switching. The basis of operation of such switching and routing devices can be based on the properties of spatial solitons. Their generation in LCs is relatively easy and can be achieved for optical power of single mW. In principle, the direction of propagation and the width of solitons can be changed by modification of the light power, light polarization, phase and by interaction with another beams or external fields. In this context, spatial solitons can be used to create reconfigurable photonic circuits (created by the light itself), where all-optical switching and processing can be additionally achieved though the evolution and interaction of many beams (including solitons).

Acknowledgement: This work was partially supported by the Polish National Science Center (NCN) under the grant no. DEC-2013/11/B/ST7/04330.

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# Using absorption bands for photonic band gap engineering in cholesteric liquid crystals

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Due to their chiral molecular order, cholesteric liquid crystals (CLCs) act as one-dimensional photonic crystals. Conventional systems exhibit exactly one selective reflection band (SRB), i.e. one photonic band gap for circularly polarized light with the same helicity as the cholesteric order. In a theoretical treatment, we show that double reflection bands can be created by introducing narrow-band absorption into the liquid crystal.

The limiting vacuum wavelengths of the SRB are $n_o p$ and $n_e p$, where $p$ is the cholesteric pitch and $n_o$, $n_e$ are the ordinary and extraordinary refractive indices of the quasi-nematic planes, respectively. As dispersion and dissipation in an optical medium are linked by the Kramers-Kronig relations, an isolated absorption band ($n'' > 0$, Fig. 1a) is always accompanied by a wavelength interval $[\lambda_1, \lambda_2]$ of anomalous dispersion ($dn/d\lambda > 0$); for long wavelengths ($\lambda > \lambda_2$), the refractive index ($n'$) is always larger than the refractive index for short wavelengths ($\lambda < \lambda_1$), cf. Fig. 1b. If the refractive index variation introduced by an absorption band is strong enough, the wavelength inside the medium shows a non-monotonic behavior as a function of the corresponding vacuum wavelength; in case of an absorbing CLC, by choosing the cholesteric pitch appropriately, then the condition $n_o p < \lambda < n_e p$ for selective reflection is matched not only for one single wavelength interval, but for two wavelength intervals (Fig. 1c). Therefore, a strong and narrow absorption band can give rise to two selective reflection bands (Fig. 1d). By introduction of multiple absorption bands, the number of photonic band gaps in a CLC can even be further increased.

Possible applications of this effect include multi-color reflectors and liquid crystal lasers (where the additional band edge resonances might allow for improved pumping schemes as well as for multiple-wavelength emission).

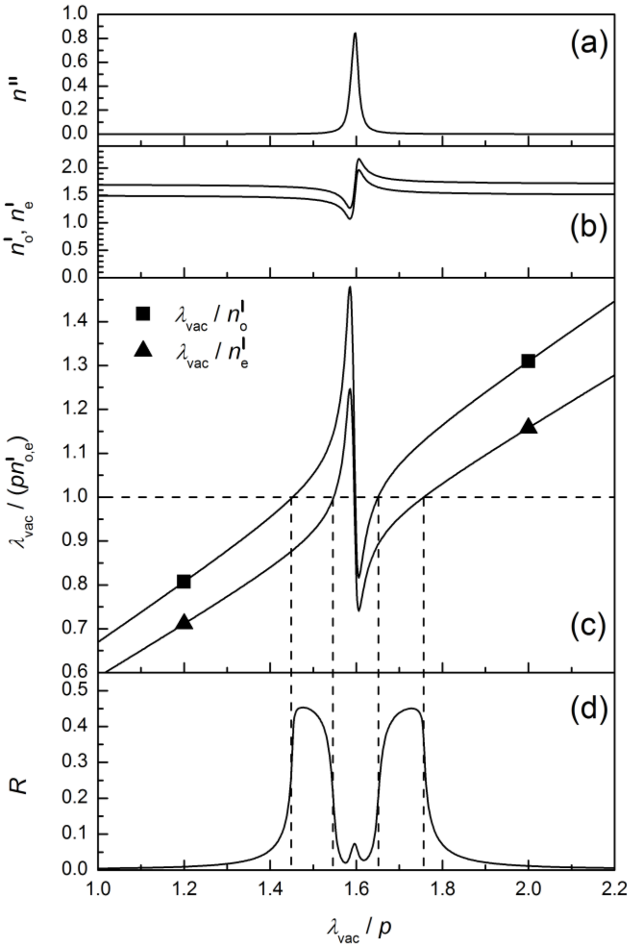


Fig. 1. Absorption band ($a$) and corresponding dispersion relations ($b$) in a CLC; wavelength intervals $\lambda_{vac} \in [pn_{o,} pn_{e,}]$ ($c$, intervals are indicated by vertical dashed lines); resulting reflectance spectrum of a CLC ($d$; assuming unpolarised illumination and neglecting multiple reflections); the abscissa for all plots is vacuum wavelength ($\lambda_{vac}$) divided by cholesteric pitch ($p$).

O2

# LIVE AND BIOCOMPATIBLE LASERS

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Lasers completely embedded within single live cells have been demonstrated. The lasers were made out of 10 µm solid polystyrene beads. We fed these laser beads to live cells in culture, which eat the lasers within a few hours. The lasers can act as very sensitive sensors, enabling us to better understand cellular processes. For example, we measured the change in the refractive index which is directly related to the concentration of chemical constituents within the cells. Further, lasers were used for cell tagging. Each laser within a cell emits light with a slightly different fingerprint that can be easily detected and used as a bar-code to tag the cell. With careful laser design and multiplexing, up to a trillion cells (1,000,000,000,000) could be uniquely tagged. This would enable to uniquely tag every single cell in the human body, providing the ability the study cell migration including cancer metastasis. Further, by using a micro pipette, we injected a tiny drop of oil containing fluorescent dye into a cell. By analyzing the light emitted by a droplet laser, we can measure that deformation and calculate the tiny forces acting within a cell. Finally, we realized that fat cells already contain lipid droplets that can work as natural lasers. That means each of us already has millions of lasers inside our fat tissue that are just waiting to be activated to produce laser light. Lasers were also made from biocompatible and biodegradable materials including cholesteric liquid crystals, so they can be implanted or injected into human body enabling better light delivery, diagnostics and medical treatments.

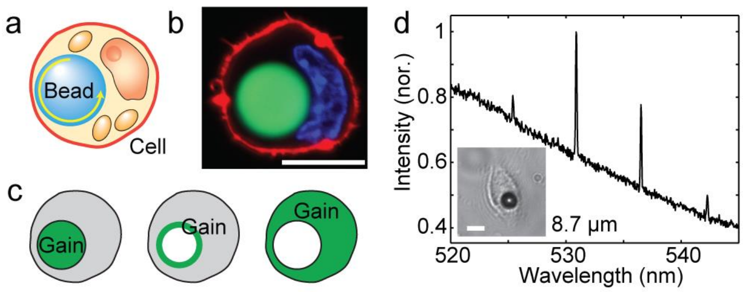


Fig. 1. (a) Configuration of the cell laser. (b) Confocal image of a polystyrene bead embedded in a HeLa cell. (c) Three locations of laser gain used in the experiments. (d) Laser emission from a BaTiO3 bead embedded in a cell containing CMFDA dye in its cytoplasm.

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# PHOTOMANIPULATION OF THE ANCHORING ENERGY AND ITS EFFECT ON THE BEHAVIOUR OF LC COLLOIDS

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Recently, photo-switchable azo-dendrimers spontaneously adsorbed at glass/LC interfaces have been shown to switch reversibly between homeotropic and planar anchoring conditions when exposed to UV [1-3]. In colloidal LC systems, this effect results in the photo-switching of the director field in the vicinity of LC droplets, or even mechanical motion of the colloidal particles in the nematic matrix [4,5]. We demonstrated that these effects are determined by a light-driven change of the anchoring energy of the glass/LC interface [4].

Here, we report measurements of the interfacial surface tension anisotropy (anchoring energy) at an ITO-glass/5CB interface under exposure to UV and VIS light illumination. We demonstrate that the anchoring strength depends on the ratio of the intensities in the UV and VIS bands. A simple model is developed to qualitatively explain the dependence of the anchoring energy on the light intensity. These results are then applied to describe the light-driven kinetics of the opto-mechanical effect which has been explored in the dependence of *both* UV and VIS illumination. Additionally, we report the structure and the order in the dendrimer layer at the glass/LC interface. Using Second Harmonic Generation and Attenuated Total Reflection IR Spectroscopy, it is shown that the dendrimer molecules adopt a polar structure, which can be reversibly suppressed by the UV illumination, and restored by the VIS illumination. Unusual behaviour is found in liquid crystalline droplets in an isotropic matrix. In case of bent-core nematics, the droplets with the LC/dendrimer mixture exhibit a spiral texture in polarising microscopy. We show that the spiral handedness can be switched by exposure to UV. We discuss a possible director configuration which can explain this behaviour.

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# OUT-OF PLANE SURFACE RELIEF GRATINGS FOR MICROPATTERNED LIQUID CRYSTAL ALIGNMENT

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Patterned alignment of liquid crystals (LCs) is the core of many advanced LCD operation modes and of several non-display LC applications. Our investigations demonstrate that two-photon polymerization-based direct laser writing (TPP-DLW) is a very convenient technique to generate complex nano- and micro-structures for LC alignment. In addition to fabrication of conventional alignment layers deposited onto glass substrates, the TPP-DLW provides also construction of out-of-plane alignment configurations. In these configurations the LC molecules are uniformly aligned via their contact to side-walls of polymer ribbons oriented perpendicular to the glass substrates. The alignment is induced by surface relief gratings that are created on side-walls of the polymer ribbons during the TPP-DLW process due to optical interference between the incident and reflected laser beams. The measured surface anchoring energy on these side-wall structures is in the range of $10^{-5}$ J/m$^2$, which is considerably higher than observed on conventional surface relief grating materials. With the aid of such polymer ribbons the compartmentalized LCs alignment in arbitrary nano/microstructures can be realized.

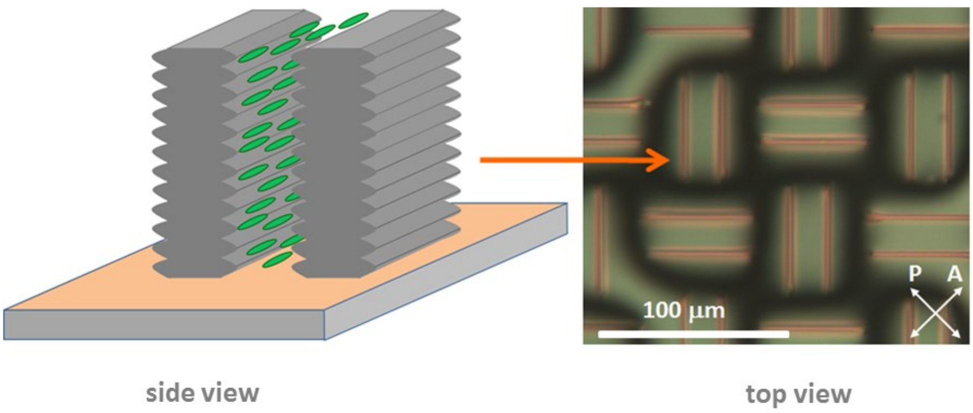


Fig. 1: Schematic drawing of the LC alignment induced by polymer ribbons exhibiting surface relief gratings and polarization optical microscopy (POM) image of the nematic LC (E7) cell with multiple ribbon pairs.

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# Spinning liquid crystal tuneable laser prototype system for biomedical microscopy applications

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Liquid crystal lasers have many advantages over traditional coherent light sources *[1]*: Their self-organsing chiral nanostructure provides a simple and inexpensive tuneable resonant cavity; the wide available range of soluble organic dyes provide a broad and continuous tuning range across the visible spectrum and beyond; they are capable of extremely high slope-efficiencies (up to 60%) *[2]*; they can be tailored to emit highly customisable light fields, including multiple simultaneous polychromatic emissions *[3]*; and they can painted or printed onto surfaces *[4,5]*. Unfortunately, despite these unique and advantageous features, liquid crystal lasers have so far failed to reach any commercial application as a light source. Many of the advances in liquid crystal laser technology have been demonstrated independently to each other, using specialist laboratory facilities. Limitations in the maximum stable average power (typically < 1 mW) have also restricted their applications. Power is limited prinicpally by repetition rate, typically < 200 Hz. Higher repetition rates lead to triplet state generation, optical fatigue, and a subsequent reduction in lasing efficiency and stability.

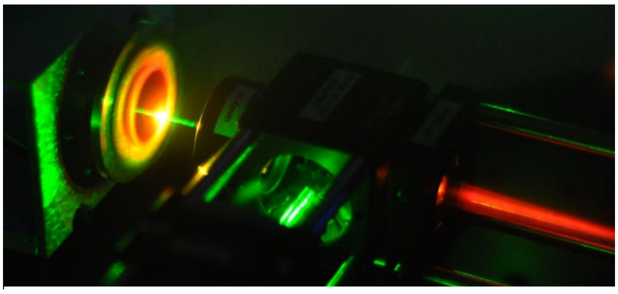

Fig.1: Spinning liquid crystal laser (left), capable of stable higher average power emission (red).

In this paper, we report on new advances in spinning liquid crystal lasers, which enable stable high repetition rate lasing (> 5 kHz) and a corresponding increase in average power output of more than an order of magnitude compared to static systems. We also report on the development of a portable high-performance liquid crystal laser prototype system, capable of tunable wavelength emission between 450 and 850 nm at these increased optical powers, and the generation of rapidly-switching (~ ms) wavelength sequences. This digitally-controlled benchtop tuneable laser system, is being developed to demonstrate new capabilities in advanced biomedical microscopy techniques, and acts as a prototype test-bed for potential future commercialisation activities.


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# FRUSTRATED STRUCTURES IN FERROMAGNETIC CHOLESTERIC LIQUID CRYSTALS

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Cholesteric liquid crystals (CLCs) form a rich variety of configurations and defect structures when confined in layers or droplets. In confined CLCs surface anchoring usually promotes uniform configuration, which competes with helical ground state of bulk CLCs. These frustrated structures can be further manipulated by electric and large magnetic fields. In suspensions of magnetic nanoplatelets in CLCs, similarly as in the suspension in nematic liquid crystals[1], ferromagnetic ordering of the platelets appears which makes the suspensions sensitive also to small magnetic fields. These ferromagnetic CLCs can be described macroscopically by two coupled order parameters: the director and the magnetization. The coupling is such that parallel orientation of the order parameters is the most favorable. The director is sensitive to the electric field and its configuration is preferably helical, while the magnetization is sensitive to small magnetic fields and it prefers homogenous state, so the frustration is inherent already in the bulk. We have studied field induced structures of such ferromagnetic CLC confined to a layer with homeotropic (perpendicular) surface anchoring and the thickness of approx. two cholesteric pitches. We used different combinations of electric and magnetic fields to manipulate the structures.

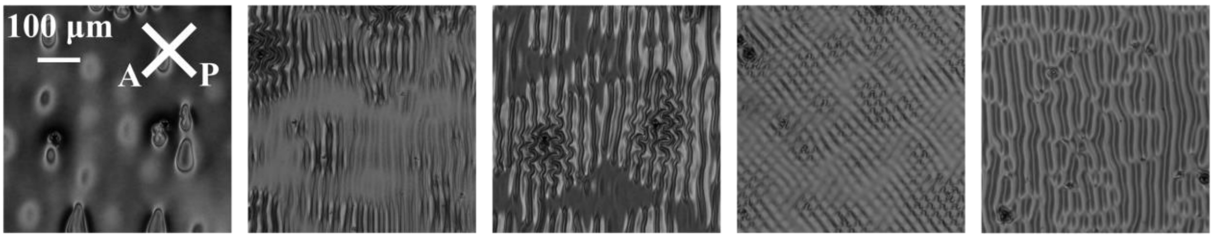


Figure 1: Different configurations of the director field as observed by polarizing microscopy.

We have prepared magnetically monodomain layer by filling the LC cell in the presence of the magnetic and the electric fields, both applied perpendicular to the layer. When both fields are switched off, a wound structure typical of ordinary CLCs appears, which can be reversibly unwound back to magnetically monodomain homogeneous structure. The two fields, when perpendicular to each other, stabilize polar translationally invariant configuration (TIC), which becomes unstable when either of the fields is slowly reduced (Figure 1). At larger electric fields the instability drives TIC to a 1D periodic structure with the wavevector along the magnetic field. At zero or small electric field, the TIC is destabilized into a 2D periodic structure. By modelling the instability numerically, we were able to determine the periodic structures.

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# Shaping the light by Bragg-Berry mirrors

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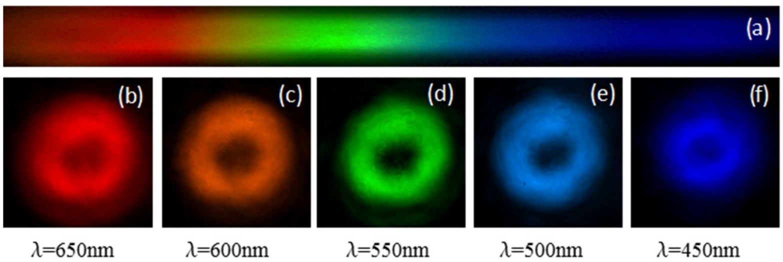
We report on highly reflective spin-orbit geometric phase optical elements based on a helicity preserving circular Bragg-reflection phenomenon [1, 2]. We show that Berry phase associated with the circular Bragg refection phenomenon in chiral anisotropic optical media brings a novel paradigm to achieve wavelength-independent pure spin-orbit topological shaping of light from two- and three-dimensional “Bragg-Berry” mirrors (i) in the reflection mode, (ii) without need for any birefringent retardation requirement. This is illustrated by the experimental realization of Bragg-Berry mirrors enabling the broadband generation of optical vortices upon reflection for both diffractive and non-diffractive light fields using spatially patterned chiral liquid crystal films. Our results foster the development of a novel generation of robust optical elements for spin-orbit photonic technologies.




Broadband optical vortex generation from an azimuthally patterned Bragg-Berry mirror. (a) Spectrum of the incident supercontinuum laser source using a dispersion prism. (b-f) Far field intensity profiles of the polychromatic vortex beam reflected off the Bragg-Berry mirror.

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# LIQUID CRYSTAL PHOTO-ALIGNMENT WITH PERIODIC PLANAR/HOMEOTROPIC ANCHORING VARIATION

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Being able to control and influence the alignment of liquid crystals (LCs) is important from a practical and fundamental point of view. Different alignment techniques have been known for many years and they all offer certain advantages. With the help of photo-alignment, LC can be aligned in complex geometries where mechanical rubbing is impossible and structures with micrometer periodicity can be attained. In this research, we specifically focused on the use of a new photo-alignment technique to create a periodic planar/homeotropic anchoring variation. This kind of periodic anchoring is especially interesting for the alignment of the in-plane lying helix structure (figure 1). To obtain a stable and robust in-plane lying helix neither uniform planar or uniform homeotropic alignment are appropriate. However, a periodic planar/homeotropic anchoring can help to stabilize the in-plane lying helix.

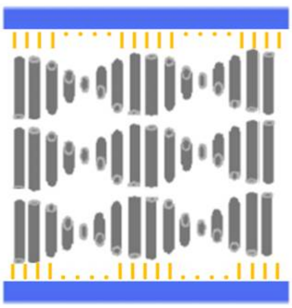

Figure 1: Schematic representation of the in-plane lying helix structure.

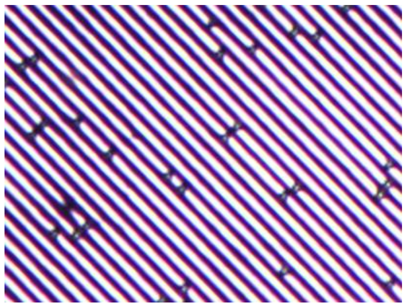

Figure 2: Polarized optical microscopy image of a cell filled with NLC.

In our experiments, a mixture of photo-alignment material (PAAD22) and homeotropic alignment material (SE4811) was used in combination with a two-beam UV interference technique. By mixing an appropriate amount of both compounds and by carefully selecting the polarization of the illumination pattern, we were able to obtain a periodic alignment pattern with planar and homeotropic anchoring variation. This has been tested by filling the cells with nematic LC and analyzing the director configuration with polarized optical microscopy (figure 2). In a second experiment, the same method is used to align chiral nematic LC with a pitch of 16$\mu$m in cells with 4$\mu$m thickness. The procedure gives rise to stabilized cholesteric fingers.

# LIGHT-INDUCED STRUCTURAL TRANSITIONS IN NEMATIC MICRODROPLETS: INFLUENCE OF TEMPERATURE AND NANOPARTICLES

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Recently we have found that UV irradiation of azobenzene nematic liquid crystal (LC) droplets in water leads to a structural transition from a bipolar configuration to the radial one [1,2]. The radial configuration is formed above the critical UV irradiation time $t_c$, which increases with the droplet radius and is inversely proportional to the light intensity. Our investigations revealed that $t_c$ could be strongly influenced by appropriate nanoparticles (NPs) in our case phospholipids - in water. Therefore, the structural transition threshold within LC droplets could be sensitively controlled by independent parameters: by changing concentration of NPs or concentration of cis-isomers. Note that the presence of cis-isomers could reduce the number of nanoparticles needed for the transition by three orders of magnitude! Moreover, the concentration of nanoparticles in water could be determined by measuring of critical irradiation time. Therefore, our results might be expoited for development of sensitive detectors of appropriate NPs.
Our further investigations reveal that $t_c$ could be also substantially influenced by temperature $T$. In this contrubution we present the results of investigations of the light-induced bipolar-radial structural transition in nematic ZhK 616 droplets (radius $r = 1 \dots 4\ \mu$m) in water on varying $T$ and concentration of phospholipids. Our investigations reveal that in the absence of the nanoparticles $t_c$ increases with temperature. However, if NPs are present $t_c$ exhibits negligible variations in the temperature range from 25°C to 50°C. Note that in Refs.[3,4] it was shown that in LC droplets dispersed in the glycerol matrix [3] (also in a polymer matrix [4]) in the presence of nanoparticles of low concentrations an increase in temperature promotes the formation of homeotropic orientation and a structural transition. Thus, the observed effect can be explained by competting action of the UV and NP driven structural transition. The obtained results could be exploited for development of biological and chemical LC sensors with temperature stability.

This work was partially supported by Ministry of Education and Science of the Russian Federation (grant No. 3.1921.2014/K), by RFBR (project No. 15-32-21143) and by a grant of the President of Russia for young scientists (MK-4886.2016.2).

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# Reconstruction of complex director fields from experimental FCPM data in chiral nematic droplets

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Fluorescent confocal polarising microscopy (FCPM) [1] relies on angle dependence of fluorescence intensity of rod-like fluorophores which align with liquid crystal (LC) molecules to determine the local orientation of LC director field. Using several excitation and detection polarisations it is possible to accurately determine the director orientation in a plane perpendicular to the optical axis of the microscope [2] but care has to be taken when trying to extract the out-of-plane tilt of the director [3]. Because all the excitation/detection polarisations lay in a plane, no information about the sign of this tilt can be extracted from experiment without tilting the sample.
We developed a procedure which takes experimental FCPM intensities as input, applies necessary corrections to them and uses a simulated annealing algorithm to numerically anneal the signs of $n_z$ director components to find a reconstructed director field which closely fits the experimental data [3]. This procedure enables us to reconstruct and analyse complex director structures without relying on theoretical models. We tested the procedure on chiral nematic droplets and found complex director structures which can appear as different optical transmission microscopy textures depending on the orientation of the structure inside the droplet. Our studies revealed that chiral nematic droplets at diameter-to-pitch ratio in the range $1-3$ when subjected to temperature quenches have metastable director structures rich in point defects which are separated by twisted cholesteric regions related to skyrmions and torons.

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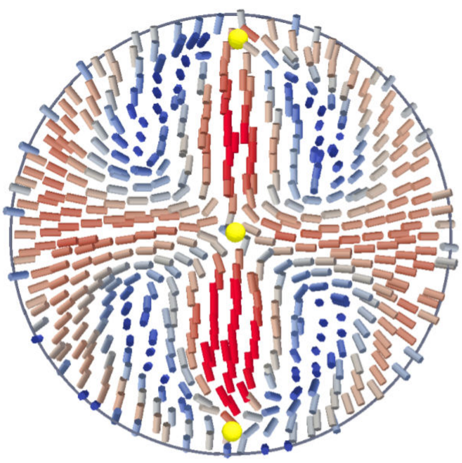

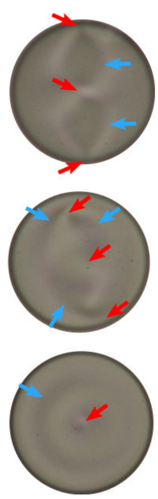

# Liquid crystal gyroids as photonic crystals

Jure Aplinc[1], Mitja Štimulak[1], Simon Čopar[1], and Miha Ravnik[1,2]

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The gyroid triply periodic surface is separating the space into two interlocking spaces with opposite chiralities, which makes it an interesting template for optically active photonic crystals. The liquid crystal gyroids are designed as composite optical materials, where we take one labyrinth of passages to be a solid dielectric, whereas the other complementing labyrinth of passages is taken to be filled by chiral or achiral nematic liquid crystal, with the intermediate gyroid surface imposing homeotropic surface anchoring.
We explore chiral and achiral nematic gyroids as photonic crystals using mesoscopic free energy minimisation to determine the nematic orientational profiles and eigen-problem Bloch-type solving of wave equation to calculate the photonics bands. The nematic inside the gyroid is shown to exhibit a variety of possible ordered, semi-ordered or completely disordered complex networks of topological defects (Figure 1). This diversity of nematic states leads to a rich structure of photonic bands, which can be tuned by the liquid crystal volume fraction and the cholesteric pitch. The variation of both parameters provides the control over direct and indirect bang gaps [1].

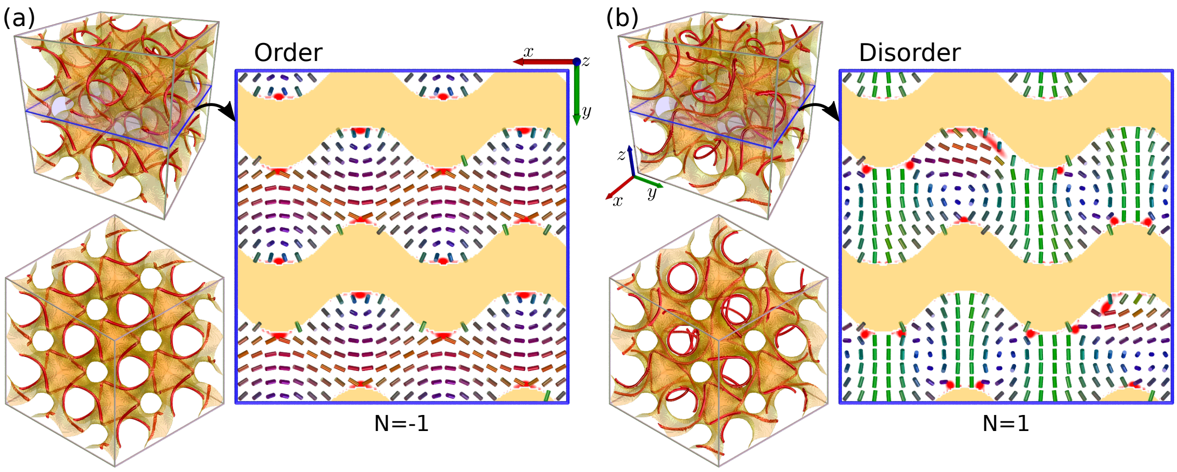


Figure 1: Examples of ordered and disordered cholesteric gyroid structure at same volume fraction and cholesteric pitch of different handedness (given by pitch number $N$). Selected cross sections show the corresponding director fields and defects of different local cross sections.

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# Refraction on a flat interface of an optically anisotropic metamaterial

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New possibilities for the fabrication of macroscopically large samples of an optical metamaterial are explored continuously [1]. One of the potential ways for the creation of novel metamaterials is combining metamaterial-like building blocks with liquid crystals [2]. In liquid crystal metamaterials, the orientational order inherently breaks the material symmetry and optical anisotropy is introduced. The inclusion of metal nanoparticles into a liquid crystal matrix can result in negative permittivity of such a material, which can lead to innovative optical effects [3]. Another advantage of liquid-crystal-metamaterials is also that they are easily tunable with electric field [1].

Whether the refraction will be positive or negative and whether the light will be (totally) absorbed depends on the sign of the material parameters: permeability $\mu$ and eigenvalues of the permittivity tensor $\varepsilon_\perp$ and $\varepsilon_\parallel$ [2]. If the permittivity eigenvalues have a different sign, the extraordinary ray will be totally absorbed for at least some angles of optical axis and the extraordinary angle of refraction will be smaller with respect to the case of equally signed $\mu$, $\varepsilon_\perp$ and $\varepsilon_\parallel$.

To model materials with different signs of permeability and ordinary and extraordinary value of permittivity we have utilised a numerical simulation of Maxwell's equations, following the finite-difference time-domain (FDTD) algorithm [4]. In order to simulate negative-index materials with frequency-dispersive permittivity function, we have used an auxiliary differential equation method (ADE) [5].

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# Investigation of Orientational Phase and Kerr Phase in Polymer-Dispersed Liquid Crystals

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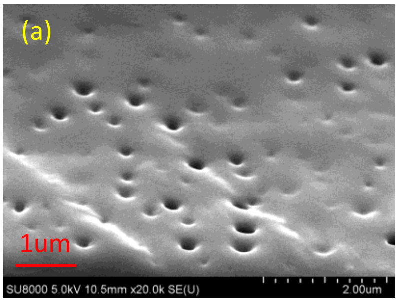
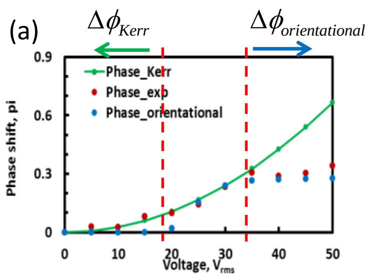
Polarization independent and pure optical phase exist in polymer-dispersed liquid crystal (PDLC) when liquid crystal(LC) directors inside LC droplets reorient to high tilt angles with random orientations at high voltage. Such a phase is orientational phase. Besides orientational phase, Kerr phase resulting from Kerr effect has reported in nano-PDLC with the droplet size smaller than the wavelength. However, Kerr phase is much smaller than orientational phase. Whether Kerr phase is always smaller than orientational phase in nano-PDLC motivates our study. In this paper, we investigated the optical phases modulated from Kerr effect and liquid crystal orientation in nano-PDLC. The study compared the phase shift and response time of nano-PDLC with different droplet size ranging from 176nm to 483nm. According to the experiments, the optical phases of nano-PDLC with droplet size below 200nm have both orientational and Kerr phase. For droplet size larger than that, the orientational phase domaniated. We concluded that in nano-PDLC, the presence of Kerr phase depends on the droplet size. We also concluded that Kerr phase dominates the phase manipulation under threshold votage while the LC orientation dominates it with voltage higher than threshold voltage.

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## Liquid microlenses and waveguides from bulk nematic birefringent profiles

Miha Čančula[1], Miha Ravnik[1,2], Slobodan Žumer[1,2], and Igor Muševič[2,1]

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We demonstrate polarization-selective microlensing and waveguiding of laser beams by birefringent profiles in bulk nematic fluids using numerical modelling. Specifically, we show that radial escaped nematic director profiles with negatice birefringence focus and guide light with radial polarization, whereas the opposite – azimuthal – polarization passes through unaffected. A converging lens is realized in a nematic with negative birefringence, and a diverging lens in a positive birefringence material. Tuning of such single-liquid lenses by an external low-frequency electric field and by adjusting the profile and intensity of the beam itself is demonstrated, combining external control with intrinsic self-adaptive focusing. Escaped radial profiles of birefringence are shown to act as single-liquid waveguides with a single distinct eigenmode and low attenuation. Finally, this work is an approach towards creating liquid photonic elements for all-soft matter photonics.

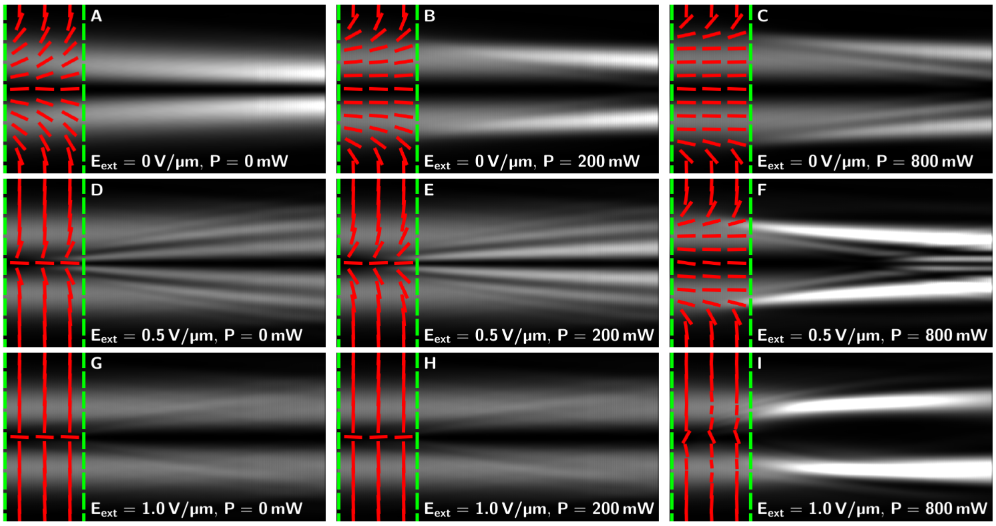


Figure 1: Lensing of high-intensity beams on an escaped disclination line in the presence of an external electric field. Competition between elastic forces, optical fields of the beam with power $P$ and an external electric field $E_{\text{ext}}$ produces a rich variety of lensing patterns. Interesting director structures form as both tuning parameters have a strong effect on the director profile and lensing.

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# Topological defect formation in systems of non-trivial geometry

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## Abstract

The formation and the structure of topological defects are of great interest in various soft matter systems. Liquid crystals exhibit universal topological behavior known from cosmology to superconductivity on a scale which is observable with optical microscopy. We study the production of topological defects along the surface of particles of various non-trivial shapes, such as Koch fractal snowflakes, tories, egg carton shapes and others, dispersed in nematic and chiral nematic liquid crystal, shown in figure 1. We use a two photon polymerization technique to create the particles, which we then disperse in various liquid crystal systems.

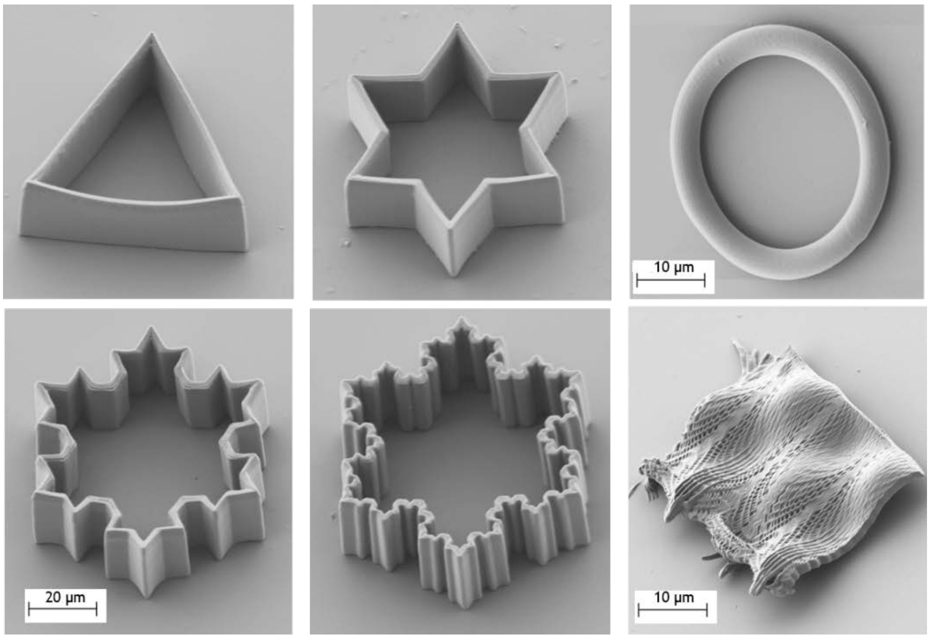


Figure 1. SEM pictures of polymer particles of non-trivial shape produces via the two photon process.

The colloidal particles are treated such that the orientation of the director field along the surfaces is homeotropic or degenerate planar. We study the formation of topological defects right after sudden temperature driven symmetry breaking phase transition induced by local heating via laser tweezers. We use polarization microscopy techniques to study the formation of stable director field configuration along the inner and outher colloidal particle surfaces. We also study the self-assembly of individual colloidal cavities of various non-trivial shape, which can be used as micro resonators for lasing.

# Self-organization of bent-core molecules with conformational degrees of freedom on a surface

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We study self-organization of model bent-core particles with conformational degrees of freedom, whose positions and orientations are limited to a planar surface or, equivalently, they are subjected to strong planar anchoring. Our model particles are trimer-like hard needles that dynamically adopt two conformational states: a chiral (*trans-*) and an achiral (*cis-*) conformations. Our model is a generalization of studies, in which both states were considered separately [1]. Using Onsager-type Density Functional Theory (similar to [2]) and constant pressure Monte Carlo simulations we show that the system composed of such molecules can exhibit a rich spectrum of stable nematic and lamellar phases. The most interesting observation is an identification of modulated phases such as nematic splay-bend. We also study the average fraction of *trans* and *cis* conformers in various phases. Our results show that while in the isotropic phase all fractions are equally populated, the smectic phases are dominated by chiral particles and the splay-bend phase is dominated by achiral ones.

Acknowledgments

This work was supported by Grant No. DEC-2013/11/B/ST3/04247 of the National Science Centre in Poland.

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# Structure formation in two-dimensional system composed of hard bent-core molecules

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We study the role of excluded-volume interactions for the stabilization of liquid crystalline structures in a system of hard bent-shaped molecules confined to the surface [1]. We investigate how the apex angle, the type of the arm edges and their thickness affect the stability of different nematic and smectic structures. Using the second virial Onsager Density Functional Theory and constant-pressure Monte Carlo we show that for molecular shapes taken into account the observed phases are dominated by the antiferroelectric smectic ($S_{AF}$). However, details of the particles can substantially influence the type of the ordering. For thicker molecules two different smectic phases are possible: smectic A phase ($S_A$) and ferroelectric smectic ($S_F$). The most interesting is the identification of the nematic splay-bend phase ($N_{SB}$), on which we focus in the presentation. $N_{SB}$ turns out to be stable for molecules with large opening angles and thin arms. This structure, predicted by the Onsager's theory, is also supported by Monte Carlo simulations.

Acknowledgments

This work was supported by Grant No. DEC-2013/11/B/ST3/04247 of the National Science Centre in Poland.

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# Controlled generation of topological defects in nematic microfluidic environment

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Control of structures in nematic liquid crystals is of interest in topology, physics of phase transitions, sensing, and assembly of colloids. The soft response of nematic material to electromagnetic fields and confinement, coupled with the nematic effective elasticity provides a means for tuning the stability of various structures [1, 2]. In active nematics and nematic microfluidics nematic defect structures are also strongly coupled to the material flow. In active nematics, this coupling results in complex field structures in both flow field and orientational profile [3, 4]. In nematic microfluidics, the control and understanding of nematic flow and ordering enables versatile applications in optics, sensing, material synthesis, and transport [5].

Here, we investigate cross-talk between structures in flow field and structures in orientational field in junctions of nematic microfluidic microchannels. We use hybrid lattice Boltzmann simulations to model nematic in proximity of junctions of multiple microchannels. Depending on the flow direction in the channels, such microfluidic junctions can induce nematic defects with different topological charges. Specifically, the occurrence of such defects is conditioned by the coupling to the velocity field. We test different geometries of the junctions and the role of the flow speed. We also analyze the dynamics of topological point defects upon application of pressure pulses in one of the junctions. Finally, this work is a contribution towards topological microfluidics of complex fluids.

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# Thin film anisotropic light emitters based on aligned nanorods in polymerizable liquid crystal

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Semiconductor nanorods have anisotropic light absorption and light emission properties. Aligned Semiconductor nanorods may have many applications such as polarized light emitters, polarized fluorescence and polarization-selective detectors. In this work, we propose a method for the deposition of semiconductor nanorods on a substrate in which an electric field [1] aligns the nanorods in a preferred direction, controls the spatial distribution of the NRs and is able to de-cluster aggregated NRs. This method is based on mixing the nanorods (NRs) with reactive liquid crystal (LC), aligning the nanorods and the liquid crystal director by an electric field and finally polymerizing the film. This method can be made compatible with large-scale processing on flexible transparent substrates. NR alignment with a polarization ratio of 0.60 of the emitted light is obtained with this method which is equivalent to a polarization contrast 4:1 (figure1). Thin fluorescent layers emitting polarized light can be used in LCD backlights to increase the efficiency. The required electric field strength to align the semiconductor nanorods is determined experimentally by examining the alignment of colloidal CdSe/CdS nanorods in non-reactive liquid crystal. Reduction of clustering of the NRs in liquid crystal is obtained by applying a high electric field. The relaxation time of the nanorods in liquid crystal is estimated experimentally.

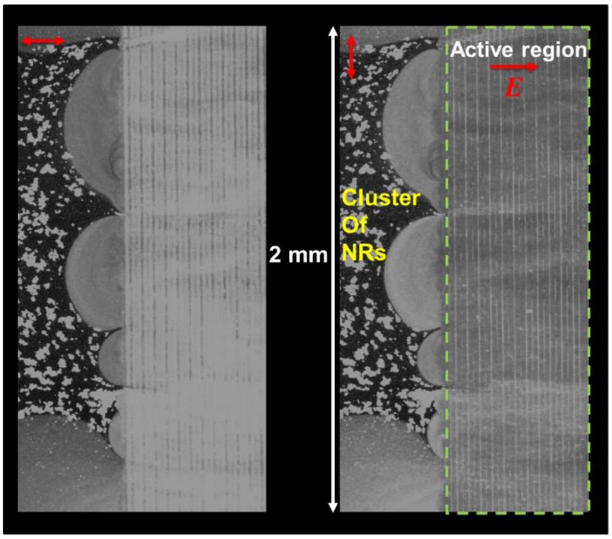


**Fig1.** Fluorescence microscopy images of a deposited layer of NRs in a polymer LC on ITO electrodes with the polarizer oriented parallel (left) and perpendicular (right) to the applied electric field.

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# LIQUID CRYSTAL MICRORESONATOR AS AN OPTICAL SWITCH

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Liquid crystal (LC) dispersions in a medium of lower refractive index can be used as various photonic microdevices. Smectic LC microfibers can act as optical waveguides supporting whispering gallery modes (WGMs) [1] and LC droplets can be used as tunable microlasers, sensitive to surfactant concentrations in the medium and to external fields [2, 3]. Radial LC droplets can also act as optical vortex generators [4].

Apart from photonic microdevices made of soft materials, in soft matter photonics we also need all-optical control of light. It can be achieved indirectly, by the use of optical Kerr effect that is induced with high intensity femtosecond laser pulses [5], or directly with the use of the Stimulated Emission Depletion (STED) mechanism [6]. Here fluorescently labeled LC sample is excited by a laser pulse of a certain wavelength. By illuminating the sample with a second pulse of a higher wavelength, the excited states get depleted which disables fluorescence.

By combining the principles of STED and WGM microresonators we propose to use LC droplets as another optical element for photonic microcircuits: an optical switch. We present preliminary results in experiments with STED beam illuminating the LC droplets after WGMs have been excited inside. We show that WGM lasing can be decreased up to 90 % by application of the STED beam which confirms ability of LC droplets to act as optical switches.

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# Optical localized states in the liquid crystal structure bordering on the metal

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In recent years, various types of surface electromagnetic waves in a photonic crystal structures are investigated. Optical Tamm states (OTS) are one of these types. OTS can be excited at the interface of the photonic crystal and a medium with negative permittivity. The OTS can be experimentally observed as a narrow peak in the transmission spectrum. In articles [1,2] we demonstrated existence optical localized state analogies to OTS in structure comprising a cholesteric liquid crystal (CLC). Changing of the wave polarization's reflected from the metal and polarization properties of the CLC are forced to use a quarter-wave phase plate, embedded between the CLC and the metal layer. Thus, the imposed conditions relating the parameters of the phase changing element and CLC are fairly strict. Therefore it is necessary to find another possibility of implementing states localized at the boundary of the CLC-metal layer without using of the quarter-wave layer. We propose to use one more cholesteric layer with the opposite helix twist. So the resulting system would involve the left-handed cholesteric, right-handed cholesteric and metal film. There are several peaks corresponding to the waveguide surface modes in transmission spectrum of the structure (Fig. 1). Each peak corresponds to a localized state. The light is localized near the metal film with the maximum electric field value at the CLC-metal interface.

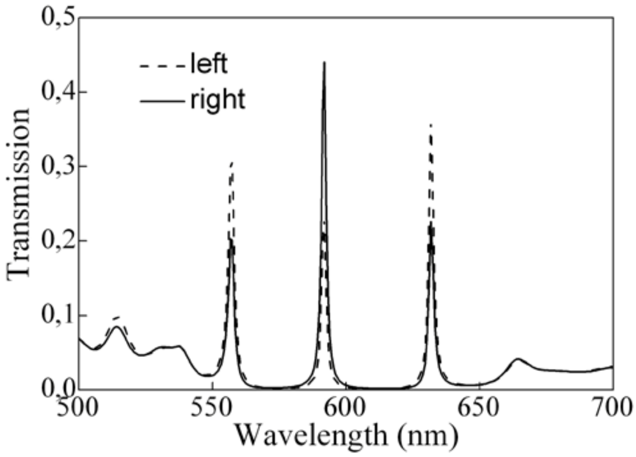


Fig. 1. The transmission spectrum of the structure under consideration for the circular polarization of the incident light

The light of any polarization is localized with the field intensity maximum at the CLC-metal interface. However, different polarizations of the waves passed through the CLC lead to different transmittances.

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PO12

# CONTROLLING THE OPTICAL PROPERTIES OF GOLD NANORODS BY USING LIQUID CRYSTAL MATERIAL

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Gold nanoparticles have attracted considerable attention due to their unique optical properties based on localized surface plasmon resonance (LSPR). In the last few years, the attention has been paid to the gold nanorods (GNRs) due to their unique shape dependent properties such as multiple plasmon bands that can be separately activated by incident light polarization, together with particularly large "hot spots" under plasmonic excitation [1]. However, for the maximum efficiency of device based on the excitation of the GNRs LSPR, GNRs need to be well aligned. Moreover, if the organization of the nanorods can be controlled as well, hot spots monitored by light polarization and wavelength are expected [1]. It is now known that distorted liquid crystal areas induce an attraction of the nanoparticles and an accumulation in the most distorted areas [2]. For oriented distorted areas, anisotropic nanoparticles assemblies can be created [3]. In presence of arrays of smectic dislocations [4], single nanoparticle chains or NP ribbons are formed, leading to anisotropic LSPR [5-7]. Single semi-conducting nanorods can be oriented as well [8].
In this presentation we will show that the presence of dense arrays of dislocations can also lead to a control of GNR LSPR and to a control of the GNR luminescence. We study it in relation with the GNR size and concentration. We show that these two parameters become crucial in order to obtain either end-to-end organization of the GNRs, or side-to-side one, in an oriented way. As a result, drastically different LSPR properties are obtained when these two parameters are varied, however always remaining strongly anisotropic and thus activated by light polarization.

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# EFFECT OF IONS ON PROPERTIES OF LIQUID CRYSTALS DOPED WITH NANOPARTICLES

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The advantages of using nematic in comparison with other types of liquid crystals are the relative simplicity of orientation and stability of the properties. The presence of ionic impurities may adversely affect the image quality of LC displays. However, the effects due to the presence of mobile ions can be used in other devices based on liquid crystals such as wavefront correctors [1] and low-frequency oscillations [2]. Adsorbed on substrates ions change anchoring of LC molecules with the substrates and result in the reorientation of molecules. The method of the liquid crystal molecules reorientation with using ionic surfactants is known [3]. Ions can absorb on substrates and generate the internal electric field which promotes formation of a meta-stable level [4].

The density and mobility of ions in NLC composites of cyanobiphenyl with core-shell type hydrophobic semiconductor quantum dots (QDs) CdSe / ZnS, as well as $TiO_2$ and $ZrO_2$ nanoparticles (NPs) with a core of 5 nm were investigated in this work. It was shown that mobile ions density linearly increases with growing NPs concentration. Mechanisms of ionic impurities occurrence are analyzed. Increase of the mobile ions density may be associated with desorption of the ionic contaminants from the surface of the NPs, destruction of the NPs shell and electron emission from QDs. Influence of the ions on rotational viscosity and dielectic properties of the NLC composites was studied [5,6].

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# Tunable liquid crystal photonic crystals

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Chiral liquid crystals form stable or metastable photonic crystal lattices when combined with solid dielectric templates or colloidal structures. Using the planewave expansion method, optical photonic bands of these photonic crystals are calculated and compared to isotropic photonic crystals with the same symmetry. We also determine possible parameters to tune optical properties of these liquid crystal photonic crystals.

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# Manipulation of Microbeads in Liquid Crystals with UV-Light

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Recently, the motions of microbeads in liquid crystals by the irradiation of light have been studied abundantly. Several research groups have reported the transportation of microbeads caused by heat, electro-osmosis, electric convection, defect or light pressure [1]. These behaviors are interesting, however, they needs external power supply or custom design of the system, for instance, a thermal controller, electrodes or laser. In the present study, we have found a new system where microbeads could be manipulated by LED light without complicated architectures [2].

The sample was prepared as follows. The mixture of 4-Cyano-4'-pentylbiphenyl (5CB) and $SiO_2$ microbeads ($\phi$10 $\mu$m) was inserted into a cell with the thickness of 50 $\mu$m. The surfaces of the cell were coated with rubbed polyimide layers for aligning liquid crystal molecules. We observed the motion of microbeads by a digital microscope during the irradiation of UV-light with the wavelength of 365 nm (150 mW/cm$^2$). We made the experiments under both 25 °C and 40 °C.

The spatio-temporal plot of the motion of the microbead with the light irradiation for 5 s at 25 °C is shown in Fig. 1. In this plot, the light was irradiated from the left-hand side, and microbead ran away quickly from the irradiation of light and returned back gradually toward the original position by the extinction of the light. We assumed that this motion was induced by the volume expansion of liquid crystals. 5CB shows a drastic increase in the thermal expansion coefficient just below the nematic-isotropic temperature [3], and thus its volume expands drastically with a slight increase in temperature just below the transition temperature. We observed that the temperature of cell surfaces increased by 1 °C during the irradiation of UV-light. We also confirmed that this increase in the temperature was caused by the photo-thermal conversion of polyimide layers. In the presentation, the motion of microbeads in different kinds of liquid crystals will be also discussed.

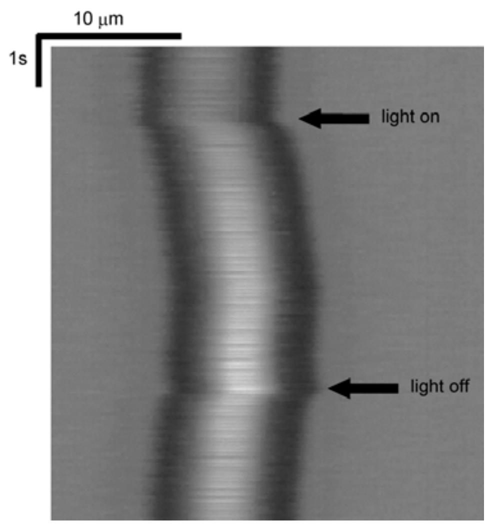


Figure 1 Spatio-temporal plot of the motion of the microbead [2].

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# Laser tweezers manipulation of a nematic mesophase in microfluidic environment

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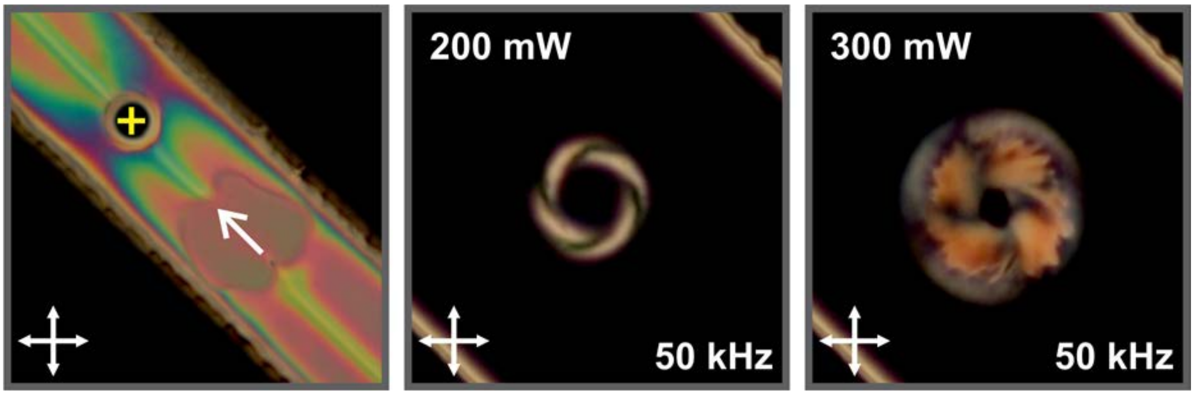
Manipulating liquid crystal orientational field at the microscale is an experimentally challenging task that stimulates one to look for complementary approaches. We apply the advantages of microfluidic confinement and laser tweezers manipulation to explore the structure and dynamics of a nematic mesophase in rectangular microchannels with homeotropic surface anchoring. We will demonstrate how the nematic reacts to thermally induced gradients in the molecular orientation field and present thermo-optical reorientation effects in a static case and in the pressure-driven microflows.

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# A FINITE DIFFERENCE IN THE FREQUENCY DOMAIN METHOD TO MODEL HIGH RESOLUTION LIQUID CRYSTAL DEVICES

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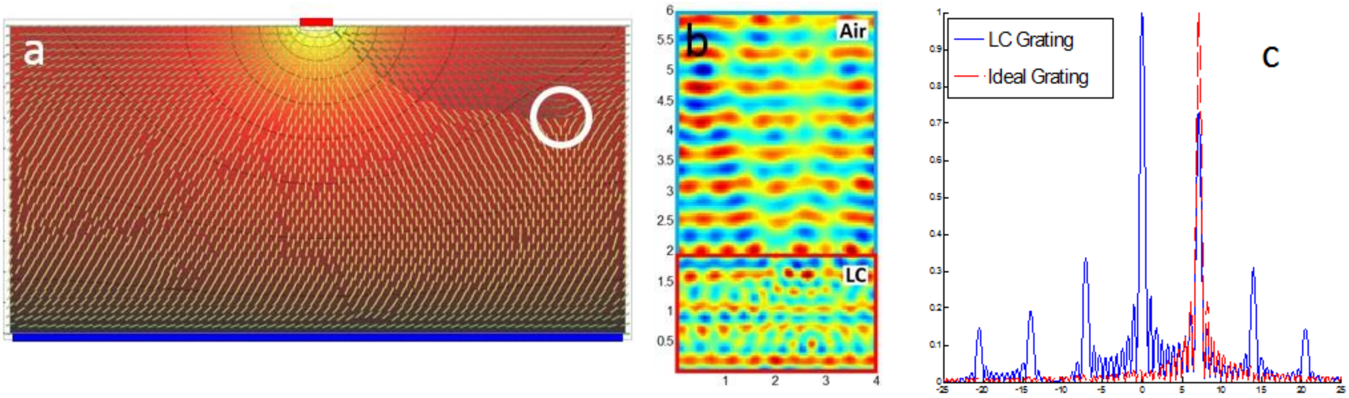
High resolution liquid crystal (LC) devices, where diffraction effects cannot be ignored or form a major part in the device operation, present significant challenges to the modelling of light propagation, which cannot be met by the standard methods in use for conventional display applications.

We are currently developing a procedure to model accurately EM propagation through LC devices and to find their far-field diffraction. The procedure starts with an accurate LC modelling [1,2] that provides the point-by-point permittivity tensor distribution. This is then mapped to a finite differences Yee grid where an FDFD method is constructed to solve the problem globally, (not as a stepping procedure) starting from the discretisation of Maxwell's equations and using the total-field/scattered-field approach [3,4]. The procedure involves only matrix-vector operations and is well suited to efficient parallel processing implementations.




(a) Director distribution showing the presence of a defect. (b) Field distribution. (c) Far-field diffraction pattern.

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[2] E. Willman, F.A. Fernandez, R. James and S.E. Day, "Modeling of Weak Anisotropic Anchoring of Nematic Liquid Crystals in the Landau-de Gennes Theory", *IEEE Trans Electron Devices*, **vol. 54**, № 10, pp. 2630-2637, Oct. 2007.

[3] K. Umashankar and A. Taflove, "A novel method to analyse electromagnetic scattering of complex objects," *IEEE Trans. Electromagn. Compat.*, **vol 24**, № 4, pp. 397-405, Nov. 1982.

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PO18

# Experimental studies on the colloidal self-assembly across the N-SmA phase transition

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Dispersion of foreign particles with pre-defined surface anchoring in an aligned nematic liquid crystal (NLC), creates an elastic distortion of the director (average orientation of molecules) around each particle and it leads to the formation of topological defects. When the micro-particles are treated to promote perpendicular alignment of molecules and dispersed in a homogeneously aligned LC, it create elastic dipole and elastic quadrupols. If the particles are treated to promote planar alignment and dispersed in homogeneously aligned LC, it creates boojum defect. We report the transformation of these defects across Nematic (N) to Smectic-A (SmA) phase transition and observed that defects are strongly influenced by the elasticity and onset of smectic layering. The nematic hyperbolic hedgehog defect that accompanies a spherical colloidal inclusion is transformed into a focal conic line in the SmA phase. Saturn ring defect changes rapidly with temperature and shrink to narrow stripes emanating from a barely visible ring-like defect on the surface of the microparticle. Boojum defects also transformed into focal conic lines across the phase transition. This defect transformation leaded by phase transition has a strong influence on the pairwise colloidal interaction and is responsible for a structural transition of two-dimensional colloidal crystals. The results on the pre-transitional behaviour of the defects are supported by the Landau-de Gennes Q-tensor modelling. The tuning of lattice parameters by temperature could be useful for controlling photonic band gap.

# Tunable guided-mode resonant filter with liquid crystal cladding

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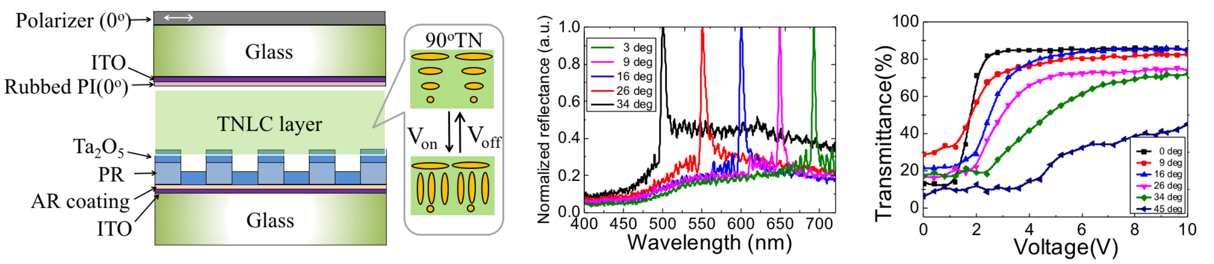
Guided-mode resonance (GMR) filters have been extensively used in various optical devices, such as optical filters, color filters, and biochemical sensors [1, 2]. Unlike traditional multilayer thin-film optical filters that consist of many layers with precise control in thicknesses and refractive indices, a GMR filter, which comprises a grating as a phase-matching element and a waveguide structure in which light propagates through the waveguide medium, exhibits excellent wavelength-selecting ability. Therefore, this work demonstrates a GMR using a mirror-tunable interference lithographical system and a E-Gun evaporation. The resonance wavelengths of the such a GMR filter depend strongly on angle of incidence, and thus the resonance wavelength can be easily chosen by changing the angle of incidence. The proposed GMR filter with the one-dimensional SWG structure also depends on polarization of incidence. Thus, we further proposes a tunable guided-mode resonant (GMR) filter that incorporates a $90^{o}$ twisted nematic liquid crystal (TNLC), as shown in Figure 1(a). The GMR grating acts as an optical resonator that reflects strongly at the resonance wavelength and as an alignment layer for LC. The $90^{o}$ TNLC functions as an achromic polarization rotator that alters the polarization of incident light. The resonance wavelength and reflectance of such a filter can be controlled by setting the angle of incidence and driving the $90^{o}$ TNLC, respectively. Figure 1 (b) presents the reflection spectra of the negative first-diffraction mode under many oblique angles of incidence. At the normal incidence, the resonance wavelength of the proposed device is at 710nm, which is at near-infrared region. As the incident angle was increased, the resonance wavelength shifted toward short wavelengths. The resonance wavelengths of the negative first-diffraction mode at oblique angles of 3, 9, 16, 26, and 34 $^{o}$ are 690, 650, 600, 550, and 500 nm, respectively. The corresponding FWHMs of the reflected peak are 5, 6, 7, 9, and 10 nm. Figure 1(c) displays the voltage-transmittance (V-T) curves of the proposed filter at various angles of incidence. Without an applied voltage, the corresponding resonance wavelengths were 710, 650, 550, 450 nm. The transmittance increased with the increasing aplied voltages because less TM-polarized light was generated after the incident light that passed through the top linear polarizer was converted to TE-polarized light by $90^{o}$ TNLCs. As the angle of incidence gradually increased, the required voltage increased owing to the electro-optic properties of the $90^{o}$ TNLCs. When the angle of incidence reached $45^{o}$, the strong Fresnel reflection from the glass substrate reduced the tuning range of transmittance of the filter between 10 and 45 %.




(a) (b) (c)

[1] Y.-T. Yoon, H.-S. Lee, S.-S. Lee, S. H. Kim, J.-D. Park, and K.-D. Lee, "Color filter incorporating a subwavelength patterned grating in poly silicon," Opt. Express **16**, 2374-2380 (2008).

[2] D. Rosenblatt, A. Sharon, and A. A. Friesem, "Resonant grating waveguide structures,'' IEEE J. Quantum Electron. **33**, 2038-2059 (1997).

# Dislocations in blue phases

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Disclinations in blue phase I and blue phase II exhibit a regular cubic lattice structure analogous to atomic arrangement in crystals. As a result, dislocations, which are conventionally found in crystalline solids, are also expected to exist in blue phase disclination networks. In this work, we employ finite difference relaxation method to simulate both edge and screw dislocations in blue phases. By calculating and visualizing the order parameter field in the regions of dislocations, several possible structures are predicted. Dislocations with lowest strengths (smallest Burgers vectors) are found to be energetically favorable, same is the case with dislocations in crystalline solids.

# A compensation of optical path variation induced by vibration via a movable lens on liquid crystal and polymer composite film

Yu-Jen Wang, Yu-Shih Tsou, Ming-Syuan Chen, and Yi-Hsin Lin

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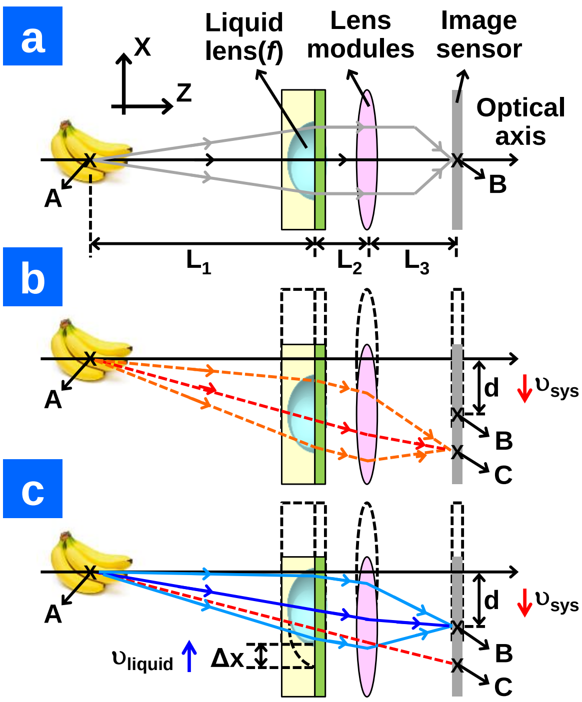
We propose and demonstrate a compensation of optical path variation induced by vibration using a movable liquid lens on liquid crystal and polymer composite film(LCPCF). The change of position of the liquid lens compensates the deviation of light as the image system is under a handshake vibration. The mechanism of the liquid lens is based on droplet movement on LCPCF whose position changes because electrically tunable orientations of liquid crystal molecules on the surface of LCPCF. As a result, the image system under handshake vibrations could keep a clear image. Such a system is so-called optical image stabilization (OIS). The operating principles are introduced and the experiments are performed and discussed. The concept in this paper can also be extended to design other optical components for modulating direction of light.




[1] Yu-Jen Wang, Yu-Shih Tsou, Ming-Syuan Chen, and Yi-Hsin Lin, “An optical image stabilisation using a droplet manipulation on a liquid crystal and polymer composite film,” Liquid Crystals, page 1-7 (2016), http://dx.doi.org/10.1080/02678292.2016.1215561 [Invited paper]

# METAMATERIALS, LIQUID CRYSTALS AND PASTA

Saša Ziherl[1] and Mojca Čepič[1,2]

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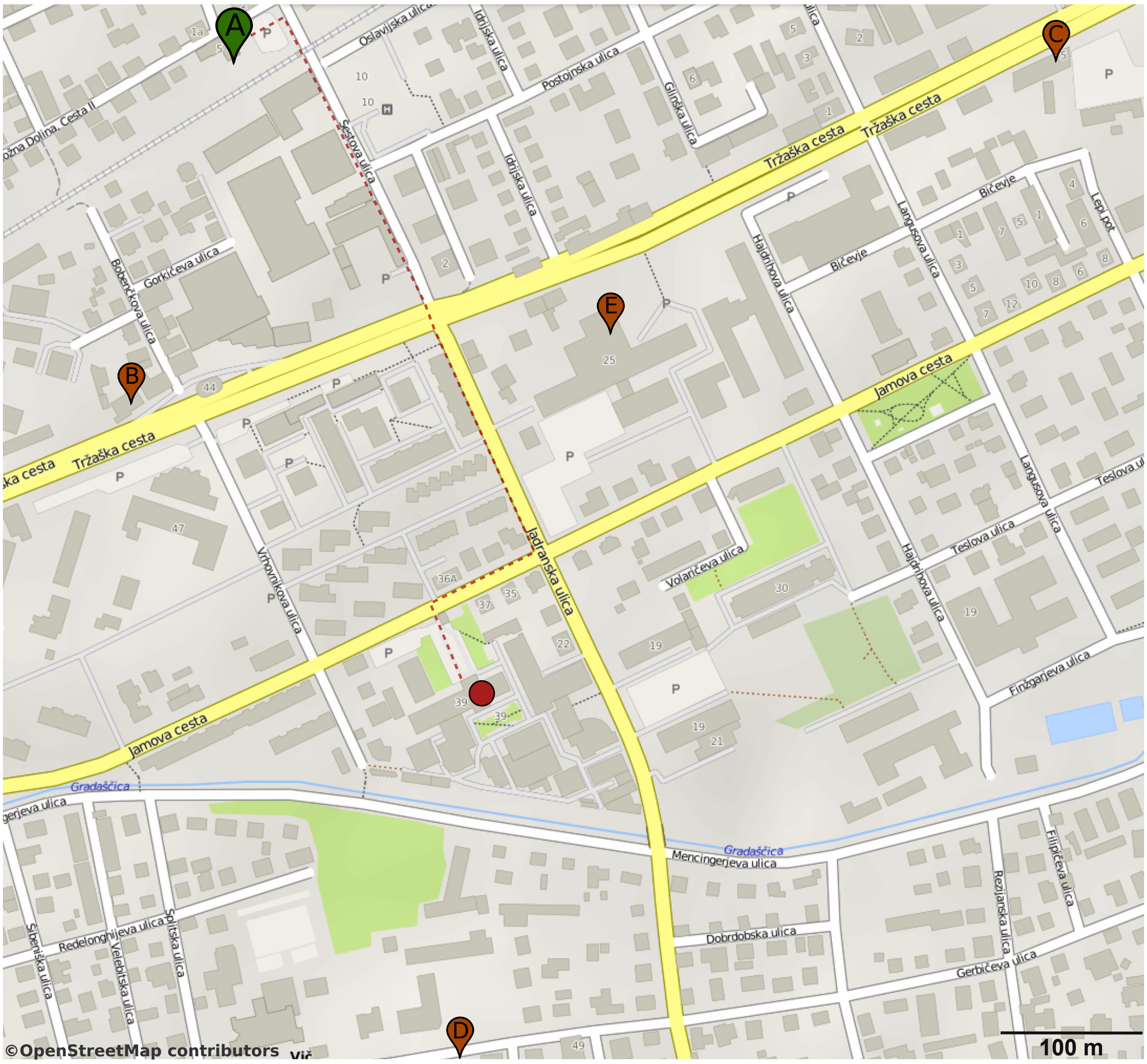
Analogies and models play an important role during teaching/learning/researching in complex fields of science. Liquid crystals are surely complex and therefore difficult to comprehend, so models and analogies can be very helpful for students as well as for researchers. One analogy with liquid crystals has already been presented. Wood and microwaves present an ideal system for showing basic optical properties of nematic, cholesteric and isotropic phase of liquid crystals. We have developed a series of experiments with wooden models and microwaves for the purpose of demonstration and investigation of optical properties of these phases. With its visible anisotropic structure, wood illustrates the complex and for the naked eye invisible structure of liquid crystals.

A new analogy is presented in this contribution. Interesting models can be made of pasta, which offer tremendous opportunities in the composition of various structures, due to their forms. Like wooden plates, pasta is basically transparent for microwave electromagnetic radiation and the transmitted waves are modified by the interaction with the pasta microstructure. A block of spaghetti can therefore be used instead of wooden models, as it also has an anisotropic structure. Another interesting (from the “liquid crystalline point of view”) form of pasta is a drill bit (pasta in the form of a drill, also called fusilli). Drill bits are chiral and combining them into crystalline structure allows for the analysis of the combination of phenomena in highly chiral liquid crystals – from isotropic to helical phase. Therefore, with the proper set up of fusilli also the structures of various chiral phases, like blue phases for example, can be shown.  In addition, alligned drill bits can be also addressed as a metamaterial as they have, depending on the geometry, interesting and unusual influence on the microwaves. By using a school microwave transmitter and receiver, the optical properties of these models can be demonstrated and studied.

# Nearby restaurants




Venue – Jožef Stefan Institute

Suggested place for lunch – Rožna hiša

Other possible options:

- Za pumpo
- Mirje (Italian food)
- Hombre (Mexican food)
- FE/FRI canteen

Online map:

## Program of 6th Workshop on Liquid Crystals for Photonics

*Plenary talks (P, 45mins), Invited talks (I, 30mins), Contributed talks (O, 15mins), Posters (PO)*

**Wednesday, 14th Sep – Day 1**

| | | |
|---|---|---|
| 8.00 - 9.00 | | *registration* |
| 9.00 - 9.15 | | *welcome & opening* |
| 9.15 - 9.45 | I1 - Lavrentovich | Electro-optics of chiral nematics formed by molecular dimers |
| 9.45 - 10.15 | I2 - Brasselet | Optical vortex coronagraphy from liquid crystal topological defects |
| 10.15 - 10.45 | I3 - Neyts (presented by J. Beeckman) | Lasing from dye doped liquid crystal devices |
| 10.45 - 11.15 | | *Coffee break* |
| 11.15 - 12.00 | P1 - Baets | Silicon photonics and its applications in communications and in sensing |
| 12.00 - 12.30 | I4 - Residori | Optical sensing and phase modulation detection with photo-addressed LC media |
| 12.30 - 13.00 | | *Coffee break* |
| 13.00 - 13.45 | P2 & JSI colloq. - Yun | Biophotonics |
| 13.45 - 15.30 | | *Lunch* |
| 15.30 - 16.00 | I5 - Ozaki | Flat optics with spatial phase modulation based on patterned cholesteric helix |
| 16.00 - 16.30 | I6 - Wolinski | Nanoparticles-based liquid crystals for infiltrating photonic crystal fibers |
| 16.30 - 16.45 | O1 - Schmidtke | Using absorption bands for photonic band gap engineering in cholesteric liquid crystals |
| 16.45 - 17.15 | | *Coffee break* |
| 17.15 - 17.45 | I7 - Chien | Electro-optical memory of a nano-engineered amorphous blue phase III scaffold |
| 17.45 - 18.00 | O2 - Humar | Live and biocompatible lasers |

**Thursday, 15th Sep – Day 2**

| | | |
|---|---|---|
| 9.00 - 9.30 | I8 - Broer | Morphing dynamics in light-triggered liquid crystal network coatings |
| 9.30 - 10.00 | I9 - Lin | Augmented reality with image registration, vision correction and sunlight readability via liquid crystal devices |
| 10.00 - 10.30 | I10 - Wilkinson | Liquid crystal nanophotonic holography |
| 10.30 - 11.00 | | *Coffee break* |
| 11.00 - 11.30 | I11 - Zannoni | Bottom up simulations of liquid crystal surface alignment and anisotropic wetting |
| 11.30 - 12.00 | I12 - Yamamoto | Slippery interfaces - Lubrication of director and helix rotation motions |
| 12.00 - 12.15 | O3 - Eremin | Photomanipulation of the anchoring energy and its effect on the behaviour of LC colloids |
| 12.15 - 12.30 | O4 - Drevensek Olenik | Out-of plane surface relief gratings for micropatterned liquid crystal alignment |
| 12.30 - 14.00 | | *Lunch* |
| 14.00 - 14.30 | I13 - Assanto | Bifurcation and optical bistability with Nematicons |
| 14.30 - 15.00 | I14 - Morris | Combining liquid crystals and polymers to form novel structures and photonic devices |
| 15.00 - 15.15 | O5 - Hands | Spinning liquid crystal tuneable laser prototype system for biomedical microscopy applications |
| 15.15 - 15.30 | O6 - Mertelj | Frustrated structures in ferromagnetic cholesteric liquid crystals |
| 15.30 - 16.00 | | *Coffee break* |
| 16.00 - 17.30 | PO1 – PO21 | Poster session |
| | | |
| 18.45 | | *Meet at Preseren square* |
| 19.30 | | *Dinner at Ljubljana Castle (Gostilna Na Gradu)* |

**Friday, 16th Sep – Day 3**

| | | |
|---|---|---|
| 9.00 - 9.30 | I15 - D'Alessandro | LC:PDMS optical waveguides: a new proposal for flexible photonics |
| 9.30 - 10.00 | I16 – Smalyukh (presented by S. Park) | Colloidal dispersions of nanoparticles in liquid crystals for photonics applications |
| 10.00 - 10.30 | I17 - Moreno | Liquid-crystal spatial light modulator based optical architecture for the full polarization modulation – application to encode optical polarization devices |
| 10.30 - 11.00 | | *Coffee break* |
| 11.00 - 11.30 | I18 - Fukuda | Calculation of confocal microscope images of cholesteric blue phases |
| 11.30 - 12.00 | I19 - Campos | Use of liquid crystal cells to control polarization state and degree of polarization |
| 12.00 - 12.30 | I20 - Wilkes | The development of Liquid Crystal Display technology through Partnerships |
| 12.30 - 12.45 | O7 - Rafayelyan | Shaping the light by Bragg-Berry mirrors |
| 12.45 - 13.00 | O8 - Nys | Liquid crystal photo-alignment with periodic planar/homeotropic anchoring variation |
| 13.00 - 14.30 | | *Lunch* |
| 14.30 - 15.00 | I21 - Beeckman | Bridging the electrode gap with ferroelectric thin films |
| 15.00 - 15.30 | I22 - Rutkowska | Liquid crystalline periodic waveguiding structures |
| 15.30 - 15.45 | O9 - Dubtsov | Light-induced structural transitions in nematic microdroplets |
| 15.45 - 16.00 | O10 - Posnjak | Reconstruction of director from experimental FCPM data in chiral nematic droplets |
| 16.00 - 16.05 | | *Closing* |