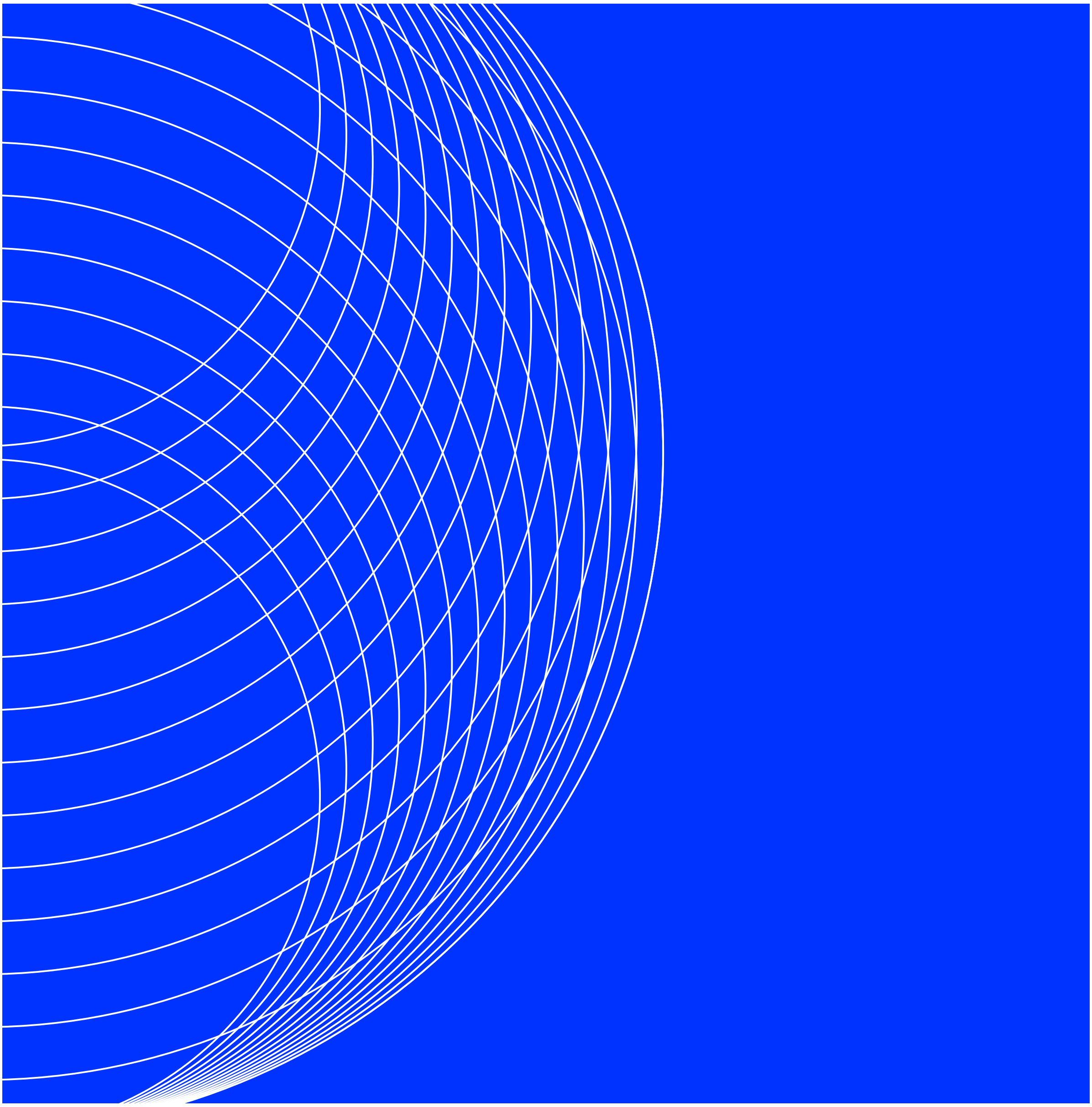
Complex Nanophotonics Science Camp

CUMBERLAND LODGE
Windsor Great Park
Berkshire, SL4 2HP, UK
25th-28th July 2017



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Preface

The aim of the 'camp' is to bring together ~60 early-career scientists in the field of photonics, but also science writers and editors, in an unconventional format, mixing contributed and invited talks, seminars and debates, to present and discuss the latest research and future directions of the field in an open atmosphere, and help developing the community of complex nanophotonics.

Cumberland Lodge

The Camp will be held at Cumberland Lodge, a beautiful 17th Century country house in Windsor Great Park, close to London. The Lodge is now occupied by a education charitable foundation and holds a very diverse range of conferences, lectures and discussions.

-> **CUMBERLAND LODGE, THE GREAT PARK, WINDSOR SL4 2HP**
WWW.CUMBERLANDLODGE.AC.UK
TEL: 01784432316 FAX: 01784497799

Directions

BY PLANE The closest airport is Heathrow, at just 20 minutes by car. Gatwick airport is 40 minutes by car.

BY TRAIN The closest train station is Egham, that is well connected to both London Waterloo and Reading.

BY TAXI The appropriate fares to Cumberland Lodge are about £9 from Egham Station, £25 from Heathrow and £65 from Gatwick.

BY CAR Cumberland Lodge has plenty of free parking. Please note that for Crown Estate legal reasons, GPS SatNav Systems do not work within the Great Park. However, they do work for Bishopsgate Road, Englefield Green, TW20 0XU, which is just outside the Bishopsgate ntrance to the Park, and SL4 2JA is for drivers coming from the Windsor and Ascot direction using the Ranger's Gate entrance.

Historical Foundation

Cumberland Lodge is a former Royal residence in The Great Park at Windsor. In 1947 King George VI granted the Lodge to St Catharine's, a then newly established educational charitable trust. They would be given the opportunity to discuss important social and ethical issues and to reflect on the value of their academic work in relation to society.

The Grounds

There are two main buildings - the Lodge and the Mews. The dining rooms, lounges, chapel, library and administrative offices are housed in the Lodge, while the two conference rooms and four seminar rooms are located on the ground floor of the Mews.

Accomodation

All bedrooms have en-suite bathrooms and are primarily located on the higher floors of both buildings. New visitors are surprised to learn that there are no room keys. However, we are able to secure valuables in one of our insurancerated safes by arrangement. Guests are asked to vacate bedrooms by 9.00 AM on the day of departure. Free Internet access is offered on PCs in the Mews and the basement of the Lodge, and both buildings have free Wi-Fi as well.

Recreational Facilities

Recreational facilities at the Lodge include a small gymnasium, tennis court, croquet, snooker, pool, table tennis and table football. We may also be able to provide a small number of bicycles, subject to availability. A wide variety of board games are available in the bar. There is an electronic organ in the Chapel and a grand piano in both the Drawing Room and Tapestry Hall.

The Nanophotonic Science Camp

*In the past years the number of fields influenced by photonics and nanophotonics have increased steadily.
And the boundaries between what is considered to be nanophotonics and what is not have become more and more fuzzy and difficult to define.*

*Nowadays disciplines like biophotonics, plasmonics, bio-sensing, optical imaging, quantum nanophotonics etc. are deeply interconnected with each other.
And the tendency is to go in the direction of increasing the interdisciplinarity of research.
In this novel landscape a new generation of scientists is now emerging, carrying the necessity to rethink the traditional conference format, which are often showcases of career-long investigators.*

The Complex Nanophotonics Science Camp is meant to break with the conventional schemes to engage the creativity of early-stage scientists and create new scientific connections, fostering critical thinking.

A Camp for Young Minds

The main target of this Science Camp are junior scientists, post-docs and PhD students. In order to give them space to discuss and present their own work and ideas, we decided on a strict <10 from PhD rule for both invited and submitted contributions.

The Poster Session

The poster session is a very important part of the Science Camp.
We think that a poster session is a magnificent occasion to discuss that must be exploited. In addition we will feature a “poster pitch” session. Everyone presenting a poster will be given the possibility to make a 2 minutes pitch, aimed at advertising the work and attract public to the poster.

Clarity and conciseness will have to be staple of the pitches, that will have to be delivered without the aid of computer slides. The time constraint will be strictly enforced.

Support & Prizes

We thank EPSRC for the kind support that makes this Science Camp possible.
In addition we acknowledge *Boston Micromachines Corporation*, *Delmic* and *Zurich Instruments* for sponsoring the camp.
A prize for the best poster will be awarded at the end of the Camp.

Evening Debate

There will be two open debates, on the first evening with John Hammersley and Sybil Wong and on the second evening with Philip Moriarty.

Scientific Committee

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HOW MANY PIXELS DOES YOUR CAMERA HAVE? OURS HAS ONLY ONE!

Cameras are often marketed in terms of the number of pixels they have – the more pixels the "better" the camera. Rather than increasing the number of pixels we ask the question "how can a camera work with only a single pixel?". This talk will link the field of computational ghost imaging to that of single-pixel cameras explaining how components found within a standard data projector, more commonly used for projecting films and the like, can be used to create both still and video cameras using a single photodiode.

Such single pixel approaches are particularly useful for imaging at wavelengths where detector arrays are either very expensive or even unobtainable. The ability to image at unusual wavelengths means that one can make cameras that can see through fog or smoke or even image invisible gases as they leak from pipes.

Beyond imaging at these unusual wavelengths, by adding time resolution to the camera it is possible to see in 3D, perhaps useful for autonomous vehicles and other robotic applications.

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SLM-BASED SYNTHETIC HOLOGRAPHY OR THE IMPORTANCE OF SHAPING YOUR WAVEFRONT

Wavefront shaping with spatial light modulators (SLMs) has become a powerful tool in Biophotonics. In holographic optical tweezers, for instance, optical traps can be steered and controlled in real time. But an SLM can also be integrated into optical imaging systems, using it, for instance, as a programmable Fourier-filter emulating classic microscopy techniques for contrast enhancement. This is done by sending a pre-calculated voltage pattern to the pixels of the SLM placed in a Fourier plane with respect to the sample, which imprints a spatially-varying phase shift to the optical wavefront.

Going from dark-field microscopy, to Zernike phase contrast or to spiral phase contrast, and toggling between these modalities, is as simple as replacing the phase pattern on the SLM. Thus microscopy becomes programmable and customizable with respect to a given sample.

A particular strength of this Synthetic Holography approach with programmable phase masks is the possibility to "pack several things into one hologram", i.e. for multiplex-imaging. One can, for instance, take microscopic images that contain sub-images belonging to different imaging modalities, to different depths inside the sample, or to different parameter settings.

Opportunities as well as limitations of SLM-based wavefront shaping in optical imaging will be discussed.

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OPTICAL BINDING AND LIGHT PROPAGATION IN COMPLEX MEDIA: MULTIPLE SCATTERING AND NEAR-FIELD EFFECTS

Appropriate combinations of laser beams can be used to trap and manipulate small particles with “optical tweezers” as well as to induce significant “optical binding” forces between particles. Here we review some basic concepts related to the optical forces on small particles, focusing on the interplay between scattering asymmetry and momentum transfer.

These forces are, in general, non-conservative (curl forces) which lead to a number of intriguing predictions regarding the dynamics of nanoparticles.

As we will see, the seemingly unrelated problems of propagation of light in complex media and optical forces are tied together by the close relation between transport mean free path and radiation pressure cross section.

We will discuss the role of multiple scattering and near-field effects on the optically induced interaction between particles as well as in the different regimes of light transport at mesoscopic scales.

Invited Talks

Harish Bhaskaran

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PHASE CHANGE MATERIALS IN OPTOELECTRONICS

In this talk, I will discuss how the use of phase change materials in photonics and optoelectronics can enable a host of interesting applications from Solid State Reflective Displays to integrated photonic non volatile memories and potentially, non-von Newmann computing paradigms on a photonic chip.

Although the materials are extremely well known (for example used in rewritable CDs and DVDs), a combination of developments in nanofabrication and photonics, as well as in phase change memories in the electrical domain and a renewed interest in memcomputing have provided an impetus to this field.

Rachel Grange

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BEYOND PLASMONICS: OXIDE AND SEMICONDUCTOR NANOMATERIALS FOR ENHANCING NONLINEAR OPTICAL SIGNALS

Nonlinear optical processes are known to be weak in bulk materials and extremely small at the nanoscale since they mainly scale with the volume. Here I will show several strategies to maximize nonlinear optical signals in nano-oxides with Perovskite crystalline structure and in III-V nanowires.

First, I will demowng the scattering properties of individual barium titanate (BaTiO3) nanoparticles. We use the Mie resonances to achieve an SHG enhancement of four orders of magnitude within the same nanoparticle [1]. Our results suggest that a strong increase of the SHG signal can be obtained without using plasmonic or hybrid nanostructures.

Besides chemically synthesized nanostructures, we developed lithography processes to obtain high aspect ratio lithium niobate (LiNbO3) nanowaveguides. We demonstrate phase-matching and use it to increase the guided SHG power by a factor of more than 40. We also increase non-phase-matched guided second-harmonic by engineering the nanowire length [2,3]. Those bright nanostructures can serve for developing compact efficient nonlinear optical sources or waveguides. Finally I will report on cavity effects in GaAs nanowires and on a powerful multiphoton imaging method to distinguish various crystal structures in individual nanowires [4].

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IMAGING WITH SCATTERED LIGHT: LOOKING THROUGH THE 'FOG'

Scattering of light in complex samples such as biological tissue renders most samples opaque to conventional optical imaging techniques, limiting the penetration depth of even the state of the art microscopy techniques to a fraction of a millimeter in tissue.

However, although random, scattering is a deterministic process, and it can be undone, controlled, and even exploited by carefully shaping the input wavefront, forming the basis for the emerging field of optical wavefront-shaping[1,2], and opening the path to imaging through visually opaque samples[3] and to the control of scattered ultrashort pulses [4]. avUnfortunately, many of these pioneering demonstrations [1-4] required an invasive implantation of an optical probe at the target for determining the wavefront distortions.

I will present some of our recent efforts in addressing this challenge [5-11]. These include the use of the photoacoustic effect to focus and control light non-invasively inside a scattering medium [5-7], and the use of optical non-linearities to focus light noninvasively through scattering samples [8].

I will also show how one can surprisingly image through opaque samples and 'around corners' using nothing but a smartphone camera[9], by exploiting the inherent correlations of scattered light, challenging the common view on diffuse scattered light as an information-less halo. If time permits I will present our efforts in exploiting these principles for novel endoscopic techniques [10-11].

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[11] A.Porat et al., "Widefield lensless imaging through a fiber bundle via speckle-correlations", Optics Express (2016)

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SHINING LIGHT ON THE BRAIN: IMAGING HUMAN BRAIN FUNCTION WITH DIFFUSE OPTICAL TOMOGRAPHY

Mapping distributed brain activity in humans revolutionized our understanding of how brain function underlies our actions and thoughts. Additionally, brain development, aging, and neurological diseases all manifest as measurable alterations in distributed brain networks. Brain function traditionally has been imaged with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). However, PET uses ionizing radiation, which is not permitted as an experimental procedure in children; fMRI involves exposure to strong magnetic fields and induced electric fields, and so is contraindicated in patients with implanted electronic devices (e.g., deep brain stimulators, pacemakers, cochlear implants).

Optical methods utilize near-infrared spectroscopy (NIRS), a safe technique (employed in pulse oximeters) that leverages sensitivity to blood volume and oxygenation to report blood-oxygen-level-dependent (BOLD) signals via measurements of light absorption.

Our lab develops systems that utilize densely-packed and spatially-overlapping NIRS measurements, along with tomographic reconstruction techniques, to obtain fMRI-comparable image quality and extend mapping of brain function beyond current limitations. These diffuse optical tomography (DOT) systems provide a silent and portable alternative to traditional methods for functional neuroimaging.Our efforts are focused on three broad areas: hardware development, software and algorithm development, and applications from basic science to clinical care. Hardware development projects concentrate on optimizing signal-to-noise, image quality, subject comfort, and portability. Software and algorithm projects include Finite Element Modeling of light propagation, tomographic image reconstruction speed and accuracy, spatial-temporal registration of multiple data types, and development of a self-contained MATLAB-based toolbox, NeuroDOT, for acquisition and analysis of DOT data.

To further understanding of brain function in health and disease, our lab is focused on basic science and clinical applications including autism spectrum disorder, Parkinson's disease, bedside imaging in the Intensive Care Unit, language processing, and brain plasticity from childhood development throughout the lifespan.

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SUPER-COULOMBIC AND SPIN MOMENTUM LOCKED DIPOLE DIPOLE INTERACTIONS BETWEEN QUANTUM EMITTERS

Over the last decade, important work has shed light on the challenges in engineering dipole-dipole interactions (DDI) between quantum emitters in fields as varied as atomic physics, circuit QED, photonic crystal waveguide QED and chemical sensing. In the context of organic electronics and biochemical markers, such interactions have been exploited for non-radiative energy transfer between isolated photoluminescent molecules.

However, the role of the photonic environment in controlling , enhancing and suppressing such interactions has been widely debated. Here, we place fundamental bounds on what a nanophotonic environment can achieve in engineering dipole-dipole interactions. We show clearly that the photonic density of states which sheds light on spontaneous emission engineering does not control these quantum interactions and hence is not the correct figure of merit. However, a carefully structured environment can certainly modify dipole-dipole interactions.

Finally, we show experimentally how super-Coulombic dipole dipole interactions can be achieved using a metamaterial environment where the near-field interactions can surprisingly persist at intermediate field regimes - 10 times the Forster radius. We also present universal spin-momentum locking of light, a phenomenon closely linked to electronic topological insulators, and its role on chiral unidirectional dipole dipole interactions.

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MIE-RESONANT SEMICONDUCTOR METASURFACES

Nanoparticles composed of high refractive index semiconductors can support multipolar Mie-type resonances while exhibiting very low absorption losses at optical frequencies. Using the capabilities of modern nanotechnology, these resonances can be tuned with high precision by the nanoparticle design and environment. Based on this possibility, such nanoparticles represent versatile building blocks of nanoantennas or metasurfaces with tailored optical properties[1].

This talk will provide an overview of our recent advances in controlling the generation and propagation of light with optical metasurfaces composed of high-index semiconductor nanoresonators.

First, I will discuss passive and linear metasurfaces designed to impose a spatially variant phase shift onto an incident light field, thereby providing control over its wave front. Based on the simultaneous excitation of electric and magnetic dipole resonances, the nanoresonators can be tailored to emulate the behaviour of the forward-propagating elementary wavelets known from Huygens' principle, thereby allowing for almost fully transparent structures. Based on this concept, we have realized various wave front shaping devices with high transmittance efficiency, full phase coverage, and a polarization insensitive response.

In the second part of this talk, I will then focus on the enhancement of light-matter interactions in Mie-resonant semiconductor metasurfaces, in particular on spatial and spectral tailoring of spontaneous emission from nanoscale light sources. Various experimental strategies for incorporating emitters into Mie-resonant semiconductor metasurfaces will be introduced, and the influence of the metasurface design on the properties of the emitted light will be analysed in detail.

[1] M. Decker and I. Staude, "Resonant Dielectric Nanostructures: A Low-Loss Platform for Functional Nanophotonics", J. Opt. 18, 103001 (2016).

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ELECTROMAGNETIC MODELING OF COMPLEX RESONANT NANOSTRUCTURES: CHALLENGES AND NEW CONCEPTS

Kevin Vynck, Alexis Devilez, Thibault Pichon, Philippe Lalanne

Controlling the interaction of light with nanoparticles is one of the spearheads of research in modern optics and photonics. Metallo-dielectric nanoparticles enable strong light scattering at frequencies that are tunable over the whole visible and near-infrared ranges, and to control the directivity of light scattering as a function of the angle and polarisation of the incident wave. When these nanoparticles are placed in thin-film stacks, their optical properties are further enriched thanks to the interaction of the nanoparticles with the stratified medium and to the mutual interaction between nanoparticles.

Such nanostructured surfaces can be fabricated by bottom-up techniques (hence at low cost and on large scales) and could exhibit new, exotic optical properties, thereby impacting technologies as diverse as photovoltaic panels, organic light-emitting diodes, biosensors, or even transparent displays for augmented reality devices. Unfortunately, theoretically predicting the optical properties of such complex nanostructures has remained a seemingly insurmountable challenge up to now, due to the difficulty to consider simultaneously the coherent phenomena occurring down to the nano-scale – at the level of the individual nanoparticle – up to the mesoscopic scale – at the level of the nanoparticle ensemble.

In this presentation, I will present the methods that we are currently developing and employing to theoretically/numerically model the light scattering by complex nanostructures. In particular, we will present a formalism based on the concept of quasi-normal modes that allows analyzing individual nanoparticles with great physical insight and reduced computational cost, and propose a computational method enabling the modeling of disordered ensembles of complex nanoparticles strongly interacting with planar interfaces.

This work has been carried out with financial support from the French State, managed by the French National Research Agency (ANR), via the NanoMiX project (ANR-16-CE30-0008) and the ``Investment for the Future'' Programme IdEx Bordeaux - LAPHIA (ANR-10-IDEX-03-02).

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TOPOLOGICAL PHASE TRANSITIONS IN PHOTONIC LATTICES

Topologically non-trivial bandstructures can be realized in a variety of specially-designed photonic systems, such as photonic crystals and arrays of coupled optical waveguides. In some of these photonic systems, it is exceptionally easy to tune system parameters to drive the bandstructure through a topological phase transition, which can produce various interesting effects.

In this talk, I discuss an optical waveguide array that exhibits a particularly accessible transition between a 2D conventional insulator and a 2D topological insulator phase. The transition point corresponds in the full 3D bandstructure to a Type-II Weyl point, the first to be found experimentally in photonics.

Moreover, in the regime of nonlinear optics, I show that the topological phase transition gives rise to a novel family of "self-induced topological solitons", which inherit the properties of gap solitons as well as topological edge states.

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COMPLEX PHOTONICS OF BIOPHOTONIC STRUCTURES VAND SELF-ASSEMBLED OPTICAL METAMATERIALS

Nature produces structural colours with staggeringly diverse set of complex nanostructures, most often encountered in the wings of butterflies and beetles and the feathers of birds. The arrangement of materials in these structures reach an astonishing precision and is accurately reproduced within many individuals to a level that easily surpasses lab-based structures. The biological world has optimized such photonic structures in fish scales, bird feathers and insect wings. By changing the dimensions of such nanostructures or the amount of order and disorder in these systems, these diverse nanostructures allow manipulation of incident electromagnetic radiation so to achieve colors that extend over the entire visible wavelength range and that are employed in courtship or to escape predation risk by camouflage.

Here, I will present the optical properties of different topologies of biological photonics structures, what we know about the development of these functional nanostructures, and hypothesize about the formation pathway in the case of gyroid-structured photonic crystals in a butterfly.

I will also discuss how such structures and topologies can be optically understood and serve as an inspiration to develop novel optical materials and describe our recent advances in the manufacture of optical metamaterials.

Contributed Talks

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EXACT EIGENMODE FORMULATION FOR OPEN/LOSSY (NANO-PHOTONIC) SYSTEMS

Any theoretical study of light-matter interactions in non-trivial nano-photonic systems, and nano-plasmonic systems in particular, necessitates the solution of the Maxwell's equations. While this can be easily done e.g. using standard commercial software, some of the more complicated effects, such as spontaneous emission engineering, thermal emission, optical forces, quantum friction, dipole-dipole interaction etc., involve an extremely large number of simulations, effectively prohibiting steady progress in the study of these problems.

One may seek a solution based on normal-mode or eigenmode expansions and the computation of the Green function of the structure - this enables efficient calculation of the scattering of fields generated by any configuration of point, bulk, or far-field sources without repeated simulation. However, energy loss due to absorption and open boundaries prohibit the use of standard eigenmodal formulations, and involves a range of conceptual and numerical implementation problems. This is true also of quantum scattering problems, or any system described by a wave equation involving open and/or lossy resonators.

In this talk, I will present a simple, practical formulation that overcomes all complexities and deficiencies of previous approaches. Specifically, our eigenmodes are obtained from a linear eigenvalue equation, and do not exhibit non-physical far- field divergence. The modes are complete, with a discrete set capable of replacing a continuous set of radiation modes, thus, simplifying a range of scattering problems. In most cases, few modes are necessary, facilitating both analytic calculations and unified insight.

Our method yields the Green's function and its variation over source and detector positions and orientations, thus, enabling a relatively simple calculation of the various effects mentioned above.

I will demonstrate the method for structures of increasing complexity, as well as for the study of a range of different physical problems.

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FOCUSING INSIDE DISORDERED MEDIA WITH THE GENERALIZED WIGNER-SMITH OPERATOR

P. Ambichl, A. Brandstötter, J. Böhm, M. Kühmayer, U. Kuhl and S. Rotter

In the emerging field of "wavefront shaping" spectacular advances have recently been made, such as to focus light behind an opaque layer, or to send and retrieve images across it. Thanks to these advances also the focusing of light inside highly disordered media could recently be demonstrated using embedded fluorescent probes and nano-crystals or with digital optical phase conjugation to focus light onto a target moving inside an otherwise static environment.

Here we present a new approach for focusing inside a disordered material that has the considerable advantage of working without the requirement to implant a fluorescent body at the focus or to phase-conjugate a wave scattered at the focus position [1]. Our technique is based on a generalization of the established Wigner-Smith time-delay operator [2,3].

The key ingredient for our approach is the scattering (or transmission) matrix of the medium [4,5] and its derivative with respect to the position of the target one aims to focus on. A specific experimental realization in the microwave regime is presented showing that the eigenstates of a corresponding operator are sorted by their focusing strength – ranging from strongly focusing on the designated target to completely bypassing it.

Our protocol works without optimization or phase-conjugation and we expect it to be particularly attractive for optical imaging in disordered media.

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POLARIZATION CONTROL OF LIGHT TRANSMISSION THROUGH A MULTIMODE FIBER WITH STRONG POLARIZATION AND MODE COUPLING

A multimode fibre subjected to random mode and polarization mixing represents a complex photonic system with coupling of spatial, temporal, spectral and polarization degrees of freedom. By exploiting such coupling, we demonstrate a full control of the polarization state of light transmitted through a multimode fibre by adjusting the spatial profile of the incident field.

We measure the polarization-dependent transmission matrices, and find the transmission eigenchannels. By launching light to specific eigenchannnels, we are able to preserve the polarization state despite strong polarization mixing in the multimode fibre, or to convert all transmitted light to the orthogonal polarization state. In addition, we show that the linearly polarized input light can be changed completely to circularly polarized output.

Furthermore, arbitrary polarization states can be realized for individual spatial channels at the output by tailoring the incident wavefront of a single polarization. Our numerical simulation shows that the strong coupling of spatial and polarization degrees of freedom is essential to achieve a complete control of polarization. We also explore how many spatial degrees of freedom are required.

Such a global control of the polarization states of all output channels is more challenging than the local control of the polarization state of a single output channel. Utilizing spatial degrees of freedom, we are able to use a multimode fibre as a reconfigurable waveplate.

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IMAGING & SENSING WITH MULTIPLE SCATTERING MEDIA

Rebecca French, Sylvain Gigan, Otto L. Muskens

With the advancement of modern camera technology, an attractive way to obtain increased functionality is to utilise the improved spatial resolution of these devices to extend into the spectral domain. The incorporation of wavelength information into a monochromatic image is of interest as it enables the measurement of multispectral datasets and can provide more information per exposure.

While impressive results have been shown using diffractive or refractive elements, the trade-off between the accessible spectral range and the resolution can limit the performance of certain applications; for instance, in broadband spectroscopy techniques.

In recent years, the utilisation of multiple scattering media in imaging and sensing has seen an increase in interest. With the emergence of wavefront shaping, transmission matrix techniques, and characterisation of frequency-dependent speckle patterns, the properties of multiple scattering media can be harnessed to develop new methods of manipulating spatial and spectral information.

Here, we demonstrate that a 1.5 μm thick multiple scattering layer of semiconductor nanowires which, in combination with a microlens array, can be used to encode both spectral and spatial information simultaneously onto a monochromatic camera. Using compressive sensing techniques, we reduce the amount of data measured at the acquisition stage, well below the Nyquist-Shannon sampling limit, in order to decrease the computational demands required to recover spatial and spectral information.

Our technique enables measurements of sparse and noisy narrowband signals over a wide spectral range within a small detection area, for potential applications in machine vision or molecular finger-printing techniques, such as Raman spectroscopy.

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THE JOINT OPTICAL MEMORY EFFECT

Roarke Horstmeyer, Gerwin Osnabrugge, Ioannis Papadopoulos, Benjamin Judkewitz, Ivo M. Vellekoop

The scattering nature of tissue makes it challenging to form clear biomedical images. It also limits the depth to which one can focus light inside biological media. Techniques like adaptive optics and optical phase conjugation can correct for scattering to produce clear images and/or sharp focal spots, but only over a limited field of view (FOV) within a given scattering sample.

In both cases of imaging and focusing, the extent of the FOV is a function of how correlated the optical field remains as it is tilted or shifted through different areas of the scattering tissue. In this work, we present a unified "joint memory effect" model of optical correlations inside scattering media that accounts for both tilting and shifting.

Our new model can lead to a maximized correction FOV for a given sample. The joint memory effect combines the optical memory effect with a recently proposed anisotropic memory effect to provide an accurate description of spatio-angular correlations within arbitrary scattering media.

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CORRELATIONS BETWEEN REFLECTED AND TRANSMITTED INTENSITIES IN WAVE TRANSPORT THROUGH OPAQUE DISORDERED MEDIA

It is well known that the speckle produced by light scattering in a disordered material presents correlations. The correlations between different points in the same speckle pattern are well studied, however the correlation between the reflected and the transmitted patterns received far less attention. We report the first direct experimental ob-

servation of the correlation between reflected and transmitted speckle patterns. This correlation consists of two contributions. One of them is a sharp and positive peak, while the second is a much broader and negative dip.

We study the behavior of this correlation depending on the optical properties of the scattering medium, in particular its thickness and mean free path, covering the transition from quasi-ballistic to completely diffusive transport. We find that the positive part depends only on the optical density of the sample, while the negative part appears to be more sensitive to the sample thickness than to its mean free path.

We also study the dependence of the correlation function on the angle of incidence of the incoming wave, showing that the position of the positive peak does not depend on the angle of incidence, while the center of the negative part of the correlation function shifts linearly with it.

The existence of this correlation opens new possibilities for the wave-front shaping and imaging techniques since it indicates that despite being separated by the scattering medium, the intensity distribution on both its sides carry some amount of information about each other.

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SEMICONDUCTOR NANOANTENNAS FOR STRONG AND DIRECTIONAL LIGHT-MATTER INTERACTION

Alberto G. Curto, Mehmet Mutlu, Ahmet Fatih Cihan, Soren Raza and Mark L. Brongersma

High-refractive index optical antennas have emerged as promising tools for the control of light at the nanoscale, benefitting from mature fabrication technologies and potential integration with on-chip optoelectronic systems. Here, we exploit two of the advantages of silicon nanostructures to reach the strong coupling regime between light and matter and to direct light emission.

First, thanks to the narrow Mie resonances of silicon nanobeams, we demonstrate strong coupling to a molecular J-aggregate, with a Rabi frequency of 150 meV. Both hybrid polariton branches are visible in photocurrent measurements, tailoring the optoelectronic response of both materials.

Second, thanks to the coexistence of magnetic and electric dipole responses in silicon nanowires, we demonstrate directional emission from an atomically thin MoS2 monolayer. Compared to the so-called Kerker condition for plane wave scattering based on the interference of electric and magnetic dipoles, we show that there are two possible mechanisms to direct the emission of a source dipole with a nanowire.

Our results illustrate the broad applications of semiconductor nanoantennas in nanophotonics-based technologies , ranging from improved efficiency and performance in lightning and displays, to the modification of the intrinsic optolectronic properties of materials.

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DIELECTRIC NANOANTENNAS FOR CONTROLLING, GUIDING AND ENHANCING LIGHT

Optical antennas transform light from freely propagating waves into highly localized excitations that interact strongly with matter. In particular, plasmonic nanostructures acting as nanonantennas have been employed to obtain strong light-matter interactions at deep subwavelength size scales. However, its ohmic losses lead to temperature increase in the metal and surroundings.

This effect is well known and some applications take advantage of it, such as photothermal imaging or cancer therapy. However, for other applications, it is detrimental as it strongly limits the power that can be delivered to a hot spot before the particle reshapes or melts, affecting its nanoscale lighting or the emission properties of molecules near the nanoantennas. Another limitation of metals is the difficulty to generate optical magnetic response.

Recently, the use of low-loss resonators made of high-permittivity dielectric materials (non-plasmonic), has shown to be efficient in enhancing the interaction of light with molecules. Here we will describe first how that non-plasmonic nanoantennas, can produce both, large near field enhancement and good scattering efficiencies while generating small temperature increases in their hot spots and surrounding environments. And second, another key aspect of these nanoantennas, which is the possibility of exciting nanoscale displacement currents that can lead to magnetic response, allowing the tuning of the amplitude and phase difference of electric and magnetic resonances independently. Then, by just conveniently designing the shape and size of the nanostructures, they can arbitrarily interfere to direct light towards a desired direction.

All this could show non-plasmonic nanoantennas as a basic unit for the development of more efficient light emitting devices aimed at integrated photonics, sensing, spectroscopic techniques (SERS or SEF) or optical nanocircuits, where tuning the light propagation direction would be beneficial to improve its performance.

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LONGITUDINAL ELECTROMAGNETIC FIELDS IN LIGHT SCATTERING BY DIELECTRIC SPHERES

The role played by longitudinal electromagnetic fields in light scattering by optically dense media has recently come into focus of research on Anderson localization of light. It turns out, for example, that the longitudinal fields can prevent Anderson localization in 3D for point scatterers. We study the longitudinal electromagnetic fields generated in light scattering by a dielectric sphere (homogeneous, coated, or hollow) and show that its intensity is, generally, increased compared to the point-scatterer case. This suggests that longitudinal fields are likely to continue playing a negative role for Anderson localization in the case of dielectric scatterers as well. Our results allow for choosing the optimal parameters of a dielectric spherical scatterer that would yield the largest scattering efficiency along with the smallest possible longitudinal field. The optimization may be achieved by using coated or hollow spheres with accurately adjusted radius and shell thickness. A random medium composed of such "optimal scatterers" would be the best candidate to search for Anderson localization of light in 3D.

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OPTICAL MANIPULATION WITH RANDOM LIGHT FIELDS: FROM FUNDAMENTAL PHYSICS TO APPLICATIONS

**Giorgio Volpe, Sylvain Gigan
and Giovanni Volpe**

Optical tweezers have been widely applied to non-invasively manipulate micro- and nano-objects. They have, therefore, gained increasing importance as tools in microbiology and biophysics both for fundamental studies and for more advanced applications, such as optical sorting and optical delivery. Most of current optical manipulation techniques, however, rely either on carefully engineered optical systems or advanced fabrication tools. Although similar conditions are routinely met in research laboratories, these requirements can be very stringent and limit the applicability of these techniques, for example, to biomedical and microfluidic applications, where simplicity, low-cost and high-throughput are key aspects.One more challenge common to all these techniques in optical manipulation is the light scattering occurring in optically complex media, such as biological tissues, turbid liquids and rough surfaces, which naturally gives rise to apparently random light fields known as speckles. In this talk, I will show how the statistical properties of speckle light fields can be used to transform them into a versatile tool to efficiently perform fundamental optical manipulation tasks such as trapping, guiding and sorting. Similarly, we show how speckle light fields can be used to control and tune the diffusion property of a Brownian particle, becoming an ideal model system to study the motion of particles in random potentials at equilibrium and out of equilibrium.

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INVARIANCE OF THE MEAN PATH LENGTH IN MULTIPLE LIGHT SCATTERING

Romolo Savo, Romain Pierrat, Ulysse Najar, Rémi Carminati, Stefan Rotter and Sylvain Gigan

Our everyday experience teaches us that the structure of the complex medium is inherently linked to its physical behavior, in particular to the properties of waves scattering through this medium. Correspondingly, much of the progress in wave scattering applications has been linked to the ability to modify and engineer the medium structure such as to fulfil a desired purpose.

In stark contrast with this view, a recent theoretical study pointed out that a very fundamental property of wave transport is completely insensitive to the structure of the underlying medium [1]. To arrive at this result, an invariance property first found for random walks [2] was generalized to arbitrary wave scattering scenarios. Specifically, it was shown that under very general assumptions the mean path length <s> associated with wave scattering through a medium only depends on the medium's boundary geometry, but not on its internal microstructure, namely <s> = 4V/S, where V is volume and S the surface of the medium. Applying this theoretical predictions to the paradigmatic case of a fully disordered medium would mean that a change of the transport mean free path should leave the mean path length invariant.

Here, we experimentally demonstrate this surprising property explicitly, for multiple scattering of light in colloidal suspensions. By varying the concentration and size of the scattering particles, we tune the mean free path by almost two orders of magnitude, covering the range of a nearly transparent to a very opaque system. We measure the mean length of light trajectories from the temporal decorrelation of an optical speckle pattern in each one of these suspensions, and unambiguously observe this invariance.

This very general, fundamental and counterintuitive result can be extended to a wide range of systems, however ordered, correlated, or disordered, and has important consequences for many fields, including light trapping and harvesting for solar cells and more generally in photonic structure design.

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LIFETIME STATISTICS OF ANDERSON LOCALISATION LASER

Randhir Kumar, Sushil Mujumdar

Anderson localisation induced lasing is one of the exceptional phenomena arising due to the complex interplay between disorder-induced light localisation and amplification. Amplifying disordered media possess a rich underlying physics of complex photonics. Till date, investigations on the random lasing has mostly been focused on its spectral properties and reports on its temporal behavior are sparse in the literature. However, any investigation of lasing is complete only after proper studies of its temporal evolution.

Here, we report on the experimental measurement of the spatio-temporal characteristics of Anderson localisation lasers. We use a liquid micro-droplet array (diameter of 16-20 µm) made up of a laser dye as the sample. The system is pumped with ~35 ps Nd:YAG laser. We observe

signature exponentially decaying tails in the spatial profiles of these Anderson localized modes measured using a spectrometer. The distribution of localisation lengths normalized to the system size peaks at ~0.17 showing their strong localisation character. The wavelength resolved temporal measurements are done by coupling the spectrometer to an ultrafast streak camera (temporal resolution 2 ps).

At higher disorder, when the droplet size dispersion is ~100 nm, the lifetimes of the lasing modes show a single peaked left-skewed distribution centered at 65 ps. On reducing the disorder below 10 nm, the distribution becomes dual peaked with an additional smaller peak emerging at 36 ps. To further investigate this peculiar transition, we develop a numerical model based on transfer-matrix-method and coupled atom-cavity rate equations. The lifetime distributions in both disorder regimes predicted by the model are in excellent quantitative agreement with the experimental distributions. The emergence of the additional short-lived peak is attributed to the modal overlap and gain competition between the modes.

We believe our studies will open up new research directions in complex photonics of the interplay between disorder and amplification.

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LIGHT-MATTER INTERACTION IN NATURAL PHOTOSYNTHETIC PHOTONIC STRUCTURES

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Photosynthesis (PS) is the ultimate light-matter interaction process in nature. Although PS has been extensively studied from a molecular point of view, light scattering by the photosynthetic tissue has been seldom explored and specially overlooked by the photonics community. A surprising fact given the detail studies available on the structural colour in insects and animals. The current renewed interest in technological and fundamental aspects of PS makes understanding the PS-photonic interplay very timely.

To give a flavor on this topic I will present our recent results on the study of so called iridoplast [1]. Iridoplasts are ≈ 10 μm wide organelles present in the adaxial epidermal cells of several plant species known to grow under low light conditions. They are formed by multilayers of photosynthetic tissue with period ≈ 150 nm. The first consequence of the presence of iridoplasts in the otherwise green leaves is that they show a metallic blue (450-500 nm) iridescence under low light conditions. Therefore, iridoplast are a natural system where the photonic structure is directly linked to PS performance. Not only this structuration produces a strong iridescence but it can have important implications in the light harvesting process. In fact, our results suggest that the functionalities of these photonic structures are twofold. On the one hand optical models of this organelles show that the absorbance of the photonic structure is enhanced at $\lambda \approx$ 500-560 nm. On the other one, the photosynthetic quantum efficiency of this organelles is higher than in non-photonic chloroplasts of the same species.

Time allowing I will also show other examples of photonic structures in photosynthetic cells to discuss what we can learn and specially what we do not know about the interplay between photonics and PS in nature.

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BIOMIMETIC COMPUTATIONAL IMAGING

David B. Phillips, Ming-Jie Sun, Jonathan M. Taylor, Matthew P. Edgar, Stephen M. Barnett, Graham M. Gibson, Miles J. Padgett

Many animal vision systems have evolved naturally to operate in a compressive manner: for example the retina in the human (vertebrate) camera eye possesses a region of high visual acuity (the fovea centralis) surrounded by an area of lower resolution (peripheral vision).

The key to the widespread success of this kind of vision is in its adaptive nature. Our gaze is continually redirected towards objects of interest. Unlike a simple zoom, the entire field-of-view is continuously monitored, enabling gaze redirection to be triggered by peripheral stimuli such as motion or pattern recognition.

This form of spatially-variant vision exploits the temporal redundancy present in many dynamic scenes to reduce the amount of information that must be recorded and processed per frame: essentially performing intelligent lossy compression at the point of data acquisition.

This in turn speeds up the frame-rate of such a vision system, and enables us to react to our surroundings more fluidly. I will describe how we can mimic animal vision to enhance the useful data gathering performance of a computational imaging system, with potential applications to single-pixel imaging and imaging through scattering environments.

This architecture provides unusual video streams in which both the resolution and exposure-time spatially vary and adapt dynamically in response to the evolution of the scene.

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DETAILED ANALYSIS OF A NATURAL PHOTONIC SYSTEM

Villads Egede Johansen, Colin Ingham, Silvia Vignolini

Bacteria may exhibit bright and brilliant colouration through the way they organise in colonies. When they stack in a highly ordered fashion, their 300-400 nm rod-shaped bodies form a photonic crystal exhibiting strong light interaction and giving colour to these otherwise bleak, yellow bacteria. Understanding the light-matter interaction with the colonies proves a challenge involving clever measuring and modelling techniques.

This talk aims at giving insight into the complexity of analysing natural photonic systems that exhibit so-called structural colouration. The difficulty lies in finding out when which methods are appropriate and how to design the measurements to acquire data that can verify the modelling. This is particularly true because such systems suffer the curse of dimensionality since its behaviour is expressed - at a bare minimum - by two incident light angles, two reflection angles, wavelength dependency and natural variation of and between samples. To overcome this, the analysis is broken down into more manageable sizes.

The results from these experiments are then correlated with simulations using tools such as finite elements, scattering matrix formalisms and analytical methods to extract different geometrical parameters of the system.

Such analysis is a strong tool in probing in-vivo bacterial organisation and by that working towards a better understanding of the behaviour of bacteria colonies.

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OPTICAL POLARIZATION MÖBIUS STRIPS ON ALL-DIELECTRIC OPTICAL SCATTERERS

In this article, we study the emergence of polarization singularities in the scattering of optical resonators excited by linearly polarized light. First, we prove analytically that spherical all-dielectric nanoparticles described by combinations of electric and magnetic isotropic polarizabilities can sustain L surfaces and C lines that propagate from the near-field to the far field. Based on these analytical results, we are able to derive anomalous scattering Kerker conditions using singular optics arguments. Next, through using full-field calculations, we demonstrate that high refractive index spherical resonators present such topologically protected features. We calculate the polarization structure of light around the generated C lines, unveiling a Möbius strip structure in the main axis of the polarization ellipse when calculated on a closed path around the C line.

These results prove that high-index nanoparticles are excellent candidates for the generation of polarization singularities and that they may lead to new platforms for the experimental study of the topology of light fields around optical antennas.

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HYPERUNIFORM DISORDERED PHONONIC STRUCTURES

We introduce and discuss a new class of structurally disordered phononic crystals that efficiently combine the behaviour of periodic and disordered structures. These structures were inspired by their photonic counterparts that have already been studied to a certain extent. Phononic crystals have shown remarkable applications over the last two decades, while stealthy hyperuniform disordered structures (HUDS), formed by appropriately decorating a 2D stealthy hyperuniform point pattern, have shown remarkable behaviour as photon cavities and waveguides.

Here, the underlying mechanisms for the formation of large phononic band gaps in HUDS will be thoroughly presented and comparison to the photonics case will be discussed. As an example, we numerically investigate, through finite element calculations, the formation of band gaps in HUDS made of 500 lead cylinders in an epoxy matrix.

In the 2D case (infinite height of the cylinders) the elastic wave for both in-plane and out-of-plane polarization exhibits large phononic band gaps, similar to the periodic ones. Due to their high mismatch of the media underlying the structure very high Q-factors (Q~10^14), when disregarding intrinsic phonon-phonon scattering can be found. These Q-factors will be compared to what was previously found in the photonics case.

The combination of these effects could lead to efficient acousto-optic structures. We will also present, a new bottom-up approach available for HUDS, to form arbitrary shaped waveguides with 100% transmission through sharp bends, not possible in the periodic structures. Comparison with photonic waveguides using this approach will also be discussed and compared to the phononics case. Application of this efficient technique to Fiber Optics will also be addressed.

Finally, we will discuss 3D elastic wave propagation through finite height slabs of HUDS and the existence of high-Q modes and efficient waveguiding. Applications of these structures as MEMS, thermoelectric devices, elastooptic devices, integrated phonon circuits, etc., are anticipated.

Posters

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BROADBAND SPECTRAL SPLITTING OF LIGHT USING WAVEFRONT SHAPING

Splitting of light to different frequencies is an important tool for several photonic research and applications. One of those applications is increasing the absorption of light via spectral splitting in solar energy systems. Nowadays, this splitting process is realized by fixed diffraction gratings. However, these structures can't adapt to the environmental changes and their efficiencies differ from season to season.

A structure that can adapt to environmental changes would certainly increase the efficiency of solar energy systems. When the dimensions of a medium are comparable to wavelength of light, diffraction plays a major role in wave propagation and it differs by wavelength. Thus, it is possible to obtain intended phase difference for each frequency by changing the thickness or refractive index of the medium.

As a result, waves at a specific frequency can be controlled to constructively interfere at a desired point. Liquid crystal displays, which enable to control refractive indices of each pixels via modulating the amplitude of the applied electric field can be used to control diffraction. By this programmable control, the spatial phase of light can be changed between 0-2π and the phase pattern for spectral splitting can be determined. As a result, light can be spectrally split using an adaptive medium.

In this thesis, we will use liquid crystal displays to determine a micro structure that can achieve spectral splitting at different angles of incident light. In accordance with this purpose, spectral splitting of light will be customized to a region or a building. In addition, we will also investigate the effectiveness of the spectral splitting and the splitting ratio.

Our spectral splitting patterns promise an increase in solar cell efficiency given that the effectiveness will be customized to the location where the solar cell will be positioned.

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BROADBAND EFFECTS ON WAVEFRONT SHAPING

Hilton B. de Aguiar, M. Mounaix, S. Gigan, S. Brasselet

Wavefront shaping holds the potential of increasing the penetration depth of diffraction-limited microscopy, by exploiting uniquely multiply-scattered light. While most results in wavefront shaping up to date were performed in a quasi-monochromatic regime, there have been a series of experiments reporting surprising new effects when performing a broadband wavefront shaping. Understanding wavefront shaping with broadband sources is highly relevant, given the general use of broadband lasers in biomedical applications.

In this contribution, we discuss effects arising from broadband wavefront shaping. We have recently reported that a broadband wavefront shaping experiment naturally recover a well-defined polarization state, even though the speckle is depolarised. This is a remarkable result as shaping with monochromatic sources would lead to randomly ellipticaly polarized light. In other to understand the origin of these effects, we will present further experiments evaluating the time-of-flight of photons leaving a multiple scattering medium. These experiments gives microscopic insights into the broadband wavefront shaping experiment, and its difference from a monochromatic case.

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NANOANTENNA-ASSISTED ELECTRICAL GENERATION OF SURFACE PLASMONS VIA INELASTIC TUNNELING

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Surface plasmons polaritons (SPP) are charge-density surface waves, confined at the interface between a metal and an insulator. This confinement property makes SPPs good candidates for optoelectronic devices miniaturization. Recently, several groups have used a scanning tunneling microscope (STM) tip to generate surface plasmons via inelastic tunneling. This elegant technique suggests the possibility to integrate an electrical SPP source directly into the SPP circuit. Yet, the efficiency is very low and the radiation spectrum is very large. We introduce a resonant plasmonic nanoantenna to circumvent these issues. Our study predicts an enhancement by more than two orders of magnitude of the electrical power conversion to SPP as well as a tunable narrow emission spectrum. Our analysis allows one to understand recent experiments from other groups demonstrating such an enhancement. Some of those results were published recently.

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CONTROLLING LIGHT INSIDE A MULTI-MODE FIBER BY WAVEFRONT SHAPING

Light is the primary tool used for collecting information from macroscopic and microscopic structures of matter. Micro-nano technology based materials like microcavities, waveguides, photonic crystals and fibers are used for confining light in space and the latter enable long distance information transfer. To increase the capacity of an information link, the core size of an optical fiber must be increased.

Due to increased size of the fiber, the number of supported modes increases and becomes a multi-mode fiber. Given the increased number of modes, interference starts to play a major role and a random speckle pattern forms at the output of the fiber.

This speckle pattern is controlled via controlling interference of the fiber modes by shaping the wavefront of the incident light. Wavefront shaping is developed for guiding light through highly scattering materials by spatially modulating the wavefront of an incident coherent beam. The most common way to shape the wavefront is to use a spatial light modulator (SLM).

To program the wavefront of light, we will develop an optimization algorithm which will enable us to control the interference of the fiber modes. This algorithm aims to spatially divide the wavefront into an number segments and controlling the phase of each segment. As a result, the speckle like pattern will be modified such that the beams passing through a multi-mode fiber will be focused in the desired position.

This presentation will develop and investigate a method that can provide knowledge and experience for developing advanced technologies for life sciences and communication technologies.

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FOCUSING THROUGH DYNAMIC TISSUES USING FAST ITERATIVE WAVEFRONT SHAPING

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The propagation of light in biological tissues is rapidly dominated by multiple scattering: ballistic light is exponentially attenuated, which limits the penetration depth of conventional microscopy techniques. For coherent light, the recombination of the different scattered paths creates a complex interference (speckle). Recently, different wavefront shaping techniques [1] have been developed to coherently manipulate the speckle. It opens the possibility to focus light through complex media and ultimately to image in them, provided however that the medium can be considered as stationary.

We have studied the possibility to focus in and through biological tissues. Their intrinsic temporal dynamics creates a fast decorrelation of the speckle pattern. Therefore, focusing through biological tissues requires fast wavefront shaping devices, sensors and algorithms. We have investigated the use of a MEMS-based spatial light modulator (SLM) and a fast photodetector, combined with FPGA electronics to implement a closed-loop optimization. Our optimization process is just limited by the temporal dynamics of the SLM (200µs) and the computation time (45µs), thus corresponding to a rate of 4 kHz (i.e. 245µs is required to optimize one mode). To our knowledge, it's the fastest closed loop optimization using phase modulators.

We have studied the focusing of scattered light through colloidal solutions of TiO_2 particles in glycerol, whose scattering properties are similar to biological tissues. Moreover the temporal dynamics of this sample can be tuned by changing its temperature, thus matching the different timescales of the speckle decorrelation observed with biological tissues. We have shown that our set-up fulfills the required characteristic to focus through fast decorrelating samples. We have explored also the properties of the resulting focus, and in particular its decorrelation time, as well as the possibility to scan it to build an image.

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ACTIVE SPONTANEOUS EMISSION MODULATION BY COUPLING TO ALL-DIELECTRIC-METASURFACES EMBEDDED IN A LIQUID CRYSTAL CELL

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Metasurfaces composed of Mie-resonant semiconductor nanoparticles allow for controlling the spectrum, polarization and wavefront of light fields with high efficiency [1]. Tuning of their optical response was previously demonstrated by integrating the metasurfaces into a liquid crystal cell and using the reorientation of the liquid crystal molecules as a function of temperature [2] or applied electric field [3]. On the other hand, Mie resonant semiconductor metasurfaces can be employed as nanoantenna arrays to enhance the emission from resonantly coupled emitters [1]. Here we combine these capabilities and demonstrate active tuning of photoluminescense by coupling emitters to a silicon nanodisk metasurface integrated into a liquid crystal cell.

First, we analysed the emission enhancement for quantum dot emission as well as for the intrinsic fluorescence of the glass substrate around 900 nm wavelength coupled to metasurfaces in air, i.e. without liquid crystals. Then, we integrated the coupled system consisting of the metasurface and the emitters into a liquid crystal cell and studied the emission properties as a function of the controlled parameters, namely the temperature and applied voltage. Furthermore, we numerically studied the parameter dependent transmittance of our metasurfaces using the software packet Comsol by embedding the nanodisks in an uniformly rotatable liquid crystal.

As our central result, the substrate fluorescence showed a strong dependence on both control parameters. These results can be explained by spectral tuning of the metasurface resonances by roughly 10 nm with respect to the spectral fluorescence maximum.

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OPTIMAL IMAGING THROUGH GRADED INDEX MEDIA

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Gradient index (GRIN) rods are widely used for endoscopic imaging in areas where a small device is desireable, such as the brain. They allow for increased imaging performance for the same diameter compared to conventional endoscopes, such as chip-on-a-tip devices or fiber imaging bundles. However, the optical performance of GRIN rods degrades towards the edges of the field of view. This limits the lowest diameter that can be achieved for a particular resolution and endoscope length. These limits are not caused by inaccuracies in the refractive index profile, but rather result from the fact that this rod is a waveguide.

We demonstrate that we can completely predict the optical performance of these rods, with a model based light propagation through a graded-index waveguide. This enables diffraction-limited imaging in a larger area. As a next step, we also show that the same model applies up to a degree for graded-index fibers, which would be a very interesting candidate for further miniaturisation of endoscopes.

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OPTICAL RESOLUTION PHOTOACOUSTIC ENDOSCOPY USING SPECKLE ILLUMINATION

Antonio M. Caravaca Aguirre and Emmanuel Bossy

We present a thin endoscopy system for optical resolution photoacoustic (PA) microscopy. The system is based on an optical multimode fiber (MMF) for light delivery attached to a fiber-optic hydrophone for PA detection. To control the illumination at the distal tip of the MMF, a digital micromirror device modulates the amplitude of the optical wavefront which is coupled into the MMF. A pre-calibrated speckle illumination combined with reconstruction algorithm allows to image different two dimensional sparse samples.

The imaging system requires two steps; First, the illumination system is calibrated projecting a set of N binary masks on the DMD and recording each speckle intensity pattern generated at the distal tip of the MMF using a CMOS camera. This calibration takes less than 10 seconds due to the fast projection capability of the DMD. After the calibration, the sample is placed next to the distal tip of the MMF and the hydrophone. Each PA signal generated for each calibrated speckle pattern is collected by the hydrophone, digitalized and recorded with a DAQ card. We invert the linear relation between the speckle distribution and the PA signal generated to obtain an image of the sample.

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ALL-OPTICAL MODULATION OF SINGLE NANOANTENNA ON VANADIUM DIOXIDE

Bigeng Chen, Daniel Traviss, Luca Bergamini, Nerea Zabala, Javier Aizpurua, Jeff Gaskell, David W. Sheel, Otto L. Muskens

Single nanoantenna has intrigued vast interest due to its exceptional properties such as light harvesting and field enhancement, which provide the opportunities for strengthening light-matter interaction and efficient photon manipulation in nano-scale. On the other hand, materials with structural or electronic phase transition have been employed to achieve large optical modulation contrast, making them promising building blocks for high-performance optical circuits and devices. In this context we demonstrate nano-scale all-optical modulation with single Au antennas fabricated on phase-transition material vanadium dioxide (VO2) substrate.

We use a pump-probe spectroscopy to characterise the modulation feature of the antenna/VO2. The pump beam at 1060 nm wavelength is used to introduce a local heating for VO2's phase transition and the probe beam is for readout of the modulated extinction cross-section of a single-nanoantenna owing to the dielectric environment change. A spatial modulation technique is also used to extract the extinction cross-sections. As a result, the modulation depth of the differential effective extinction cross-section at telecom wavelengths is up to 100% with pump pulse energy below 1 nJ while the time for fully switch-on is less than 50ps.

We also investigate the time response of the extinction cross-section dependent on the pulse repetition rate and substrate temperature, respectively, which show that the heat accumulation and thermal equilibrium time plays important roles in the achievable modulation speed.

The single-nanoantenna/VO2 structure may find applications in nano-scale optoelectronics for multiple functionalities including modulation, memory and so on.

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ENTANGLEMENT PROPAGATION THROUGH DISORDERED MATERIAL

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Taking advantage of the quantum nature of light is a promising avenue to develop new technologies dedicated to information processing and communication. To fully exploit the information-carrying capacities of photons, all relevant degree of freedom – polarization, position and frequency – must be utilized. Thus far, photon polarization has been considered as the preferred qubit embodiment to encode and process information with light [1].

The quest for increasing the information-carrying capacity of photons necessitates the use of other degrees of freedom that offer higher dimensionality. In the last decades, new classes of photonic systems that can harness such high-dimensional degrees of freedom have been investigated, such as photonic integrated circuits and disordered materials [2,3]. The benefits accrued are even greater if entanglement is utilized in such large dimensional systems.

Spatially entangled photon pairs naturally inhabit a high-dimensional Hilbert space. As a drawback, the characterization of the spatial correlations over a wide range of spatial modes can be costly, implying a large number of measurements. It has been previously demonstrated that Electron Multiplying Charge Coupled Device (EMCCD) cameras can be used to extract some entanglement information from spatially entangled photon pairs[4]. In our work, we extend this approach to the full reconstruction the amplitude of the two-photon wave function of photon-pairs entangled over more than 106 spatial modes. We use this technique to study the propagation of entanglement through high-dimensional linear disordered systems, such as multimode fibers. By combining wavefront shaping techniques [5] with our high-dimensional detection technique, we investigate how entanglement properties of spatially entangled photon pairs can be retrieved after propagation through a disordered medium.

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ULTRAFAST PHOTOMODULATION FOR DEVICE-LEVEL CHARACTERISATION OF PHOTONIC INTEGRATED CIRCUITS

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Long haul communication networks are exclusively realised using optical signals transported via glass fibres. We are now seeing traditionally short-range electrical connections also being replaced by optical links, and this is occurring at ever shorter length scales.

Silicon is frequently the choice of material to fabricate such devices, due to its direct compatibility with CMOS electronics and processing techniques that stem from decades of development in the electronics industry.

However, a large proportion of the costs in silicon photonics are associated with component testing, which is creating an increased demand for effective device-level characterisation.

Here we investigate the spatial alteration of the refractive index profile of silicon-on-insulator waveguides via free-carrier injection. Optical pumping is used to create the localised perturbations in the silicon's refractive index, which in turn modulates the transmitted light.

By scanning the pump spot over the device and recorded both the transmission and change in transmission at each point, it is possible to build up a spatial photomodulation map. Such maps provide a direct visualisation of the flow of light through a device and, in particular, are used here investigate mode structures of multimode interference devices

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OPTICAL CONTROL OF LIGHT SCATTERING

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In recent years a lot of attention has been dedicated to the study of light propagation in scattering media, due to its relevance in applications ranging from biophotonics to optical communications [1,2,3]. This has led to the development of advanced techniques to control the interaction of light with a random material, from wavefront shaping to the tailoring of the material composition, e.g. for imaging and diffusion cloaking applications [1,4].

Recently it also has been demonstrated that it is possible to control dynamically the propagation of light in scattering materials, using optically-induced magnetic responses[5].

Here we demonstrate all optical reversible tuning of light interaction in a silica aerogel (SA) sample. This weakly scattering medium, with effective refractive index close to that of air, has peculiar optothermal properties, which make it particularly suitable for nonlinear optical applications[6,7]. Here we show that we can take advantage of these properties to control all optically light displacement.

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PHOTONIC NETWORK RANDOM LASING

Michele Gaio, Alain Quentel, Dhruv Saxena, Dario Pisignano, Andrea Camposeo and Riccardo Sapienza

I will introduce photonic network random lasing, an unconventional laser designed on a network topology.

Disordered nanophotonic networks composed of doped connected sub-wavelength waveguides are an ideal scattering geometry to route photons, promote coupling between embedded emitters and enhance stimulated emission. The optical properties can be designed from their topological correlations, such as the network degree and topology, and are revealed by the complex multi-modal random lasing action.

Network random lasing can be dynamically controlled via adaptive pumping of the network modes, with potential for future on-chip integration.

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TOPOLOGICAL PHOTONICS

A key feature of topological insulators is the presence of surface states immune to disorder and impurities due to topological protection. These states modify the optical properties of topological insulators compared to their ordinary counterparts.

We show that topological insulators nanoparticles sustain a new kind of excitation when interacting with light. This is a topological localized surface plasmon polariton obtained perturbing the nanoparticle surface electron state with light.

As well as, we will show that photonic crystal can sustain all optical modes that present topological protection without the need of magnetic fields.

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QUANTUM STATE ENGINEERING THROUGH MULTIPHOTON SCATTERING IN RANDOM MATERIALS

Luca Innocenti, Saroch Leedumrongwatthanakun, Sylvain Gigan, Alessandro Ferraro, Mauro Paternostro

Control over the propagation of coherent and nonclassical light through random materials has been demonstrated in a variety of platforms. In particular two-photon quantum walks through multiple-scattering media have recently been demonstrated (Defienne et al., sciadv 1501054 (2016), Wolterink et al., PRA 93, 053817 (2016)).

An as yet unexplored possibility offered by random materials is their use for quantum state engineering of entangled states. Indeed, the very high number of degrees of freedom offered by such platforms potentially translates into an high control over the produced quantum states, with a relatively low experimental effort with respect to that necessary in more common quantum optical setups.

The natural Hilbert space of these states is however the Fock space, while many interesting quantum states are formulated for systems of many qubits (or qudits). The question of how to encode many-qubit states into many-boson ones is, to our knowledge, still open. We investigate this relation, showing in particular how to encode states useful for distributed quantum communication protocols, like W and Dicke states.

Another open problem stems from the impossibility to engineer an arbitrary many-photon dynamics. The set of probability amplitudes describing the evolution of many indistinguishable photons into a multi-port interferometer is indeed non-trivially determined by how single photons evolve in it. We show how, by suitably choosing the interferometer, it is nevertheless possible to evolve an input many-photon state into a target superposition of output many-photon states -- thus allowing to engineer arbitrary many-boson states.

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BIO-INSPIRED DISORDERED MATERIALS

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The scattering strenght of a material is determined by the arrangement, the geometrical features and the refractive index of its components. In general, biological systems show small scattering strength because they are composed of low-refractive index materials (n <1.6).

A particular genus of white beetle, which scientific name is Cyphochilus, is an exception to this general trend. In fact, although it is made up of chitin it has an extraordinary scattering strength. This important optical property is obtained thanks to the nanometric random network present in the Cyphochilus scales that optimises the scattering parameters (diameter, inter-distance and density of the scatterers).

After quantifying its scattering efficiency using a coherent backscattering setup, we took inspiration from the beetle structure for the realisation of bio-inspired white materials. In particular, collaborating with the Holscher group in KIT, we used manufactured PMMA films using a precipitation by solvent evaporation technique. Changing the morphology of these structures (the dimension of their pores and the starting molecular weight of the polymer) we obtain films with a mean-free-path up to 0.8μm and a reflectivity of around 90% compared to a standard white diffuser (using 4μm of thickness).

Moreover, these bio-inspired materials show the possibility to switch from an opaque, white appearance (high scattering regime) to a transparent film (ballistic regime) simply wetting them.

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PROGRAMMABLE QUANTUM STATE ENGINEERING IN MULTIMODE FIBERS

Saroch Leedumrongwatthanakun, Luca Innocenti, Hugo Defienne, Thomas Juffmann, Mauro Paternostro, Sylvain Gigan

Programmable two-photon quantum walks through a multimode fiber, acting as a linear coherent multimode optical platform, can be implemented by using the knowledge of its transmission matrix in combination with wavefront shaping. Propagation of indistinguishable photons in a complex manner allows designing useful high-dimensional states.

We will describe our theoretical and experimental efforts towards generating high dimensional one and two-photon states, namely W state and Dicke state. This work paves the way for an unconventional platform of controllable photonic circuit for quantum information processing.

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GRAPHENE-DNA RANDOM LASER

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Random lasers are a kind of lasers with specific characteristics[1], same of them are shared with the traditional laser like amplifying medium or external pumping but other are absent like a external cavity. In RL the feedback is provided by scattering medium or surface roughness like in the Resonant Feedback Random Laser (RFRL) [2]. However, control of the electromagnetic modes, wavelength emission or external tuneability are still a challenge. Recently, graphene has been proposed to control the chaotic behavior of the RL [3] . This approach explores nonlinear properties of graphene like Saturable Absorption (SA), Reverse Saturable Absorption (RSA) or Two Photon Absorption(TPA). Starting with this idea we propose to use a hybrid material with polymeric DNA doped with organic dye and graphene nanoflakes. We use this material to fabricate thin films and Resonant Feedback Random Laser and study the effects of the graphene. We have found that emission of the RFRL is attenuated by the absorption of graphene.

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DIFFUSE METASURFACES TO BRING COMPUTER GRAPHICS TRICKS TO OPTICAL SYSTEMS

Alexander E. Minovich, Manuel Peter, Felix Bleckmann, Manuel Becker, Stefan Linden and Anatoly V. Zayats

Metasurfaces represent a highly efficient tool for the manipulation of wavefront in optics allowing for a number of useful applications such as beam steering, focusing with planar aberrationless lenses, carpet cloaks, to name but a few.

In this work we demonstrate that a concept of normal mapping can be implemented using sub-wavelength thin reflective metasurface patterns. Normal mapping is widely used in computer graphics as a modelling trick to display 3D-like features on surface texture – such as regular patterns, graininess, bumps, ripples, and bevels for letters or numbers. For scattering surfaces, the orientation of the surface normal determines, in general, lighting and shading effects for a 3D object such that the faces which are turned away from the illumination source look darker in a 2D projection. Shading effect is an important aspect of a 3D visualization which was used long before stereo-photography and holography. It is essential for our perception of volume and depth of two-dimensional images. An incorrect representation of shading in drawings may easily cause confusion similar to Penrose's "impossible triangle". For the demonstration of the normal mapping method we have fabricated and characterized a flat diffuse metasurface imitating lighting and shading of a 3D object (a cube) and showed its performance for both coherent and incoherent illumination.

The metasurface structure utilized the geometric phase concept. The normal mapping introduces an additional degree of freedom to the design of optical elements, in addition to traditional optical engineering methods of surface profiling and gradient refractive index.

The visual effects based on the surface normal mapping which we have demonstrated can be utilized in security holography, display technology, metrology and applications requiring optical systems with engineered scattering (including off-axis geometries). The developed diffuse metasurface has highly versatile and controllable properties enriching the range of natural, holographic, and laser-written diffusers.

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BOOSTING EMISSION THROUGH OPTICAL DISORDER: THE MIE GLASS. DESIGN AND CHARACTERIZATION OF A NOVEL OPTICALLY RANDOM MEDIUM

José M. Miranda-Muñoz, Gabriel Lozano and Hernán Míguez

Herein, we present a solid including optical disorder, which behaves as a liquid dilute suspension of monodisperse particles, which represents a novel demonstration of a Mie glass.

We demonstrate that it is possible to describe light transport throughout this material employing Mie theory, thus, solely taking into account single-particle considerations.

Mie glass is an inexpensive material synthesized by solution-processing methods comprising a mesoporous TiO2 matrix, in which crystalline TiO2 monodisperse nanospheres are dispersed in a random manner.

Performing a characterization based on parameters typically employed for the description of the properties of random media, specifically, the scattering mean free path and the transport mean free path, we were able to confirm fair agreement in certain spectral ranges between measurements and analytical predictions based on Mie formalism for diverse conditions of scattering centre size and concentration. This shows the possibility of tailoring the disorder for the fabrication of a diffuse material with the desired value of the scattering properties.

We demonstrate that this medium is able to boost light harvesting efficiency in bifacial solar cells when the porous matrix is sensitized with a dye [1].

We also demonstrate that soaking the material with fluorescent dye molecules yields brighter color conversion layers, which we attribute to a combination of resonant excitation and a better out-coupling of the emitted light [2]. In this way, Mie glass is proven to be an excellent candidate for applications in which accurate control of light absorption or color conversion is required.

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MANIPULATING SINGLE PHOTONS BY HYBRID DIELECTRIC-METAL ANTENNAS

Sergii Morozov, Avi Braun, Michele Gaio, Simon Fairclough, Stefan A Maier and Riccardo Sapienza

We report a hybrid parabolic dielectric-metal antenna made by direct laser writing over a single photon emitter.

We show theoretically and experimentally that unidirectional far-field radiation patterns can be achieved.

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COHERENT SPATIO-TEMPORAL CONTROL OF PULSED LIGHT THROUGH MULTIPLE SCATTERING MEDIA

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Optical imaging through highly disordered media such as biological tissue or white paint remains a challenge as spatial information gets mixed because of multiple scattering. At depth where ballistic light is no more present, common microscopy techniques become impossible. Nonetheless, previous work had shown that using a spatial light modulator (SLM) and coherent light from a monochromatic laser, the spatial speckle pattern can be controlled at the output of a random medium with wavefront shaping techniques, be it via a feedback loop or with the measurement of the optical transmission matrix.

However, if a broadband ultrashort pulse is incident on a complex medium, it gets temporally broadened as the medium respond differently for the different spectral components of the pulse. In an equivalent temporal point of view, transmitted photons are exiting the medium with a broader temporal distribution. Therefore, all the applications requiring an ultrashort pulse are strongly limited in scattering media.

In this work, we introduce a technique to measure either the Multispectral or the Time-Resolved Transmission Matrix, thus fully describing the propagation of the broadband pulse either in the spectral or temporal domain. Exploiting this information, and using a single SLM, we demonstrate full spatio-temporal control of the profile of the pulse at the output of a thick scattering medium. We show in particular spatio-temporal focusing of an ultrashort pulse of light after the medium, with a temporal compression almost to its initial time-width in different space-time position, as well as different temporal profile such as a double pulse in a single spatial position. We exploit this spatio-temporal focusing beam to enhance a two-photon excitation, thus opening interesting perspectives in coherent control, light-matter interactions and multiphotonic imaging.

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CORRELATION AND INFORMATION BETWEEN REFLECTED AND TRANSMITTED SPECKLE PATTERN.

N.Fayard, A.Cazé , A. Goetschy, R. Pierrat, A.D Paniagua, I. Starshinov, J. Bertolotti and R. Carminati

Scattering of a wave by a complex media leads to highly contrasted intensity patterns in both reflection and transmission usually called speckles. For now one decade, people manage to overcome the scattering of the light by the medium using wave-front shaping techniques for which transmission measurements are needed. Understanding the statistical link that exists between the reflected and the transmitted speckle pattern may be useful in order to control transmission properties with reflection measurements only. In this work we study analytically, numerically and experimentally the correlation between the scattered light in transmission and in reflection and show that it is a long range negative function when the medium is thick.

We extend the concept of correlation to what information theory has called Mutual Information between numerous speckle spots in transmission and in reflection. This quantity, directly linked to the long range correlation studied before, has a subtle behavior when the number and/or the distance between speckles considered in transmission and in reflection change.

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MANIPULATING SPECKLE PATTERNS BY WAVEFRONT SHAPING TECHNIQUES

Alba M. Paniagua-Diaz, Williams L. Barnes, Jacopo Bertolotti

Ideally wavefront shaping techniques are able to completely control light propagation and even revert the effect of scattering. It is common to think about wavefront shaping as the manipulation of a plane wave to obtain the desired wavefront (i.e. the one that will focus light through a scattering material), but the manipulation of light after the scattering process already happened, e.g. to restore the beam quality, presents a whole new set of problems given that phase vortices are present in the illumination beam to be shaped. In this work we study the implications of manipulating a speckle pattern as initial wavefront instead of a plane wave and show how wavefront shaping can work efficiently under a completely random intensity pattern illumination.

We demonstrate this using a speckle pattern generated by passing a laser through a multimode optical fibre that scramble the phases from the different propagating modes. By using wavefront shaping techniques on the speckle pattern generated at the end of the fibre, we are able to redistribute the initial random intensity pattern into a diffraction limited spot, with an intensity 300 times larger than the average speckled illumination and containing up to 25% of the initial intensity. After the optimization, the final beam quality was considerably improved, reducing the M^2 factor from 59 to 1.2.

These results show the robustness of wavefront shaping, demonstrating for the first time that wavefront shaping can still be an efficient technique even when completely random illumination is used. This opens new possibilities for the application of wavefront shaping to solve real life problems, such as improving beam quality of a laser beam without losing orders of magnitude of energy.

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FANO RESONANCE REVEALS PERCOLATION IN PHOTONIC CRYSTALS

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Percolation is a geometrical concept concerning end-to-end connectivity of a minority phase across a system which has brought new understanding to several areas of physics, mathematics and other areas of science.

Percolation can have tremendous impact on the physical response of the system [1]. Although this effect is well understood for some systems (e.g. transition from insulating to conducting) the effects of percolation in the optical response (transport) of photonic structures is still a matter of study.

Here we show how by using photonic crystals where precise amounts of random vacancies can be easily incorporated it is possible to reach the percolation threshold for an fcc while recording its optical response. We have found that these vacancies introduce a background of diffuse scattering which couples with the photonic band gap and give rise to asymmetric resonances in the optical spectra that follow the Fano line shape [2]. A fine control of the vacancies density [3] permits to prepare the systems so that different asymmetric profiles, characterized by the parameter q.

We found that at the percolation threshold, probably due to the divergence of cluster size and subsequent enhanced diffuse scattering, q changes sign as signaled by the photonic band gap collapse.

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CHIRAL SURFACE WAVES FOR ENHANCED CIRCULAR DICHROISM AND ALL-OPTICAL ENANTIOSELECTIVE SORTING

Giovanni Pellegrini, Marco Finazzi, Michele Celebrano, Lamberto Duò, and Paolo Biagioni

Chiral objects are three-dimensional bodies characterized by being geometrically distinct from their mirror image. This geometrical feature is ubiquitous in living systems and finds its most outstanding examples in DNA and proteins. Therefore, the analysis and separation of chiral molecules has gained increasing importance in the pharmaceutical and biochemical industry, with 95% of medicines expected to be chiral by 2020.

Circular dichroism (CD) spectroscopy is one of the most relevant tools for the discrimination of enantiomers. However, CD signals are usually extremely weak, making the analysis of small amounts of chiral analytes very challenging. Recently, novel 'superchiral' approaches have been proposed to enhance the CD signal by tailoring the properties of the electromagnetic field through the control of the associated optical chirality C, which is defined as $C = (-\varepsilon_0 \omega/2)\mathrm{Im}(E^* \cdot B)$ [1].

In this framework, we introduce a chiral sensing platform based on the combination of a 1D photonic crystal with a metamaterial surface defect. This platform supports 'superchiral surface waves' originating from the coherent superposition of the TE and TM surface modes, providing (i) homogeneous, (ii) broadband and (iii) switchable superchiral fields over arbitrarily large areas and wide spectral ranges. Additionally, the use of standard dielectric materials allows moving the operation wavelength towards the UV end of the spectrum.

The present design provides optical chirality enhancements well above 1 order of magnitude and CD signal enhancements of more than 2 orders of magnitude, along with enantioselective optical forces 2 orders of magnitude larger than those provided by standard evanescent waves [2]. These findings pave the way towards surface enhanced chiral sensing, spectroscopy, and all-optical manipulation.

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DIRECTING FLUORESCENCE EMISSION

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White solid-state lighting typically works by partial conversion of a blue light source, by means of fluorescence from a phosphor, to longer visible wavelengths.

The isotropy of emission from a phosphor can present significant inefficiencies when attempting to utilise all of the fluoresced light. Our research aims address this inefficiency, by providing a means of generating highly directional emission from phosphors.

At the macroscale, a parabolic reflector dish provides a familiar and effective means of directing radiation. As such, it has formed the starting point of our investigations into the interactions of phosphors with metallic substrates, patterned on the microscale. Finite-element simulations of radiating dipoles within metallic paraboloids, of size comparable to the wavelength, have been performed. We present the dependence of the power radiated into a desired solid angle, as a function of the position and orientation of the source dipole.

We observe a strong deviation of the emission direction's dependence on source location within the paraboloid, from the macroscale case. Specifically, the well-defined focus of the macroscale paraboloid has been replaced by several hot spots of directional emission.

The locations of which are dependent on the orientation of the dipolar emitter and do not coincide with the geometrical focus.

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MAPPING MOLECULE - PLASMONIC NANOSTRUCTURE INTERACTIONS AT THE NANOSCALE

Lisa Saemisch, Matz Liebel, Niek van Hulst

We image the local excitation/emission enhancement of freely diffusing dye molecules close to plasmonic nanostructures (gold nanorods) using super-resolution based fluorescence localisation microscopy. By tuning the nanorod length we observe the transition from fluorescence excitation to emission enhancement and are, additionally, able to resolve interference induced excitation probability modulations in the vicinity of the structures.

Recently, several groups have employed approaches from super-resolution microscopy to access the near-field of plasmonic nanostructures.

These studies resolved regions of enhanced fluorescence intensity which are due to local enhancement of either the excitation field or the fluorescence rate and, additionally, pointed towards the difficulties associated with far-field localisation microscopy near nanostructures.

Here, we employ total internal reflection (TIRF) based super-resolution imaging of freely diffusing molecules in the vicinity of gold nanorods. By changing the antenna length as well as the excitation polarisation we actively tune the molecule-nanostructure interaction thus resolving the transition from excitation to emission enhancement.

This transition manifests itself in a dramatic change in the spatial extend of the region of strong enhancement around the nanostructure.

We then apply an “inverse” super-resolution approach to reconstruct the excitation field amplitude further away from the particle. By reconstructing images from weakly enhanced emitters exhibiting poor localisation precision we are able to resolve the interference between the direct excitation field and the field component scattered off the nanostructure resulting in a spatially varying excitation density surrounding the structure. Beyond the TIRF induced asymmetry we observe spatially oscillating fluorescence intensities.

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RESONANT NEAR-FIELD EFFECTS IN PHOTONIC GLASSES

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A fundamental quantity in multiple scattering is the transport mean free path whose inverse describes the scattering strength of a sample. Here, we emphasize the importance of an appropriate description of the effective refractive index in multiple light scattering to accurately describe the light transport in dense photonic glasses.

Using the effective refractive index as calculated by the Energy Coherent Potential Approximation we are able to predict the transport mean free path of monodisperse photonic glass. This model without any fit parameter is in qualitative agreement with numerical simulations and in quantitative agreement with spectrally resolved coherent

backscattering measurements on new specially synthesized polystyrene photonic glasses and earlier published data [1,2]. These materials exhibit resonant light scattering perturbed by strong near field coupling, all captured within the model. Wave transport in multiple scattering 3D media predicts a disorder driven phase transition from diffusion to localization [3,4]. Recently it was shown that for light 3D Anderson localization has never been observed experimentally [5,6]. One possible reason is that the disorder in the studied systems is too low. Our model might be used to maximize the scattering strength of high index photonic glasses, which are a key in the search for Anderson Localization of light in 3D.

To reach a new scattering regime and to test the validity of our model in high index materials titanium dioxide photonic glasses are produced and characterized in optical experiments.

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DESIGN AND DEMONSTRATION OF GAAS/ALGA AS MULTIPLE QUANTUM WELL NANOWIRE LASERS

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Semiconductor nanowires are promising structures for developing compact lasers that can be used in future nanophotonic integrated circuits.

Over the past 15 years, nanowire lasers have been demonstrated in a wide range of material systems. Most of the demonstrations, however, have used homogenous bulk gain semiconductors. Incorporating quantum confined active regions into nanowires has a number of potential benefits, such as lower threshold, larger differential gain and higher modulation bandwidth.

In this work, we demonstrate low-threshold room-temperature lasing in nanowires with GaAs/AlGaAs coaxial multi-quantum well (MQW) active regions. We achieve this by proper cavity design and by optimising our growth procedure to realise high quality MQW nanowire heterostructures based on the design.

Lasing is demonstrated by optical pumping individual nanowires and the threshold fluence is shown to be a factor of two smaller compared to bulk GaAs nanowire lasers of similar dimensions.

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COHERENT SPECKLE MITIGATION IN IMAGING

T. Abhilash, A.P. Mosk

Imaging of sub-micrometer objects has always been a challenge to the scientific community in disciplines varying from nanomaterials science to biology. In this context, the most commonly used method is wide-field imaging using incoherent light.

The reason for using incoherent light is that it prevents artifacts (speckle) due to the interference of scattered light inherent to a coherent illumination [1]. However, coherent imaging techniques are highly desirable as it would allow to replace incoherent light sources with bright and collimated laser beams.

Recently there have been several methods to reduce speckle, glare and artifacts in imaging configurations where some information is carried by incoherent light [2,3]. We propose a fully coherent method to remove speckle in laser-illuminated imaging applications [4].

The method makes use of an off-axis holography set-up to acquire fields associated with images of different samples and reference objects. We define a normalized field difference that is sensitive to the object features but greatly reduces speckle.

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ENHANCING CONTRAST IN LIGHT SHEET MICROSCOPY

Optical sectioning by light sheet fluorescence microscopy allows high resolution imaging of thick biological samples. Fluorescence excitation in a single plane, orthogonal to the detection axis, enables rapid wide-field image acquisition with minimal sample irradiation and therefore photo-damage or photo-bleaching. Although light sheet microscopy is able to resolve sub-cellular features at depth in model organisms, elevated levels of endogenous auto-fluorescence often preclude good contrast in more general scenarios.

We demonstrate how photo-switchable fluorophores can be exploited to boost the contrast of fluorescent structures of interest.

A photo-switchable fluorophore only becomes fluorescent after exposure to light of a specific, activation, wavelength. Once activated, it will fluoresce for a few milliseconds under light of the excitation wavelength of the fluorophore. This process can be repeated hundreds of times and is best known for its use in super-resolution imaging. Perhaps less well known is the ability of such dyes to enhance contrast. Here we show that the characteristic switching pattern can be exploited to distinguish photo-switchable fluorophores from those that fluoresce after excitation at either the activation or excitation wavelength. We constructed a digitally scanned light sheet microscope with optical lock-in detection capability and used cross-correlation analysis to reveale features with high contrast in samples marked with the reversibly switchable protein rsEGFP. We explored strategies to account for any non-uniformity in the light distributions in biological samples and further show that adaptations to the algorithm lead to a significant improvement in specificity and optical sectioning.

We demonstrate how photo-switchable fluorophores can be exploited to enhance contrast in light sheet microscopy. In particular, we investigate how for light sheet illumination the characteristic emission patterns can be filtered with higher specificity.

Our experiments show that structures hidden well below a fluorescent background level can be revealed.

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CELLULOSE PHONICS

Nature's most vivid colours rely on the ability to produce complex and hierarchical photonic structures with lattice constants on the order of the wavelength of visible radiation [1]. A recurring strategy design that is found both in the animal and plant kingdoms for producing such effects is the helicoidal multilayers [2,3].

In such structures, a series of individual nano-fibers (made of natural polymers as cellulose and chitin) are arranged parallel to each other in stacked planes. When distance between such planes is comparable to the wavelength of light, a strong polarised, colour selective response can be obtained [4].

These helicoidal multilayers are generally structured on the micro-scale and macroscopic scale, giving rise to complex hierarchical structures enriching their visual appearance.

Biomimetic with cellulose-based architectures enables us to fabricate novel photonic structures using low cost materials in ambient conditions [5-7]. Importantly, it also allows us to understand the biological processes at work during the growth of these structures in plants.

In this talk the route for the fabrication of complex bio-mimetic cellulose-based photonic structures will be presented and the optical properties of artificial structures will be analyzed and compared with the natural ones.

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Timetable

Tuesday 25 July

15.00	Arrival at the Cumberland Lodge
15.30 - 15.40	Opening
15.40 - 16.40	Keynote talk (Padgett)
16.50 - 17.30	2 contributed talks (Sivan, Brandstötter)
17.30 - 18.30	2 invited (Bhaskaran, Grange)
18.30 - 20.30	Dinner
20.30 - 21.00	Evening debate (Hammersley and Wong)

Wednesday 26 July

09.30 - 10.50	4 contributed talks (Xiong, French, Horstmeyer, Starshynov)
10.50 - 11.30	Coffee break
11.30 - 12.30	2 invited talks (Katz, Eggebrecht)
12.30 - 15.00	Lunch
15.00 - 16.00	Keynote talk (Ritsch-Marte)
16.00 - 16.30	Poster pitch
16.30 - 18.30	Poster session
18.30 - 20.30	Dinner
20.30 - 21.30	Evening debate (Moriarty)

Thursday 27 July

09.30 - 10.30	3 contributed talks (Curto, Albella, Escalante)
10.30 - 11.30	Coffee break
11.30 - 12.30	2 invited talks (Jacob, Staude)
12.30 - 15.00	Lunch
15.00 - 16.00	Keynote talk (Saenz)
16.00 - 17.00	3 contributed talks (Volpe, Savo, Kumar)
17.00 - 17.30	Coffee break
17.30 - 18.30	2 invited talks (Kevin, Yidong)
18.30 - 20.30	Dinner
20.30 - 21.30	Self organized session (Hoff)

Friday 28 July

09.30 - 10.30	3 contributed talks (Lopez-Garcia, Phillips, Egede)
10.30 - 11.20	Coffee break
11.20 - 12.00	2 contributed talks (Garcia-Etxarri, Gkantzounis)
12.00 - 12.30	1 invited talk (Wilts)
12.30 - 13.00	Closing remarks + poster award
13.00 - 14.00	Lunch
14.00	Departure