EUROPA / ERASMUS MUNDUS — Education and Culture DG

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Europhotonics EMJD Doctorate Program
phD projects 2010 – 2013

1. Transport at the nanoscale

Involved institutions : LENS (Diederik Wiersma), ICFO (Niek Van Hulst)

Transport phenomena are crucial in many fields of science, including solid state and cold atom physics, photonics, and condensed matter physics. Examples of fascinating effects that emphasize the interdisciplinary character of this field are Anderson localization, Bloch oscillations and Zener tunneling, the Hall effect, various scaling phenomena, and anomalous transport like Levy flights. These effects have by now been observed or are under active study on very different systems, ranging from degenerate matter (Bose-Einstein condensates, Fermion systems) to photonic crystals and Levy glasses.

The transport of optical waves through disordered systems can exhibit remarkable interference effects, in analogy to the transport of electrons in solids. The most dramatic of all interference phenomena is that of strong localization.

We are interest in localization effects in photonic structures, especially in three dimensional systems like photonic crystals with controlled amount of disorder or fully random structures like powdered semiconductors.

2. Functional bio-imaging in cells and tissues

Involved institutions : LENS (Francesco Pavone), Institut Fresnel (Sophie Brasselet)

Imaging techniques based on linear and non linear laser interactions are currently thoroughly developed at LENS [1,2] and Institut Fresnel (MOSAIC tram) [3,4], in order to study functional biological mechanisms with high sensitivity and high resolution, from single molecules in vitro to living cells and tissues. Among those techniques, particular attention is brought to multiphoton optical processes involving nonlinear interactions, which provide interesting capacities in terms of optical resolution and depth penetration abilities in scattering media. This project aims at developing new microscopy tools based on nonlinear contrasts to enhance optical signatures in cells and tissues, in relation with biological functions. In particular, morpho-functional aspects in tissue imaging (from the brain, skin, cornea, bladder, in relation with biological laboratories and clinic research collaborations) will be investigated using complementary tools developed at both LENS and Institut Fresnel, involving nonlinear contrasts such as multi-photon fluorescence, second and third harmonic generation and CARS (Coherent Anti Stokes Raman scattering). Novel techniques based on wavefront and time shaping of optical fields as well as polarization resolution will be explored, in order to improve contrasts and provide structural information in scattering media such as thick tissues.

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[2] R. Cicchi, D. Massi, S. Sestini, P. Carli, V. De Giorgi, T. Lotti, and F. S. Pavone, Multidimensional non-linear laser imaging of Basal Cell Carcinoma, Opt. Express, vol 15 pp 10135-10148 (2007).

[3] A. Gasecka, T.-J. Han, C. Favard, B.R. Cho, S. Brasselet, "Quantitative imaging of molecular order in lipid membranes using two-photon fluorescence polarimetry", BioPhys J. 97 (10) 2854-2862 (2009)

[4] P. Schön, M. Behrndt, D. Ait-Belkacem, H. Rigneault, S. Brasselet, “Polarization and Phase Pulse Shaping applied to Structural Contrast in Nonlinear Microscopy Imaging”, Phys. Rev. B, accepted (2009)

3. Metamaterial-based optical manipulation and trapping

Involved institutions : Institut Fresnel (Stefan Enoch) and ICFO (Romain Quidant)

Optical forces, originating from the momentum transfer of light to matter, lead to several interesting effects such as trapping and manipulation of small objects or the Casimir effect. Recently, it has been proposed to pattern a surface with plasmonic nanostructures to nano-engineer two-dimensional optical force fields able to trap submicron objects [1-3]. Metamaterials are artificial materials engineered to provide properties that are not found in nature. They usually gain their properties from structure rather than composition, using sub-wavelength structuring to enact effective macroscopic behavior. Metamaterials can offer properties as unusual as negative refraction. In this project, the student will investigate the ability of 1D and 2D metamaterials to engineer unique optical force fields able to extend the applicability range of optical trapping and manipulation. The project will rely on a close interaction between advanced numerical simulations (CLARTE group-Fresnel Institute) and advanced nanofabrication and optics experiments (plasmon nano-optics group-ICFO). Special attention will be paid to studying the use of metametarials to achieve efficient nanooptical trapping and to demonstrate repulsive Casimir forces for quantum levitation [4].

1- Self-induced back-action optical trapping of dielectric nanoparticles, M. L. Juan, R. Gordon, Y. Pang, F. Eftekhari, R. Quidant, Nature Phys. [Online publication] (2009) doi: 10.1038/NPHYS1422

2- Nano-optical trapping of Rayleigh particles and Escherichia coli bacteria with resonant op4cal antennas, M. Righini, P. Ghenuche, S. Cherukulappurath, V. Myroshnychenko, F. J. García de Abajo, R. Quidant, Nano Lett. 9, 3387–3391 (2009)

3- Parallel and selective trapping in a patterned plasmonic landscape, M. Righini, A. S. Zelenina, C. Girard, R. Quidant, Nature Phys. 3, 477-480 (2007)

4- U. Leonhardt and T. G. Philbin, "Quantum levitation by left-handed metamaterials", New Journal of Physics 9, 254 (2007

4. Hybrid transparent electrodes for organic optoelectronic devices

Involved institutions : ICFO (Valerio Pruneri), KIT (Uli Lemmer)

Abstract: The project aims at developing a new generation of transparent electrodes that combines Karlsruhe's polymer technology and ICFO's ultrathin metal film technology. Both technologies have demonstrated to reach individually more than 70% transparency with a sheet resistance of the order of 10 ohm/square. Besides optical and electrical performance optimization, other advantages in the hybrid approach are foreseen, including optimization of interfaces (e.g. work function) and stability of the electrode and other materials forming the devices (e.g. active materials).

5. Volume reduction and enhanced molecular detection with Nano-antennas

Involved institutions : Institut Fresnel (Hervé Rigneault, Sophie Brasselet)- ICFO (Niek Van Hulst)

Nano-antennas of controlled shape and dimensions have the ability to generate strong electromagnetic field on dimensions that are significantly smaller than the wavelength of light. These localized ‘hot spot’ are attracting to enhance the interaction between light and molecule and ultimately be the basis block to build ultrasensitive detection devices for sensor and bio-assays. The group at ICFO has a strong expertise in fabricating free-standing metallic nano-antennas using focused ion beam technology and exploiting single fluorescent molecules as nano-detectors to probe the local antenna field [1]. The group at Fresnel Institute has been working for years on volume reduction analysis and characterization using the technique of Fluorescence Correlation Spectroscopy (FCS) [2]. This group is also developing nonlinear microscopy tools, based on frequency mixing including CARS which addresses molecular vibrations [3]. Our goal is to join both expertises to probe the effective volume excitation under a nano-antenna enhancement. This characterization will provide a valuable tool to explore the enhancement of nonlinear signals of a small number of molecules by such structures.

References :

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[2] P.-F. Lenne, H. Rigneault, D. Marguet, J. Wenger, 'Fluorescence fluctuations analysis in nanoapertures : Physical concepts and biological applications', Histochem Cell Biol 130:795–805 (2008)

[3] D. Gachet, F. Billard, and H. Rigneault, "Coherent anti-Stokes Raman scattering in a microcavity," Opt. Lett. 34, 1789-1791 (2009)

6. Nanostructuring for light trapping in solar cells

Involved institutions : Institute Fresnel <u>(Nicolas Bonod)</u> – ICFO (Jordi Martorel)

Solar cell technology is currently based on silicon wafer. The major drawback of this technology is the large amount of silicon required which represents 40% of the cost of solar cells. Solar cell industry is looking for alternative technologies to drastically decrease the cost of photovoltaic cells with good efficiencies. Organic materials are one of these alternatives which are cost effective and flexible offering a great potential to enlarge conditions of use of solar cells. The efficiency is still lower than those measured with inorganic cells but an increase from 6 % to 9 % could impose this technology in the photovoltaic industry. A part of this increase will be provided by a stronger light matter-interaction in the organic material.

This PhD thesis is a joint project between The Fresnel Institute and ICFO-Institute of photonic sciences with the goal to search for innovative designs of nanostructures in organic solar cells in order to increase the light harvesting in the active layer. Topics to be considered include the study of: Metallic particles which offer great possibilities in solar cells technology because the wavelength of resonance can be tuned by modifying their shape and their size, Nanoshells which are also good candidates for organic solar cells because they support a red-shifted resonance towards the IR radiation, and their scattering cross-section pattern could highly increase the light trapping inside the organic layer. Besides metallic nanoparticles, the metallic cathode could also be nanostructured, periodically, or pseudo periodically to scatter light in diffractive orders in order to increase the optical path length of light in the active layer. Ultrathin organic-metallic coatings which present very interesting optical properties to trap light into the organic material will be studied too.

In the Clarte team at the Fresnel Institute the successful PhD candidate will study theoretically and numerically nanostructured organic cells. She/he will use numerical methods developed by the team, such as the differential method for the study of organic-metallic coatings and periodical structures, or the Lorentz-Mie theory in the case of spherical nano-shells or nanoparticles. This method is currently developed in order to rigorously model the interaction of light with metallic particles and flat interfaces. While at ICFO she/he will be involved in the design and testing of the of ultrathin organo-metallic photovoltaic devices which will be fabricated according to the results of the numerical study performed at the Fresnel Institute.

7. Depth Resolved Cerebral Blood Flow (CBF) Imaging in Animal Models using Spatial and Temporal Statistics of Laser Speckle

Involved institutions : ICFO (Turgut Durduran) - Institut Fresnel (Anabela Da Silva)

The present PhD subject is proposed by two laboratories (ICFO/Institut Fresnel) involved in Biomedical Optics which is a growing domain of interdisciplinary research (theoretical and fundamental physics, biology, medicine…) aiming at developing new state-of-the-art optical techniques to probe tissue function and morphology. More specifically, the projects developed at Medical Optics group from ICFO (Barcelona, Spain) encompasses furthering of fundamental understanding of physiology such as the neuro-vascular coupling in response to stimuli to development of clinically deployable bed-side monitors in neuro-critical care to optical mammography for monitoring of cancer treatment. The research of MAP2 (Random Media and Power Photonics) group from Institut Fresnel (Marseille, France) is focused on developing new methodologies for screening different kinds of random media and in particular biological tissues.

8. Plasmon-soliton coupling

Involved institutions : ICFO (Yaroslav Kartashov) - Institut Fresnel (Gilles Renversez, André Nicolet)

During the last few years, the fabrication and study of nanoscale metal structures leads to the development of plasmonics as a part of photonics [1]. The main advantage of the involved waves (Surface Plasmon Polarition SPP) in these structures is their tight spatial confinement near the metal/dielectrics interface. Several applications have already
been proposed or realized [2]. To extend the capabilities of these structures, one way is to consider the coupling between the plasmons and optical solitons. This way is not studied yet except in one article which mentions their coupling but focusing only on the soliton properties [3]. The solution we propose would allow us to control optically the plasmon-based nanodevice using the field intensity in the nonlinear region. These hybrid devices would also allow to eliminate or to reduce the limitations of conventional SPP-based structures, enerated by the high losses due to the metals.

References

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9. Photogrammetric fringe-projection techniques for reflective surfaces

Involved institutions : KIT (Christoph Stiller), UPC (Santiago Royo)

Fringe-projection techniques are well established optical metrology strategies for measurement of topographic features of objects. Different arrangements have been proposed, using configurations with one or two cameras, always in very robust setups. A dual camera system combines the sampling density of photogrammetry with the resolution of a classical fringe-projection strategy [1-2]. However, the technique presents relevant problems when applied to reflective objects, due to the imaging process developed for fringe projection, as usually it is only applied to diffusive objects. The field has a number of relevant technological and industrial applications to be solved (from automotive glass to free-form lens shape measurement [3-4]). By the way, the limits of the technique, and its benefits and drawbacks when compared to similar measurement strategies will also be analyzed.

References

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10. Optimization of light supercontinuum generation by temporal pulse shaping for nonlinear microscopy

Involved institutions : Institut Fresnel (Hervé Rigneault), ICFO (David Artigas - Pablo Loza-Alvarez)

Photonics Crystal Fibres (PCF) are novel fibre optics that exhibit nanoscale structuration. When illuminated with ultra-short laser pulses, PCF can generate a broadband radiation extended from the blue to the infra-red part of the spectrum; such a radiation is called a supercontinuum (SC). Fig 2 shows a PCF injected with a 200fs IR laser pulse that generates a broad SC that covers the entire visible spectrum. Up to now only short pulses have been used to generate SC but recent work have shown that SC spectrum is very dependent of the temporal shape of the incoming pulse.

Recent advances in laser technology permit nowadays to control the temporal shape of an ultrashort laser pulse thanks to a spatial light modulator (SLM). With this SLM it is possible to generate a laser pulse with an arbitrary temporal shape. This shaped pulse can be further injected into a PCF to generate a SC.

In this project we aim a optimizing the temporal shape of a laser pulse to generated a controlled SC. We aim at controlling the SC in amplitude (spectral amplitude) and phase (spectral phase).

We aim at using this broadband coherent SC as an ultra-short pulse source for multiphoton microscopy applications that are both developed at I Fresnel and ICFO: TPEF (Two Photon Excitation Fluorescence), SHG (Second Harmonic Generation), THG (Third Harmonic Generation), CARS (Coherent Anti-stokes Raman Scattering). We will concentrate on cell (neurones and fibroblast) and tissue imaging (skin and melanoma).

References

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11. Light propagation in periodic gain/loss modulated materials

Involved institutions : UPC (Kestutis Staliunas), LENS (Diederik Wiersma)

Photonic crystals, the materials where the index of refraction is spatially modulated on the wavelength scale are well known to modify the dispersion and diffraction properties of the light. We proposed recently that the materials where not the refraction index, but rather the gain/loss profile is spatially modulated on the wavelength scale can also exhibit very interesting beam propagation phenomena, like the self-collimation, spatial filtering, and beam focalization [1]. Differently from the photonic crystals the gain/loss modulated materials have never been studied in detail before (except for [1]).

The proposed idea is of huge potential of application, as in principle proposes, among others, a novel efficient method of formation of high spatial quality beams in optical amplifiers. The idea is quite new, a lot of work, theoretical, numerical and experimental is needed to develop the idea, and to bring it closer to the applications. The topic therefore is well suited for a challenging and successful PhD work.

The possible tasks of the PhD student range from conceptual-theoretical work (writing a theory of the light propagation in such materials), to numerical investigations (calculating the light propagation, the band diagrams, the Bloch-like modes in concrete materials and concrete architectures), and to experimental studies (measuring the light propagation in different samples as e.g. optical micro-amplifiers with periodically modulated pump profile, or/and photonic crystals doped with amplifying media). The concrete participation in each task will depend on whether the candidate is more attracted by theoretical, numerical or experimental work.

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12. Integrated Atom devices

Involved institutions : LENS (Francesco Saverio Cataliotti), ICFO (not identified)

We intend to fabricate light guides and micro-optics directly on an atom-chip. This will allow to guide laser light to the atoms for manipulation of internal and external degrees of freedom and for atomic detection. The use of nano-structured optical materials with a wide variety of optical mechanical and electrical properties (wide band optical transmission, optical gain, nonlinearity ferroelectricity, pyroelectricity, photorefractivity, etc.) will open up a wealth of new possibilities by permitting the true integration of optical circuits on an atom-chip. Cooling atoms of different statistics to quantum degeneracy and bringing them at submicron distances from nanostructured surface will offer the opportunity of having a precise knowledge of the model Hamiltonian, of manipulating its coupling constants or working with controllable disorder thus offering a unique opportunity of studying matter wave transport. Furthermore one will have the chance of controlling the optical properties of the photonic structures by actively changing the boundary conditions for the optical modes in the structures. This will allow the possible realization of new devices such as quantum switches, quantum gates and quantum states sources.

13. Nanostructured photonic materials

Involved institutions: KIT (Georg von Freymann), LENS (Diederik Wiersma)

This project will deal with the realization of nano scale photonic structures using a sophisticated direct laser writing technique.

This fascinating method allows to create photonic structures with a smallest feature size of about 150 nm and an accuracy down to several nanometers.

The structures are first patterned into polymers by scanning a focussed laser beam through a block of material,

and later on chemically 'inverted' into Silicon Oxide and the back-inverted into e.g. Silicon.

In a way, this is the 'lost wax' casting technique, as often used by artists to create sculptures, but here applied on a nano meter length scale.

We will use this technique to create e.g. photonic quasi crystals, crystals with controlled amounts of disorder, and photonic micro resonators and study the optical properties of these structures with sophisticated optical techniques like near-field scanning optical microscopy, ultra-fast time-resolved spectroscopy (upconversion), and microscopic photoluminescence.

The candidate will be inserted in a strong ongoing collaboration between KIT and LENS that has already led to several key publications in the field of nano photonics in Nature and PRL. For more information see also the group pages: http://www.complexphotonics.org/ and http://www.aph.kit.edu/wegener/ag/wegener/index.en.html

14. Photonic quasicrystals

Involved institutions : LENS (Diederik Wiersma), Institut Fresnel (Sébastien Guenneau, Stefan Enoch)

Quasicrystals were discovered by D. Shechtman et al., and exhibit unique electronic properties [1]. The key feature of such structures is the existence of more complex ordered structures than the periodic crystal. In this PhD we propose to study their photonic analogue, i.e. photonic quasicrystals and their physical properties. Quasicrystals have been shown to exhibit specific behaviour that could not be observed with periodic structures such as low frequency bandgaps, localized modes etc... [2,3] Quasicrystals have fascinating properties that lie somewhere in between those of ordered systems (crystals) and disordered ones, and are so far largely unexplored. However, singular perturbation analysis allows for an elegant mathematical formulation of the problem, suggesting possible links between quasi-crystals and Anderson localization, at least in the realm of acoustics [4], with light and sound interplay further enhanced via Brillouin scattering due to highly localized phonon eigenstates.

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scattering in photonic quasicrystals with Penrose lattice,” Phys. Rev. Lett. 94, 183903 (2005).

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15. 3D Deflectometric measurement techniques for highly reflecting surfaces

Involved institutions : KIT (Christoph Stiller), UPC (Santiago Royo)

Many surfaces dealt with in industrial production are reflecting. Some examples are windshields, car body panels, various press tools and polished, glazed, varnished or chrome coated objects. To ensure the quality of such surfaces, technical processes are needed to detect defects, control the contour accuracy and measure the three dimensional shape. Since the direct acquisition of a reflecting surface with optical imaging devices is not possible, an indirect approach must be taken. One possible approach is offered by deflectometry, which already occupies a broad field in quality assurance in industrial applications: A computer controlled screen displays a pattern; a camera acquires the image reflected by the surface of interest. The image is distorted by the shape of the reflecting surface - very much like the image of a human is shrunk or elongated by a magic mirror.

While 2D techniques for quality assurance are already well understood[1] and applied in industry, there is only very basic results available for 3 dimensional metrology using deflectometry. The knowledge is only applicable for very specific and limited use cases [2]. This research will deepen the understanding of the challenges for the 3D case and will investigate and advance possible solutions.

References

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