IESL-Science Days

22-24 May 2019

Scientific program and Book of Abstracts

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Scientific program

Day 1: Wednesday 22 May			
08:50-9:00	S.H. Anastasiadis	IESL Director	Opening of IESL-Science Days 2019
Session I: AMO Physics			
Chair: D. Petrosyan			
09:00-09:30 *(25 min+ 5 min)*	P. Tzallas	IESL	Linking quantum optics with strong-field laser physics
09:30-10:00 *(25 min+ 5 min)*	S. Tzortzakis	UoC/IESL	Molded ultrashort laser filaments and applications
10:00-10:30 *(25 min+ 5 min)*	P. Samartzis	IESL	Chemical reaction dynamics probed with photons and electrons
10:30-10:50	Coffee break		
Chair: P. Samartzis			
10:50-11:20 *(25 min+ 5 min)*	T. P. Rakitzis	UoC/IESL	Polarization spectroscopy: Cavity-based polarimetries, and production of spin-polarized atoms and molecules
11:20-11:50 *(25 min+ 5 min)*	W. von Klitzing	IESL	Hypersonic Transport of Bose-Einstein Condensates in a Neutral-Atom Accelerator Ring
11:50-12:20 *(25 min+ 5 min)*	D. Petrosyan	IESL	Quantum Gates and Simulations with Strongly Interacting Rydberg Atoms
12:20-13:20	Lunch		
Session II: Photon Science applications			
Chair: W. von Klitzing			
13:20-13:50 *(25 min+ 5 min)*	S. Pissadakis	IESL	Optical Fiber Devices into New Paths
13:50-14:20 *(25 min+ 5 min)*	P. Loukakos	IESL	Ultrafast time-resolved laser spectroscopy in condensed matter: Applications and prospects
14:20-14:50 *(25 min+ 5 min)*	P. Pouli	IESL	Current research and future prospects of laser ablation in Heritage Science
14:50-15:10	Coffee break		
Chair: S. Pissadakis			
15:10-15:40 *(25 min+ 5 min)*	G. Zacharakis	IESL	Novel biophotonics for imaging through complex biological systems
15:40-16:10 *(25 min+ 5 min)*	G. Filippidis	IESL	Non-linear imaging microscopy for biological applications
16:10-16:40 *(25 min+ 5 min)*	A. Mitraki (Material Science)	UoC/IESL	Amyloid Designable Peptide Materials and Their Use as Scaffolds for Biomedical and Environmental Applications
16:40-17:10 *(25 min+ 5 min)*	M. Farsari	IESL	Multiphoton Lithography: Principles, Materials and Applications
17:10-17:30	Coffee break		
Chair: S. H. Anastasiadis			
17:30-18:00 *(25 min+ 5 min)*	Κ. Φωτάκης	Αν. Υπουργός Έρευνας και Καινοτομίας	Η επιστημονική Έρευνα στην Ελλάδα: Ευκαιρίες, Προκλήσεις και Προοπτικές

Day 2: Thursday 23 May			
Session III: Micro-nano electronics			
Chair: P. Loukakos			
09:30-10:00 *(25 min+ 5 min)*	N. T. Pelekanos	UoC/IESL	Nanophotonic Semiconductor Devices
10:00-10:30 *(25 min+ 5 min)*	G. Deligiorgis	IESL	Graphene, CNT and 2D material based electronics, past present future?
10:30-10:50	Coffee break		
Chair: G. Deligiorgis			
10:50-11:20 *(25 min+ 5 min)*	P. Savvidis	UoC/IESL	Polariton Condensate Lattices: A Novel Quantum Simulator Platform
11:20-11:50 *(25 min+ 5 min)*	L. Iliopoulos	UoC/IESL	Indium Gallium Nitride (InGaN) alloys in the entire composition range: MBE epitaxy kinetics and effects on optoelectronic properties
11:50-12:20 *(25 min+ 5 min)*	G. Kiriakidis	UoC/IESL	Exploiting novel photocatalytic materials for indoor air quality control
12:20-13:30	Lunch		
Session IV: Materials Science			
Chair: G. Zacharakis			
13:30-14:00 *(25 min+ 5 min)*	G. Tsironis	UoC/IESL	Machine learning for complex systems
14:00-14:30 *(25 min+ 5 min)*	G. Kopidakis	UoC/IESL	Quantum theory of materials: from structure-property relationships to materials design
14:30-14:50	Coffee break		
Chair: M. Farsari			
14:50-15:20 *(25 min+ 5 min)*	S.H. Anastasiadis	IESL Director	Designing Materials at the Macromolecular Level: Towards High Performance Solid Polymer Electrolytes for Energy Storage
15:20-15:50 *(25 min+ 5 min)*	L. Benoit	IESL	Soft matter probed and manipulated by optical means
15:50-16:10	Coffee break		
16:10-16:40 *(25 min+ 5 min)*	M. Vamvakaki	UoC/IESL	Functional and Stimuli-Responsive “Smart” Polymers
16:40-17:10 *(25 min+ 5 min)*	K. Chrissopoulou	IESL	Structure and Dynamics in Polymer Nanohybrids
17:10-17:40 *(25 min+ 5 min)*	M. Kafesaki	UoC/IESL	Metamaterials for advanced electromagnetic wave control

Day 3: Friday 24 May			
Session V: Special event			
Chair: S.H. Anastasiadis			
11:30-12:15	G. Konstantinidis	Alternate Director of IESL	Honoring a lifetime commitment towards the scientific excellence of IESL
12:15-13:30	Lunch		
Session VI: Current status and future perspectives of IESL			
13:30-13:50 *(15 min+ 5 min)*	S.H. Anastasiadis	IESL Director	Current status of IESL
13:50-14:00	Coffee break		
14:00-14:50 *(45 min+ 5 min)*	D. Charalambidis	UoC/IESL	AMO physics
14:50-15:10	Coffee break		
15:10-16:00 *(45 min+ 5 min)*	N. Kylafis	UoC/IESL	Astrophysics
16:00-16:20	Coffee break		
16:20-17:10 *(45 min+ 5 min)*	E.N. Economou	UoC/IESL	Solid state physics
17:10-17:15	P. Tzallas	IESL	Closing remarks

Book of Abstracts

AMO Physics

Attosecond Science

Activity members			
Scientific Staff (alphabetic order)	**Research Associates**	**Students (PhD/M.Sc)**	**Technical Staff**
Prof. D. Charalambidis (University Faculty Member)	**Dr. E. Skantzakis** (PostDoctoral Fellow)	**Mr. S. Chatziathanasiou** (Ph.D. student)	**Dr. N. Papadakis** (Technician Scientist)
Dr. C. Kalpouzos (Senior application Scientist)	**Dr. I. Liontos** (PostDoctoral Fellow)	**Mr. I. Makos** (Ph.D. student)	
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Linking quantum optics with strong-field laser physics

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Abstract
Strong laser-field physics and quantum-optics, are two disjoined major research areas founded on the classical and quantum description of the electromagnetic radiation, respectively.

In strong-field physics, the interaction of matter with strong laser pulses led to the generation of high-harmonics in the extreme-ultraviolet (XUV) spectral range, and opened the way for studies in Attosecond Science. Nowadays, the understanding of the electrodynamics induced in matter by strong electromagnetic fields, is based on semi-classical approaches. Although these approaches have been used in multidisciplinary research directions in ultrafast optoelectronics they do not provide any access in the quantum optical nature of the interaction as they treat the driving-field classically and unaffected by the interaction.

On the other hand, in quantum-optics, the quantization of the electromagnetic field led to fascinating achievements in the field of Quantum Technology with the non-classical light sources having an essential role on these directions. Most of these investigations have been performed using weak electromagnetic fields where the interaction can be described by fully quantized theories allowing the field to be affected by the interaction.

Here, I will present the synthesis these two distinct modern research domains namely Quantum Technology and Attosecond Science. Specifically, I will describe how the strong-field laser-matter interaction can lead to the generation of non-classical light-states which carry the information of the ultrafast dynamics of the interaction [1-3]. Utilizing a novel detection method named "quantum spectrometer", these light states have been used to recover the high-harmonic spectrum generated in gases and semiconductor materials, and reveal information which is inaccessible by conventional approaches.

References
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Multi-XUV-photon multiple ionization processes with laser driven harmonic/attosecond sources at the atto-S&T lab

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Abstract

The research at the Attosecond Science & Technology Laboratory (atto -S&T lab) of IESL focuses since one and half decades on the development of energetic high order harmonic generation (HHG) / attosecond sources, their exploitation in the study of non-linear (NL) processes in the XUV spectral region and eventually the study of ultra-fast dynamics measured utilizing these NL processes. Back in the early 2000, due to the lack of intense enough laser sources at IESL, experiments were performed in the frame of collaborative campaigns at MPQ in Garching where the necessary technologies where available. During these years the first two-XUV-photon ionization of atoms by a high harmonic comp produced in a gas jet (Gas-HHG) was achieved [1] and eventually exploited in the implementation of the first 2nd order autocorrelation measurement of an attosecond pulse train [2, 3]. Collaborative research at MPQ further includes work of laser surface plasma harmonic generation [4]. Since the first upgrade of our laboratory at IESL the research is performed to its largest extend here. Projects include the development of techniques and instrumentation for the generation of intense XUV continua [5] and their exploitation in the first XUV-pump-XUV-probe experiments in atoms [6] and molecules [7] as well as the generation of ellipticity controlled harmonics [8].

Recently, thanks to two multi-MEuro grants obtained by the group a large scale upgrade of the lab has been implemented, involving new lab space, a new laser system and energetic attosecond beamlines. A notable achievement realized in this new lab is the development of a 20GW attosecond source. The Gas-HHG source emits attosecond pulse trains with a total train energy of ~200 μJ in the spectral region 15-35 eV and pulse duration of ~500 asec. Focusing this radiation to intensities ~10^{16} W/cm^2 we have achieved in demonstrating multi-XUV-photon multiple ionization in Argon producing charge states up to Ar^{4+} that involves 5 XUV photon absorption [9]. The XUV intensity dependence of the ion yields and its comparison with rate equation numerical calculations has revealed the dominant ionization channels. The results of this work have been compared with those of a similar experiment conducted in a Free Electron Laser (FEL) facility and differences are discussed in the frame of the different coherence properties of the two sources and the dependence of the multiphoton ionization probability on these coherence properties [10-12].

An important consequence of the achievements of the group is the attraction of substantial funding through EU projects and R&D contracts. The largest part of the funding relates to Research Infrastructures, National and European, such as the Extreme Light Infrastructure (ELI) of the ESFRI to which the laboratory contributes since its very birth.

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Ultrashort Non-linear Interactions and Sources

Activity members			
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Molded ultrashort laser filaments and applications

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Abstract

We review recent research highlights from the Ultrashort Nonlinear Interactions and Sources (UNIS) group of IESL-FORTH. We demonstrate how molded in space and time ultrashort laser filaments in the near and mid-infrared can enable breakthrough applications in photonic materials and extreme THz science.

The nonlinear propagation of ultrashort laser pulses in the form of solitons, filaments and light bullets is an exciting research field [1]. Beyond the basic studies on the complex spatio-temporal phenomena involved, the field is driven significantly by its numerous applications, like for example in materials engineering, remote spectroscopy [2], but also for their use as powerful secondary sources across the electromagnetic spectrum [3].

Here we discuss our recent advances in molding the shape, temporal and spectral properties of filaments [4] and some corresponding applications enabled through these advances. We demonstrate how it becomes possible, for the first time after 20 years of research, to achieve localized and controlled modification of the index of refraction in the bulk of silicon [5]. This advance opens the way for laser processing in the exciting field of silicon photonics.

We also discuss our recent advances in developing intense THz secondary sources using tailored laser filaments. We demonstrate that one may obtain powerful THz radiation using unconventional media, like liquids, where the medium presents strong linear absorption [6]. The mechanism responsible for this counterintuitive result is a phase locked second harmonic component in the filament that results in strong transient electron currents that radiate intense THz fields. Finally, we will also be discussing the way in achieving extreme THz electric and magnetic fields, in excess of GV/cm and kT strengths respectively, using intense two-color mid-infrared filaments [7-9].

References

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Polarization spectroscopy

Activity members			
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Polarization spectroscopy: Cavity-based polarimetries, and production of spin-polarized atoms and molecules

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Abstract

We discuss our progress in the development of ultrasensitive and fast cavity-based polarimeters and ellipsometers [1,2], and describe potential commercial applications and new directions of research, including the measurement of parity violation in new atomic and molecular systems, and aiming towards the measurement of the chirality of a single molecule.

We also describe the recent production of ultrahigh pulsed densities of spin-polarized H (SPH) and D (SPD) atoms, up to at least 10^{20} cm^{-3}, which is about 8 orders of magnitude higher than continuous production methods (such a Stern-Gerlach spin separation). We produce the dense SPH/SPD from the photodissociation of hydrogen halides with circularly polarized light, and detect the spin polarization through magnetization quantum beats using a pickup coil. This new regime of ultrahigh SPH/SPD density opens the possibility for three novel applications: (a) laser-driven ion acceleration of spin-polarized electrons or protons [5], (b) the preparation of nuclear-spin-polarized molecules, and (c) the demonstration of spin-polarized D-T or D-^{3}He laser fusion at large laser facilities such as NIF, for which a reactivity enhancement of 50% is expected [3,4].

References

[1] D. Sofikitis *et al.*, *Nature* **514**, 76 (2014).
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[5] Anna Hützen *et al.*, *High Power Laser Science and Engineering* (in press), https://arxiv.org/abs/1810.02247

BEC and Matter waves

Activity members			
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		Mr. Mas Hector (Ph.D. student)	
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Hypersonic Transport of Bose-Einstein Condensates in a Neutral-Atom Accelerator Ring

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Abstract

Some of the most sensitive and precise measurements to date are based on matterwave interferometry using freely falling atoms. Examples include ultra-high-precision measurements of inertia, gravity and rotation sensing. Unfortunately, interaction time has to be very long in order to achieve very high sensitivities, resulting in interferometers often ten or even one hundred meters. Coherent matterwave guides make possible highly compact devices having much extended interaction times and thus much increased sensitivity.

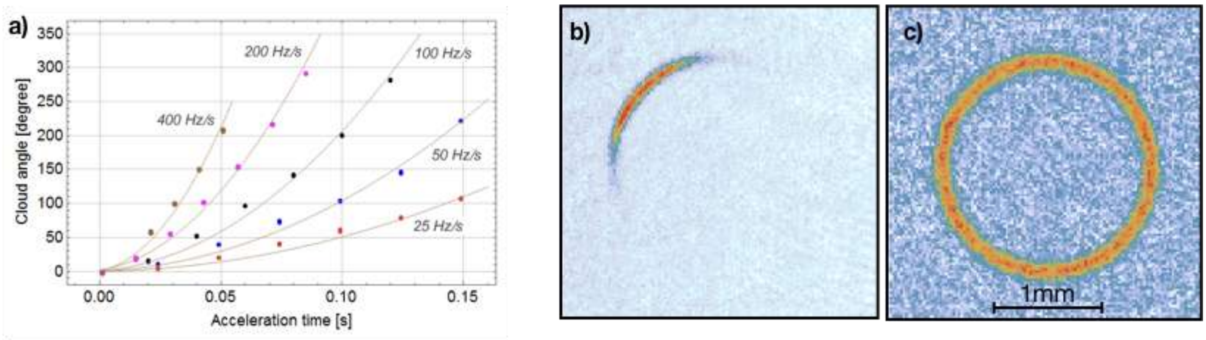

Fig. 1. a) Accelerations of BECs using optimal control theory. b) A BEC traveling in a TAAP waveguide @ 16x its velocity of sound. c) BEC filling a TAAP ring trap.

Here, we demonstrate for the first time *extremely smooth, coherence-preserving matterwave guides* based on time-averaged adiabatic potentials (TAAP). We do so by guiding Bose-Einstein condensates (BEC) over macroscopic distances without affecting their internal coherence: We use a *novel magnetic accelerator ring* to accelerate BECs to more than *16x their velocity of sound*. We transport the BECs in the TAAP over truly macroscopic distances *(15 cm)* whilst preserving their internal coherence. The BECs can also be released into the waveguide (Fig.1c) with barriers *controllable down to 200 pK* giving rise to new regimes of tunnelling and transport through mesoscopic channels. Coherent matterwave guides will result in much longer measurement times (here > 4 s) and much increased sensitivity in highly compact devices. This will raise the spectre of compact, portable guided-atom interferometers for fundamental experiments and applications like gravity mapping or navigation.

References

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Chemical Dynamics

Activity members			
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Prof. T. Kitsopoulos (University Faculty Member)			

Chemical reaction dynamics probed with photons and electrons

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Abstract
The field of Chemical Dynamics investigates the forces/potentials that govern the course of chemical reactions and determine reaction products. In the past decades, the combination of experiment and theory has advanced our understanding of elementary reaction mechanisms (such as the photolysis mechanisms of diatomic and small polyatomic molecules) down to the quantum detail level for low reaction/excitation energies. The challenge in the field today is to expand this detailed understanding to more complex systems and to higher reaction/excitation energies.

In this contribution we will present recent experimental work in different areas of Chemical Dynamics. Probing the photodissociation dynamics of highly excited states (near the ionization limit) for benchmark molecular systems (e.g. HBr, CH_3Br [1], CH_3I), we found that the interactions between different kinds of states in this energy range (Rydberg, ion-pair and ion valence states) differ not only from molecule to molecule but also from quantum state to quantum state, activating different reaction pathways and producing different reaction products. In a separate line of work, we probed photoelectron angular distributions exciting chiral molecules (e.g. fenchone, limonene) with right and left circularly polarized light and showed for the first time that the PECD phenomenon [2] (differing photoelectron angular distributions of two enantiomers) can be observed using nanosecond instead of femtosecond laser excitation. Finally we will report on the progress of an Ultrafast/Time-Resolved Electron Diffraction activity, aiming to investigate structural dynamics of gas and solid state systems.

References
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Theoretical Quantum optics and Technology

Activity members			
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Quantum Gates and Simulations with Strongly Interacting Rydberg Atoms

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Abstract
A critical ingredient to realize functional devices for quantum computing and analog and digital quantum simulations is the availability of controllable interactions between the physical systems representing quantum bits - qubits. Atoms in high-lying Rydberg states exhibit many remarkable features, including long lifetimes and giant polarizability [1]. The resulting strong, long-range interactions between the Rydberg-state atoms can be turned on and off by the excitation and de-excitation lasers. Such systems can implement high-fidelity logic gates for digital quantum information processing [2]. Moreover, arrays of Rydberg atoms are uniquely suited for realizing spin-lattice models for quantum simulations of few- and many-body physics on a lattice [3-5].

In this presentation, after a brief outline of the Rydberg atom physics and recent achievements in the field, I will discuss some of our resent work on quantum gates and simulations of few- and many-body physics with laser controlled atoms.

References
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Photon Science Applications

Photonic Material and Devices

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Optical Fiber Devices into New Paths

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Abstract
During the last decade, Photonics have undergone an extreme growth, opening new scientific horizons while conquering new markets and application fields. The domain of Optical Fibre Devices has enjoyed this growth, being the backbone for optical communications, high power lasers, and sensors. Especially for the domain of Optical Fiber Sensors, future advances rely on the demonstration of devices implementing smart materials and versatile guiding platforms for attaining novel functionalities, while targeting numerous applications in a “disruptive” approach. Different optical designs, processing and material science technologies, fuse together for constituting the “Lab-in-a-Fiber” concept, where benchtop operations are now scaled down and implemented into the robust optical fibre geometry [1-8].

The photonic devices/technologies which will be presented, refer to configurations realised in standard, tapered and microstructured optical fibres, whereas their development blends diverse photonic, processing and material technologies, demonstrating operational characteristics beyond the current state-of-the-art. The final part of the presentation will be focused in radically new approaches in the development of optical fiber photonic devices, with groundbreaking light routing and operational characteristics and functionalities, exploiting the know-how already existing in FORTH.

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Nonlinear Lithography

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Multiphoton Lithography: Principles, Materials and Applications

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Abstract
Multiphoton Lithography is a technique that allows the fabrication of three-dimensional structures with sub-100 nm resolution. [1] It is based on multi-photon absorption; when the beam of an ultrafast laser is tightly focused into the volume of a transparent, photosensitive material, polymerization can be initiated by non-linear absorption within the focal volume. By moving the laser focus three-dimensionally through the material, 3D structures can be fabricated. The technique has been implemented with a variety of materials and several components have been fabricated such as mechanical meta-materials (Fig. 1a), [2] and biomedical implants (Fig. 1b). The unique capability of Multiphoton Lithography lies in that it allows the fabrication of computer designed, fully functional 3D devices. In this talk, we summarize the principles of micro-fabrication, and present our recent research in materials processing and functionalization of 3D structures. Finally, we discuss the future applications and prospects for the technology.

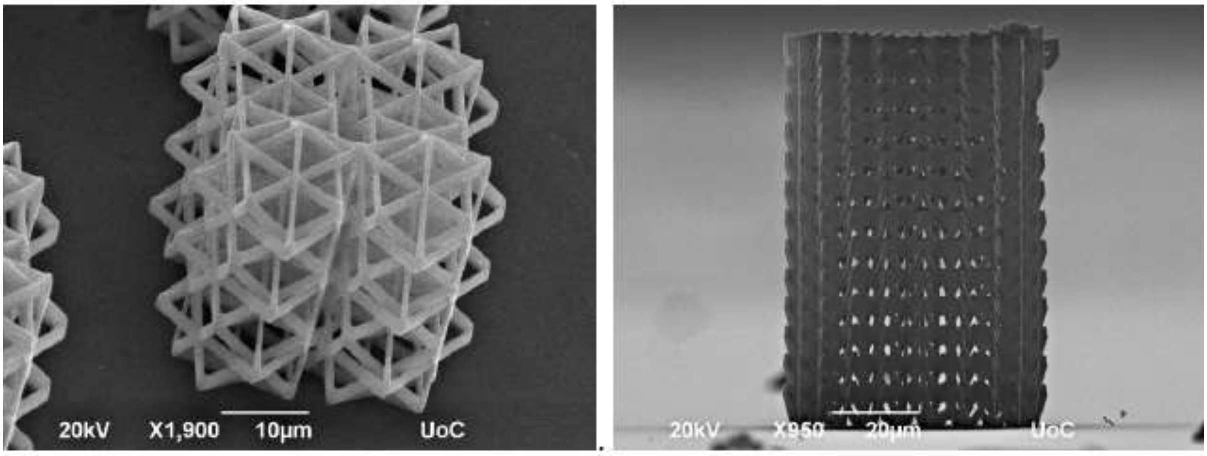

Fig. 1: A mechanical metamaterial (a), and an auxetic stent (b)

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Diagnostic Methodologies and Instrumentation

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Ultrafast time-resolved laser spectroscopy in condensed matter: Applications and prospects

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Abstract
The macroscopic properties of solids and generally condensed phase materials are imposed by the fundamental excitations in the microcosmos and the concomitant relaxation mechanisms. These dictate the interplay and interactions between the various degrees of freedom, be it electronic, phononic, magnetic, vibronic, rotations, etc. A great part of these interactions occurs in timescales well exceeding the temporal resolution of the fastest commercially available electronic devices. This time-window gap makes time-resolved laser spectroscopy an invaluable tool for the study of very fast processes which occur in matter following excitation.

In this talk I will present an overview of recent experiments and results spanning an extended range of materials and processes from hard solids and surfaces including metals, semiconductors and insulators to softer matter including enzymes and proteins. These results show the capabilities and the versatility of the employed method and reveal the potential for collaborative research addressing a broad range of materials and the pertinent light-matter interactions and processes.

Photonics for Heritage Science

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Current research and future prospects of laser ablation in Heritage Science

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Abstract
Within the past three decades laser ablation has been established as a high resolution and reliable cleaning technique which enables conservators to effectively remove unwanted material from Cultural Heritage (CH) objects and monuments. Applications involve a wide range of materials including sculptures and objects made of stone, wood and metals, easel and wall paintings, books and parchment, as well as multi-composite CH objects comprising from materials with diverse properties (i.e. removal of tarnish from historic ultrathin gilded silver threads with silk core). Highlights of this activity are the removal of pollution accumulations from the Athenian Acropolis Sculptures using a prototype laser system developed at FORTH [1] and lately the initiation of a bilateral collaboration between IESL-FORTH and the conservation department of the Palace Museum in Beijing, China with the aim to organize a laser technology joint laboratory on CH.

Among the priorities of this research is the investigation of means and techniques to monitor and control the cleaning intervention and in this respect photoacoustic imaging has been recently considered. The photoacoustic signal, being able to overcome limitations of light, enables the assessment of the treated surfaces with high detection sensitivity and spatial resolution and thus its potential for elucidating the ablation processes and for in-situ and real-time monitoring of the laser cleaning interventions is being investigated with encouraging results [2].

In parallel, the implementation of laser technology to other challenges in Heritage Conservation is examined. Research efforts have been focused to the restoration of cracks and other pathologies found on the surface of glazed ceramics on the principle of laser-induced local and controlled melting of the glaze material. The outcome of this research has direct application to a wide range of objects, including the UNESCO listed Azulejo tiles of Portugal and fine porcelains of Dutch, British and Chinese origin [3] and opens a new era in the field.

Other actions of the group, implemented through its participation to a number of EU and national projects, involve the development and upgrade of methodologies and synthetic approaches for the wide-scale implementation of the laser analytical and cleaning stations and portable instruments with the aim to establish its role within the National and EU Research Infrastructure in Heritage Science (E-RIHS). Towards this end systematic efforts target the improvement of portability, accessibility, use and data handling, as well as its active outreach to user communities through training activities.

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Biophotonics

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Novel biophotonics for imaging through complex biological systems

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Abstract
Modern advances in photonic technologies and their applications in biomedical research and clinical practice have raised immense interest in the scientific community, offering new avenues for exploration of biological function, detection and treatment of disease in living organisms and systems. It is indeed only recently that the Nobel Prize was awarded for the invention of Nanoscopy enabling us to observe and quantify biology with resolutions down to the nanometer scale [1]. For imaging larger samples methods that provide three dimensional microscopic images such as Optical Projection Tomography (OPT) and Light Sheet Fluorescence Microcopy (LSFM) [2] have been widely used. Furthermore, advances in optoacoustic imaging have allowed to image in so far non-accessible regimes with unprecedented resolutions, based on the use of light for the production of ultrasonic waves [3]. However, the use of photonic technologies still comes with significant disadvantages associated with the diffusive transport of light in biological tissue. Radically new technologies are being developed for the production, manipulation and delivery of light radiation, based on adaptive wavefront control to compensate for light diffusion and obtain high resolution images deeper than a few micrometers [4, 5].

These very exciting discoveries and advances in biophotonic technologies have now starting to revolutionize the way biological research is performed. The ability to perform *in vivo* imaging in scales ranging from microscopy to macroscopy at depths from a few micrometers to several centimeters opens up the possibility to shift biological observation towards longitudinal noninvasive studies of dynamic phenomena inside whole animals and help understand better human development, function and disease.

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Non-linear imaging microscopy for biological applications

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Abstract
Non-linear microscopy techniques are at the forefront of biomedical research over the last decade. These non destructive modalities offer improved resolution, high contrast images with increased penetration depth and complementary information while minimizing phototoxicity and photodamage effects on the biological samples. These properties characterize them as perfect imaging tools for revealing valuable and unique information of the specimen under investigation. These techniques are not limited to visualization since they also permit precise quantitative analysis and testing of specific mechanisms and biological processes. In this talk, the imaging modalities of MPEF, SHG and THG will be presented as novel diagnostic tools for the *in vivo* sub-cellular investigation of complex biological activities and the extraction of structural and morphological information from various samples (cancer cell lines [1], mouse embryos [2], *Caenorhabditis elegans* [3,4], BV-2 microglia cells [5] and T cells [6]). Moreover, the main future targets of the non-linear microscopy (NLM) group will be discussed.

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Micro-Nano Electronics

Semiconductor hetero/nano-structures and quantum technologies

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Indium Gallium Nitride (InGaN) alloys in the entire composition range: MBE epitaxy kinetics and effects on optoelectronic properties

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Abstract

$In_xGa_{1-x}N$ materials are an important alloy system since their fundamental band gap can be tuned from the near infrared region of InN to the near UV region of GaN. Epitaxial growth of high quality InGaN alloy thin films and heterostructures with compositions spanning the entire composition range is essential for contemporary and future device applications. Plasma assisted molecular beam epitaxy is particular suited for mid- and high InN mole fraction alloys growth due to its high indium incorporation efficiency and metastable growth mode. However, inherent material challenges, such as alloy immiscibility and large lattice mismatch, as well as the largely different growth conditions of the alloy system endpoints complicate epitaxy, especially when the entire composition range need to be addressed.

We will report on the fundamental kinetic growth mechanisms, namely indium desorption and InGaN decomposition and their dependence on growth temperature and surface stoichiometry. In depth quantitative understanding of the basic kinetic mechanisms leads to the derivation of a universal phenomenological model that consistently describes the InGaN alloys' epitaxy in the entire growth parameter space. This permits accurate composition control, as well as, independent tuning of the growth mode characteristics. Regarding the latter, we will present its important consequences on the epilayers' structural, electronic and optical properties. Emphasis will be given to conditions leading to high quality non-clustered thick films growth on GaN(0001) in the entire composition range.

Finally, we will report on the dependence of alloy compositional fluctuations on epitaxial growth conditions. Tuning the "non-equilibrium" character of RF-MBE epitaxy has a dramatic effect on suppressing compositional non-uniformities leading to reduced localization energies, lower PL thermal quenching activation energies and suppression of band-tail absorption. The correlation between growth conditions and optical properties could pave the way to the on demand growth of InGaN-based optoelectronic devices depending on application requirements.

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Nanophotonics

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Nanophotonic Semiconductor Devices

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Abstract
We will present an overview of our recent and ongoing activities, regarding novel nanophotonic semiconductor devices, including robust polaritonic devices operating at room temperature, tunable single photon emitters operating at elevated temperatures and semiconductor nanowire-based solar cells.

Polariton Condensate Lattices: A Novel Quantum Simulator Platform

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Abstract

Exciton-polaritons, are mixed light-matter quasiparticles resulting from the strong coupling of photons confined in a microcavity and quantum well excitons. Being bosons, polaritons can condense into macroscopically coherent many-body state and have thus emerged as prime candidates for the study of non-equilibrium systems of interacting bosons. Our recent studies, exploit non-equilibrium nature of polariton condensates, showing that polariton condensates can spontaneously magnetize [1], and how their spin can be controlled both optically and electrically [2]. Direct coupling of polaritons to leaking microcavity photons provides on-the-fly information of all characteristics of the polariton condensates such as energy, momentum, spin, and their phase.

We employ spatially patterned external laser excitation to create arbitrary potential landscapes for polaritons and demonstrate ferromagnetic and antiferromagnetic coupling between neighbouring condensates [3]. Furthermore, using such techniques, polariton condensates can now be imprinted into arbitrary two dimensional lattices with tunable inter-site interactions [4] providing exciting opportunities for devising novel and versatile quantum simulation platforms.

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Carbon and 2D electronics

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Graphene, CNT and 2D material based electronics, past present future?

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Abstract
Graphene has been around for 15 years, Carbon nanotubes since the 90's and other two dimensional materials have been investigated for a decade. Was this time enough to materialize electronics based on those systems? Does Physics allow us to have a 2D based electronic platform or is there a fundamental flaw in such a quest? Is the initial promise for beyond Silicon electronics taking shape or is there – still – nothing that can replace conventional electronics?

We will review past work on the field of 2D and CNT electronics, material and device fabrication aspects and then discuss our current understanding of the technology and device fabrication. We will also critically compare the existing Silicon and conventional semiconductor technology to what is attainable today using 2D and CNT materials.

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Transparent Conductive materials and devices

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Exploiting novel photocatalytic materials for indoor air quality control

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Abstract
Buildings are intended to provide protection to the occupants from atmospheric conditions and support their activities. Since buildings are major capital investments the prospect of the occupants experiencing the adverse health effects of air quality and/or poor thermal comfort conditions strongly contradict the aforementioned basic building's function. Especially in the case of large scale structures which host large number of occupants like office buildings or schools, several studies link indoor environmental quality (IEQ) not only to human health problems, but also to decreasing productivity. This highlights indoor climate (air quality and comfort temperature) as essential qualities these buildings must feature.

In the past decades a large number of studies have identified the presence of many polluting chemical substances in indoor environments (buildings, homes).The solution to this problem is expected by a systematic and effective way to improved indoor environment quality utilizing one the one hand Photo-Catalytic (PC) oxidation and on the other smart window coating i.e. by chromogenic material coatings, technique generally accepted as an effective way to tackle the pollutant emission problem and comfort levels for indoors .

An overview and recent advances on the synthesis and characterization of TiO2 materials doped with transition metals in different concentrations capable to absorb and activate under visible light irradiation will be presented including a report on novel PC materials as effective pollutant reducing agent, harmless to humans and suitable for indoor besides outdoor applications. The crystal structure, particle size, morphology, and porosity along with surface morphology and elemental analysis of the materials are presented and photocatalytic efficiencies are reported both for material in powder form as well as additives in a number of building envelope material matrices.

Utilization of the novel material into large scale applications and recent exploitation plans will be discussed.

Materials Science

Polymer and Colloid science

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Soft matter probed and manipulated by optical means

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Abstract
Optical techniques provide means to characterize and manipulate soft matter. Two examples are presented. The presence of a hard boundary and interactions with complex fluids may lead to local interfacial effects. In the case of flow the velocity profile is often affected by the presence and the type of boundary. Total internal reflection and its evanescent wave provide a mean to probe the dynamics within microns of the interface. We here show how the dynamic light scattering can be implemented and used to probe broad range of fluids near wall velocimetry. When submitted to laser irradiation simple polydienes solutions show an unexpected response leading to the formation of pattern. They provide spectacular examples of selfwritten waveguides, at the cross road of polymer solutions physics and nonlinear optics. We describe the main phenomenology of the response and discuss possibilities as to the origin of the response.

Hybrid nanostructures

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Functional and Stimuli-Responsive "Smart" Polymers

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Abstract
Functional and stimuli-responsive polymers represent one of the most exciting and emerging areas of scientific interest in soft matter [1]. During the last decades, scientists have been trying to mimic nature in designing "smart" synthetic materials, from functional molecular building blocks, for use in sensors, logic operations, biomedicine, tissue engineering, synthetic muscles, "smart" optical/electromechanical systems, membranes, electronics and "smart" surfaces [2]. Herein our recent developments in this field [3,4] are presented. In the first part, I will discuss the development of versatile, multi-functional polymer surfaces exhibiting controllable antimicrobial properties. Two types of polymeric surfaces were developed (i) antifouling-bactericidal mixed polymer brushes by surface-initiated atom transfer radical polymerization [5] and (ii) self-polishing-bactericidal films from diblock copolymers comprising a hydrophobic/hydrolysable block and a hydrophilic, cationic block synthesized by group transfer polymerization [6]. These surfaces lead to a long-lasting antimicrobial activity and address current limitations in antibacterial/bactericidal surfaces which become inactive when covered by dead bacteria. In the second part, our contributions to photo-sensitive materials will be described. The unpresented light-induced formation and disruption of responsive hollow polymer capsules from hybrid core-shell particles and the synergistic response of diblock copolymers, which resulted in structural reorganization and hierarchical self-assembly into complex structures in the micro- and milli-scale, was reported [7]. Novel photodegradable polyacetals undergoing main chain scission upon light irradiation at very low energies, in the absence of free radical intermediates, to produce non-toxic, low molecular weight by-products, was reported for the first time [8].

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Structure and Dynamics in Polymer Nanohybrids

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Abstract

Polymer materials are often filled with inorganics to improve their properties. The cases in which the additive exist in the form of a fine nm-sized dispersion within the polymer, thus producing a *nanocomposite*, allow the investigation of basic scientific problems. At the same time, the behavior of polymers restricted in space or close to surfaces can be very different from that in the bulk.

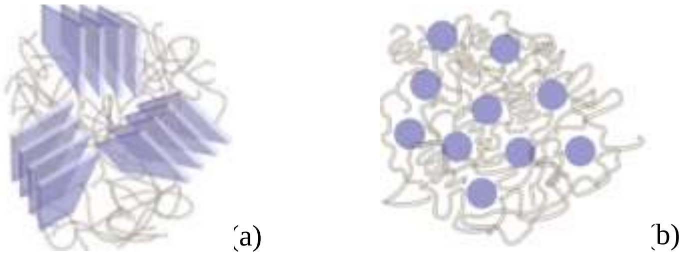

Fig. 1: Schematic representation of polymer nanohybrids with (a) layered silicates and (b) silica nanoparticles

The structure, morphology, chain conformations and thermal properties of hydrophilic polymers in nanohybrids containing either layered silicates or silica nanoparticles is investigated. Mixing polymers with layered silicates can lead to intercalated hybrids when the interactions between the constituents are appropriate; these can serve as model systems for the investigation of the static and dynamic properties of macromolecules in nano-confinement. On the other hand, using silica particles or mixtures of silica particles of largely different sizes provides the opportunity to vary the confining length. Confinement is shown to modify the polymer structure, e.g., its crystallinity and chain conformations [1], with the effect being qualitatively different for different types of confinement [2]. Moreover, polymer dynamics close to surfaces or when chains are restricted in space can be very different from that in the bulk. The confined polymer dynamics is probed utilizing polymers with different hydrophillicity, functional groups and/or different architectures to investigate the influence of the interactions between the constituents and the geometry and size of the additive on both the local motion and the segmental relaxation [3].

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Designing Materials at the Macromolecular Level: Towards High Performance Solid Polymer Electrolytes for Energy Storage#

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Abstract
Solid polymer electrolytes (SPEs) hold the promise to solve most of the problems of conventional liquid electrolytes to be utilized in lithium batteries since they are inherently safe, nonflammable and compatible with lithium metal anodes. The primary challenge, however, is the development of materials with enhanced mechanical modulus without sacrificing ionic-conductivity. We introduce the use of polymer nanostructured nanoparticles, composed of high functionality star polymers, as additives to liquid electrolytes for the synthesis of SPEs that exhibit a combination of high modulus and ionic conductivity. We discuss two different cases of multi-arm nanoparticles. In the first, high functionality PMMA stars are dispersed within low molecular weight PEO, doped with bis(trifluoromethane) sulfonimide (LiTFSI); the SPEs exhibit two orders of magnitude higher conductivity and one order of magnitude higher mechanical strength compared to their linear PMMA blend analogues [1]. This is due to the formation of a highly interconnected network of pure liquid electrolyte that leads to high ionic conductivity. In the second, mikto-arm star copolymers are introduced in which stiff insulating PS arms complement ion conducting PEO arms; SPEs are obtained with a shear modulus of $G' \sim 0.1$ GPa and ion conductivity $\sigma \sim 10^{-4}$ S/cm, very close to the real requirements. This is due to their morphology that stems from the ability of the miktoarm star nanoparticles to self-assembly in highly interconnected structures within the liquid electrolytes host [2]. Because of their molecular design and their colloid-like structure, the materials constitute the first example of all-polymer nanostructured materials where each and every building block is a nano-sized polymeric nanostructured "molecular material".

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Nonlinear and Statistical physics

Activity members			
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Machine learning for complex systems

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Abstract

Chimeras and branching are two archetypical complex phenomena that appear in many physical systems; because of their different intrinsic dynamics, they delineate opposite non-trivial limits in the complexity of wave motion and present severe challenges in predicting chaotic and singular behavior in extended physical systems. We report on the long-term forecasting capability of Long Short-Term Memory (LSTM) and reservoir computing (RC) recurrent neural networks, when they are applied to the spatiotemporal evolution of turbulent chimeras in simulated arrays of coupled superconducting quantum interference devices (SQUIDs) or lasers, and branching in the electronic flow of two-dimensional graphene with random potential. We propose a new method in which we assign one LSTM network to each system node except for "observer" nodes which provide continual "ground truth" measurements as input; we refer to this method as "Observer LSTM" (OLSTM). We demonstrate that even a small number of observers greatly improves the data-driven (model-free) long-term forecasting capability of the LSTM networks and provide the framework for a consistent comparison between the RC and LSTM methods. We find that RC requires smaller training datasets than OLSTMs, but the latter require fewer observers. Both methods are benchmarked against Feed-Forward neural networks (FNNs), also trained to make predictions with observers (OFNNs). Extensions of this method are applied in other dynamical systems.

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Quantum materials theory

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Quantum theory of materials: from structure-property relationships to materials design

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Abstract
The "Quantum Theory of Materials" group aims at the atomic-scale understanding of physical and chemical properties of amorphous, nanostructured and low-dimensional materials, as well as their role and performance in optoelectronics, catalysis, energy applications, and other cutting-edge technologies. To this end, the group develops and uses several theoretical and computational techniques. First-principles electronic structure calculations and atomistic simulations are the main tools for the study of structural, vibrational, mechanical, electronic, and optical properties of these materials. Simple models provide physical insight into complex materials, processes, and nonlinear phenomena. Recent research activities focus on two-dimensional and quasi-one-dimensional nanostructures of graphene and transition metal dichalcogenides [1-3], carbon-based [4] and metallic nanoparticles [5-7].

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Photonic-, Phononic and Meta-materials

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Topological quantization and stability

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Abstract
The familiar microscopic energy quantization stems from the wave aspect of particles. In coherent macroscopic systems the wave character is still exhibited and quantization appears in some physical quantities. Is it possible to have quantization and hence robustness against perturbations in ordinary macroscopic systems? The surprising answer is yes. Starting from the impressive Quantum Hall Effect [1], there is a proliferation of phenomena in solids [1, 2] and in photonics [3] where topological considerations are behind this third unexpected .class of quantizations. These phenomena include the so-called topological insulators [1], the Majorana fermions [1], the Weyl semimetals [4], etc.. In the latter the realization of a modifications of Maxwell equations, the so called axial electrodynamics [5], is expected to appear. I will present a simple explanation of the Quantum Hall Effect and I will refer to the integer values of the Hall conductance in units of e^2/h. I shall also examine some relatively simple models of spin-orbit coupling which allow explicit analytical results in terms of the Berry phase, the Berry connection, and the Berry curvature.

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Meta-materials for advanced electromagnetic wave control

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Abstract

Metamaterials are artificially structured materials with novel and unique electromagnetic properties arising mainly from the shape and distribution of their subwavelength-scale building blocks. Arranging properly those building blocks one can achieve properties such as negative permeability (even in the optical region), negative refractive index, extreme permittivity and permeability values, giant chirality, unusual anisotropy etc. All these properties provide a unique vehicle for the control of electromagnetic waves, and can be exploited in a variety of applications, including imaging, sensing, telecommunications and information processing, etc.

In this talk I will review some of the recent metamaterials-related activities of our group, emphasizing on (a) chiral metamaterials, able to give giant optical activity and negative refractive index in the THz range, (b) metasurfaces (i.e. thin metamaterial layers) with advanced beam steering and forming capabilities [2], (c) metamaterials suitable for perfect absorption and sensing applications [3], and (d) graphene-based metamaterials and metasurfaces [4]. All these metamaterial types have been examined in detail, in most of the cases both theoretically and experimentally, their rich physical response has been analyzed and their great capabilities in applications have been evaluated.

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Astrophysics

The Institute of Astrophysics will be represented by Prof. Nikos Kylafis

Current status and future prospects in Astrophysics in Crete

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Abstract
The Astrophysics Group in Crete has been very fortunate to be under the umbrella and support of FORTH and more specifically IESL. The Skinakas Observatory would not have been built, if it were not for FORTH. I will briefly present past accomplishments of the members of the Group, emphasizing work that has been done at Skinakas, and I will spend most of my time on future prospects in Astrophysics in Crete, using both ground and space observatories. It is amazing what you can do with a small optical telescope on the ground, if you have the right people.