ABSTRACTS
Lectures of Invited Speakers

Fundamental and Applied Metrology Based on Photonics

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It is not frequently noted, but nonetheless true, that our modern technological society is deeply dependent upon precision measurement: it is this capability that has delivered us a deep understanding of the properties of nature as well as exceedingly precise control of those properties. The most accurate and precise measurements have typically been based around photonic techniques. In these lectures I will introduce you to the concepts of precision measurement together with its constant companion: noise. We will then turn to why precise measurement is so frequently based on a measurement of time or frequency, and from there we will consider both some old and new methods for time-keeping and frequency measurement (all based on photonic methods). In particular, we will look at new types of frequency standards based on hollow-core photonic crystal fibres and micro-resonators. In the later lectures we will turn our attention to other sorts of measurements that one can make using photonics: magnetic field intensity, temperature, gravity, energy and length. Throughout the lectures I will attempt to illustrate with both practical and fundamental examples why these types of measurements are useful. We will also address the ultimate limitations to the performance of such devices.

3D optical manipulation of photopolymers

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Inorganic photorefractive materials have been extensively studied in diverse applications due to their ability to efficiently translate optical intensity patterns into index of refraction gradients with ~100nm resolution. Similarly, focused femto-second nonlinear absorption has recently received significant attention as a 3D nanofabrication method for index structures in inorganic glass. In this talk, I will describe how one-photon absorption processes in solid photopolymers held above their glass transition temperature results in complex 3D meso-structured index of refraction with resolution well below 100 nm in cm-thick volumes. This enables large-area index control via mask or holographic lithography as well as local patterning via 3D direct-write lithogrpahy. In the latter technique, demonstrated CW power levels are below 1 microwatt at mm/s write speeds and milliwatts at write speeds of 20 m/s. This combination of high resolution and high throughput has inspired diverse applications of industrial relevance. The materials are inexpensive, easy to fabricate and their properties can be simply modified by selection of monomers, initiators or inhibitors.

The study of this soft-matter/optical interaction requires several new tools. The dynamics of photo-activated polymers are typically studied on cm-scale areas with lamps emitting milliwatts of total power in a broad wavelength band. Conversely, optical intensity, reaction rates and diffusion speeds can change by 10 orders of magnitude or more when a narrowband laser is focused to submicron spot. Particularly in liquid or solid materials above their glass transition temperature, mass-transport of small molecules plays a dominant role in the development process. Thus, an understanding this coupled evolution of nonlinear optical propagation, mass transport and polymer chemistry is critical in harnessing these reactions. I will introduce lithographic tools for creating 3D structures, quantitative microscopy tools for measuring the results and compare these to diffraction/reaction/diffusion models. As an example of how this physics can be exploited to reach new performance regimes, I will describe a two-color, single-photon lithography method which exploits opposing interactions in the polymer to create material structure whose scale is not constrained by the optical diffraction limit.

Transformation Optics

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Two of the most important sets of equations in the whole of Physics are Maxwell's equations for electromagnetism, and Einstein's equations for general relativity. In recent years, inspired by seminal papers of Sir John Pendry and Ulf Leonhardt, workers in the new field of metamaterials have exploited the techniques of general relativity and the new technologies for making microstructured materials to come up with innovative designs for remarkable new photonic devices. This new field is called transformation optics. I will describe how this works, and give an idea of some of its striking outcomes.

Cloaking

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Cloaking is defined to be the hiding of objects from detection by probe waves. In the case of probing by light, this means making objects invisible over a range of wavelengths. Such cloaking is difficult, but many research groups are now using ideas and techniques like those of transformation optics to attempt to achieve this goal. I will review some of the approaches taken for cloaking with light and other types of waves, and describe their results.

Studies of surface reaction mechanisms for renewable and sustainable energy applications

WILL MEDLIN

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Solid catalyst materials are a foundational component of energy-related technologies ranging from fossil fuel refining to production and utilization of renewable and sustainable energy alternatives. The advent of modern high-speed computing and advanced spectroscopic techniques has enabled recent advances in the detailed understanding of the surface reactions that occur on such catalysts, and this in turn has led to the increased ability to design new catalytic materials with improved properties. This series of lectures will introduce basic concepts in heterogeneous catalysis and the study of surface reactions. Important surface-catalyzed processes in traditional fuel refining will be discussed, as will more recent efforts to adapt catalysts for other applications. Common structures of industrially used heterogeneous catalysts will be presented, along with methods of characterizing those catalysts both as to their physical structure and catalytic behavior. We will highlight how model studies--often conducted under ultrahigh vacuum conditions over single-crystal surfaces—can be used to map out reaction pathways and structure-property relations in detail. The "pressure gap" and "materials gap" inherent in comparing such model studies to industrial catalysis, and efforts to bridge these gaps, will also be discussed.

The latter part of the lecture series will focus on modern research in catalysis for applications in renewable and sustainable energy. Catalysts play a vital role in numerous sustainable energy technologies, including biorefining of sugars, manufacture of fuel cells for power applications, and production of fuels using solar energy. The unique challenges associated with developing catalysts for biomass refining, and some possible strategies for developing improved catalysts, will be addressed. Recent advances in electrocatalysis for fuel cell applications will also be discussed, and the relationship of such catalysts to those proposed for use in solar fuel cells will be discussed. Finally, some recent investigations in photocatalysis and photoelectrocatalysis for solar-driven water splitting will be presented. A key focus of these lectures will be emphasizing the connections across these application areas, which are in many ways united by "universal" approaches for designing optimal catalysts.

The ultrafast revolution: How ultrashort optical pulses revolutionized optical metrology

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Lasers producing pulses as short as a few femtoseconds (1 fs = 10^{-15} s) have led to tremendous advances in a large variety of scientific and commercial disciplines. Besides the obvious benefit of unprecedented temporal resolution, the optical spectrum emitted from such ultrafast lasers profoundly changed the way we measure time, distances, and optical frequencies to date. The recent developments in this field have been so substantial that it will likely affect the cornerstones of metrology: the definition of the SI-units, namely the definition of the second and all related units (time, distance, frequency, and possibly also mass, density, and temperature). Ultrashort pulses and optical frequency combs have seeped out from the domain of pure science into commercial applications, such as medical diagnostics, trace gas analysis, or fs-micromachining.

In these four lectures, I will give an introduction to modern femtosecond technology by discussing the fundamentals of ultrashort pulse generation followed by an introduction to optical combs, which are at the heart of this rapid progress. In the second half I will cover some of the ongoing research in the fields of ultrafast physics, AMO physics, and optical metrology.

Optical trapping in anisotropic liquid crystal fluids

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Optical trapping in anisotropic fluids such as liquid crystals shows inherently different behavior compared to that in isotropic media. Anisotropic optical and visco-elastic properties of these materials result in the direction-sensitive and polarization-dependent interaction of the focused laser beam with colloidal inclusions, defects, and structures of long-range molecular order, providing new means of non-contact optical control. Optical trapping properties are further enriched by laser-induced realignment of optical axis that can be observed in these liquid crystalline materials at relatively low trapping laser powers. Optical manipulation of particles and defects in these anisotropic fluids is of immense importance for their fundamental study and from the standpoint of technological applications such as the light-directed colloidal self-assembly and generation of tunable photonic architectures in liquid crystals. This lecture will overview the basic physical mechanisms related to optical trapping in anisotropic liquid crystal fluids and demonstrate how it can be employed in quantitative studies of colloidal interactions and both topological and mechanical properties of defects.

Optical structuring of matter for all-optical applications

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This lecture will introduce the optical realignment effects and then will describe the laser-induced two-dimensional periodic photonic structures formed by localized particle-like excitations in an untwisted confined cholesteric liquid crystal. The particle-like excitations dubbed Torons contain three-dimensional twist of the liquid crystal director matched to the uniform background director field by topological point defects. Using both single-beam-steering and holographic generation approaches, the periodic crystal lattices are tailored by tuning their periodicity, reorienting their crystallographic axes, introducing defects, etc. Moreover, these lattices can be dynamically generated, modified, erased and then recreated, depending on the need of photonic applications. This robust control is performed by tightly-focused laser beams of power 10-100mW and by low-frequency electric fields at voltages ~10V applied to cell electrodes.

Liquid Crystal Microlasers

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1. Introduction: Liquid crystals (LCs) and photonic effect
2. Kinds of LC microlasers: DFB lasers, Defect mode lasers, and DBR lasers
3. Tunability of LC microlasers: Wavelength, Polarization, and Direction
4. Toward cw lasing: Lowering threshold (cavity structure, excitation, dye)

In this lecture I introduce liquid crystal (LC) microlasers particularly using cholesteric LCs (CLCs). For the purpose, the first lecture is devoted to the introduction of LCs and photonic effect. In the second lecture, I summarize three kinds of LC microlasers, i.e., distributed feedback (DFB) lasers, defect mode lasers, and distributed Bragg reflector (DBR) lasers. DFB lasers are the simplest lasers using unperturbed CLC helical structures. By introducing defects such as phase jump, another thin isotropic or anisotropic layers, a defect mode emerges and gives low threshold lasing. If one inserts thick defect layers in between DBRs such as CLCs, many Fabry-Perot cavity modes emerge within the photonic band. I will emphasize Fermi golden rule for lasing emission and optical density of state.

One of the most important features in CLC microlasers is tunability. We can tune lasing wavelength, polarization state, and even directions. For wavelength tuning, external stimuli such as temperature, electric field, light irradiation, and mechanical stress can be used. If we introduce spatial variation of the helical pitch, we can achieve position-dependent wavelength tuning over the whole visible wavelength range. Polarization states such as linear and circular polarizations can be controlled by passing through a field-controlled nematic LC layer. Nonreciprocal lasing and omni-directional lasing are also introduced.

Final goal of LC microlasers is continuous wave (cw) lasing. For the purpose, a variety of effort has been made from viewpoints of cavity structures, excitation methods, and development of dyes. I will summarize such effort.