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Session 8

Lectures:

BLACKBODY RADIATION REVISITED IN THE NEAR FIELD

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The talk will start with a discussion of the properties of equilibrium radiation in the near field of a planar source. We will show that the existence of surface waves yields unexpected spatial and temporal coherence properties. These effects have been observed experimentaly indirectly a few years ago [1,2]. Infrared antennas that emit light in well defined lobes have been demonstrated.

We shall also present very recent results[3] obtained with a new near field optical microscope called Thermal Radiation Scanning Tunnelling Microscopy. We obtain images showing surface plasmons excited thermally in microcavities. These images are the first direct observation of interference fringes due to thermal radiation in the near field. We will discuss their significance in terms of electromagnetic local density of states.

1. « Coherent emission of light by thermal sources » J.J. Greffet, R. Carminati, K. Joulain, J.P. Mulet, S. Mainguy and Y Chen, Nature **416** p 61 (2002)

2. "Highly directional radiation generated by a tungsten thermal source", M. Laroche, F. Marquier, C. Arnold, R. Carminati, J.J. Greffet, S. Collin, N. Bardou, J.L. Pelouard, Opt.Lett. **30**, p 2623 (2005)

3. "Thermal Radiation Scanning Tunnelling Microscopy" Y. De Wilde, F. Formanek, R. Carminati, B. Gralak, P.A. Lemoine, K. Joulain, J.P. Mulet, Y. Chen and J.J. Greffet, Nature December 7 (2006)

Theoretical and computational concepts for periodic optical waveguides

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In recent years, the race for faster optical telecommunication and data processing has motivated research towards solutions to try to minimize the involvement of electronics in signal manipulation and to keep signals in the optical domain as long as possible. To that end, integrated circuits with more functional optoelectronic elements directly interconnected on a single chip are highly desirable. In the quest for ultimate miniaturization, integrating circuits relying on high refractive-index contrast waveguides, like semiconductor-air/oxide photonic wires ($\Delta n > 2$), appear as a promising approach. Alternatively to these systems relying on a conventional guiding in a high index core surrounded by a low index cladding, one can use a periodic structure, like photonic crystal waveguides. Photonic crystal waveguides share common feature with their z-invariant photonic-wire counterparts. They offer single mode operation in a given frequency range, high transmission around sharp bends, or z-invariant-waveguide-like dispersion relations. Additionally, due to the periodicity along the propagation axis, they may welcome guided modes with a dramatically slow group velocities and anomalous dispersion, with potential applications for true all-optical signal processing. Thus, photonic-crystal waveguides, or in general periodic waveguides, offer a robust platform for light-matter interaction phenomena, which is becoming more and more important in advanced integrated circuit design and which is much richer than that of their more traditional z-invariant counterparts.
In the analysis and design of integrated-optics circuits with classical z-invariant waveguides, modal concepts play a central role. As illustrated in Vassalo's textbook for instance, the normal mode theory of bound-radiation-leaky modes plays a central role in the analysis and in the design of integrated circuits.
Although several software are available for calculating Bloch modes of three-dimensional (3D) z-periodic waveguides, most of the time, 3D aggregates of periodic waveguides are analysed with numerical tools that relies on a full sampling in space and time and frequency modal concepts like the modal transmission or reflection are largely ignored. Although these methods may provide accurate results for various study cases, they are completely numerical and do not provide physical insight into the underlying physics of light propagation or confinement. We present a general theoretical formalism for the calculation of light emission and propagation in 3D z-periodic waveguides and in aggregates of them. Conceptually, the formalism can be seen as a generalization of the classical formalism developed for z-invariant waveguides. It allows to handle both the bound and radiation Bloch modes of periodic waveguides and by combining independent Bloch mode calculations of intermediate sections, it allows a semi-analytical treatment of light propagation in aggregates of periodic waveguides.

IN-PLANE PHOTONIC TRANSDUCTION OF NANOMECHANICAL MICROCANTILEVER MOTION TO ENABLE SENSOR ARRAYS

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Microcantilevers show significant promise in sensing minute quantities of chemical and biological analytes in vapor and liquid media. Much of the reported work on microcantilever sensors has made use of single functionalized microcantilevers, usually derived from commercially available atomic force microscope (AFM) cantilevers. However, arrays with hundreds to thousands of microcantilevers on a single chip are required to create sophisticated, broad spectrum chemical and biological sensors in which individual microcantilevers have different bio- or chemoselective coatings. Unfortunately, the most sensitive microcantilever readout mechanisms (such as laser beam reflection as used in atomic force microscopy) are not readily scalable to large arrays. We therefore introduce a new microcantilever transduction mechanism for silicon-on-insulator (SOI) microcantilevers that is designed to scale to large arrays while maintaining a very compact form factor and high sensitivity. This mechanism is based on in-plane photonic transduction of microcantilever deflection in which the microcantilever itself forms a single mode rib waveguide. Light from the end of the microcantilever is directed across a small gap to an asymmetric receiving waveguide with two outputs that enables differential detection of microcantilever deflection. Fiber input and output with compact waveguide bend and splitter arrays are needed to route light to and from the microcantilever array. Initial noise and optical power budget calculations indicate that deflection sensitivities in the 10's of picometer range should be achievable. In our presentation we will discuss progress made toward realizing photonic components necessary for in-plane transduction of microcantilever sensor arrays.

ANNULAR BRAGG RESONATORS (ABR) – THE IDEAL TOOL FOR BIOCHEMICAL SENSING, NONLINEAR OPTICS AND CAVITY QED

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ABSTRACT

Circular resonators are fundamentally interesting elements that are essential for research involving highly confined fields and strong photon-atom interactions such as cavity QED, as well as for practical applications in optical communication systems, and biochemical sensing and more. The important characteristics of a ring resonator are the Q-factor, the free spectral range (FSR) and the modal volume, where the last two are primarily determined by the resonator dimensions. The Total-Internal-Reflection (TIR) mechanism employed in "conventional" resonators couples between these characteristics and limits the ability to realize compact devices with large FSR, small modal volume and high Q. This link between the size of the resonator and the Q-factor stems from a loss mechanism called "bending losses". As the bending of the waveguide becomes smaller, the impact of this mechanism increases until it becomes the dominant loss mechanism, limiting the achievable Q-factor. Recently, we proposed and analyzed a new class of a resonator in an annular geometry that is based on a single defect surrounded by radial Bragg reflectors on both sides. The radial Bragg confinement breaks the link between the characteristics of the mode and paves a new way for the realization of compact and low loss resonators. Such properties as well as the unique mode profile of the ABRs make this class of devices an excellent tool for ultra-sensitive biochemical detection as well as for studies in nonlinear optics and cavity QED.

Planar integrated free-space optics: ongoing research

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In optical engineering, micro- and nano-structured components fabricated by lithographic techniques find increasing attention since they offer the potential for increasing the performance of an optical system. Performance can relate to various issues like functionality, suitable packaging, low cost, etc.. An important aspect of micro-fabrication is the potential of integration at a systems level.

Here, we consider specifically the concept of planar integration of free-space optical (PIFSO) systems, suggested some time ago for applications in data communications and sensing. The main feature of this concept is a folded optical axis and the integration of microoptical elements on the surfaces of a transparent substrate. The folded optical axis results in a significant reduction of the longitudinal extension of an optical system. The monolithic integration leads to an increased ruggedness and stability in comparison with conventional free-space optics. The substrate serves as both, a medium for light propagation using a tilted optical axis and as a motherboard for mounting devices like optoelectronic chips, waveguide connectors, etc..

Two specific aspects of the PIFSO concept are addressed here. These are: the need for low-cost fabrication and the need for high optical efficiency. So far, most PIFSO demonstrators were fabricated in glass (e.g., fused silica) by means of photolithography and reactive ion etching. Thus the functionality of the concept was demonstrated. The components were mostly diffractive optical elements which offer a large variety for the design, however, their use may result in a relatively large loss for the total optical system. In order to build systems or modules that are practical for real applications, we describe here also the use of plastic as a substrate material in combination with diamond turning as the fabrication technique. Plastic optics has been getting tremendous attention recently due to its good optical performance, light weight and flexible formation. In particular, its fabrication can be achieved by molding techniques which benefits the mass production much more than the conventional fabrication of glass optics. Diamond turning and cutting allows one to fabricate optical elements with a large sag which is of interest in order to make refractive or reflective components that yield a high efficiency. Using this approach we demonstrate functional and efficient microoptical systems with reduced losses as compared to earlier demonstrators.

DIFFRACTIVE CONTROL OF POLARIZATION AND COLOR

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Diffractive optics provides unparalleled opportunities to control and modulate various properties of light, including the spatial and spectral distribution of radiation in near and far fields, as well as the state of polarization. Major advances have been achieved in this field recently by application of electron beam lithography, dry etching, and thin-film-coating technologies to manufacture micro- and nanostructured optical interfaces built with either metallic or dielectric materials. An overview is given on some of the new prospects thus opened up; the emphasis is on the control of the polarization and spectral shaping of light in the visible and near-infrared regions. Among the topics covered are crossed-grating-type inductive grid filters for rejection of infrared radiation, color separation gratings capable of distributing different spectral portions of the light field into different diffraction orders, and so-called polarization gratings that enable local control of the state of the polarization of the electromagnetic field. The fundamental theory, critical fabrications aspects, and the industrial potential of such novel optical elements are discussed.

ENHANCED COHERENT THERMAL EMISSION OF COUPLED RESONANT CAVITIES DUE TO SURFACE WAVES EXCITATION

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Thermal emission of absorbing materials is affected by surface morphology as well as the excitation of surface waves (surface plasmon-polaritons in metal or surface phonon-polaritons (SPPs) in dielectric).[1] Surface modes yield a long-range spatial coherence length which may be much larger than the emitted wavelength. To transmit the near-field coherence into the far-field, a shallow grating-coupler was introduced on the surface. Such a grating only causes a smooth perturbation to the surface; therefore, the coherence length in the far-field was theoretically and experimentally found to be limited by that of the near-field.

We investigate theoretically and experimentally the thermal radiation of a relatively deep grating that was etched on an amorphous fused silica (SiO_2) substrate. A quasi-monochromatic and spatially coherent thermal emission was obtained for TM polarization state in the spectral range in which SiO_2 supports SPPs. The spatial coherence measured using the angular emission pattern in the far-field was found to be much larger than the predicted coherence length of SPPs on a flat surface in the near-field. We show that the dispersion relation of the SPPs on a flat surface is significantly modified by the structure.[2] As a result, the radiation coherence is not limited by the flat surface coherence length in the near-field. The enhanced coherence of the thermal emission is due to coherent coupling between resonant cavities obtained by horizontal SPPs standing waves, where each cavity supports standing wave-coupled SPPs.

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The Role of Photonic Band Gaps in Polarization Independent Resonant Grating Waveguide Structures

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Abstract: Polarization independent resonance occurs when two degenerate guided eigenmodes of orthogonal polarization are excited. The grating breaks the waveguide's symmetry, usually opening a band gap, removing degeneracy and polarization independence. Experimental and theoretical results are presented.

Keywords: grating waveguide; polarization independent; band gap; symmetry selection

One dimensional resonant grating waveguide structures[1] (*GWS*) are multilayered dielectrics, exhibiting a resonance type anomaly, in which abrupt variation of reflected intensity is observed. In general, resonant response is polarization dependent. We discuss the principles which allow polarization independence in one dimensional gratings, evaluating the role of Bragg coupling, band gap opening, mode symmetry and symmetry based excitation selection rules[2]. All *GWS* are polarization independent at TE-TM band crossings, having different inversion symmetry and devoid of band gaps, as shown Fig. 1.

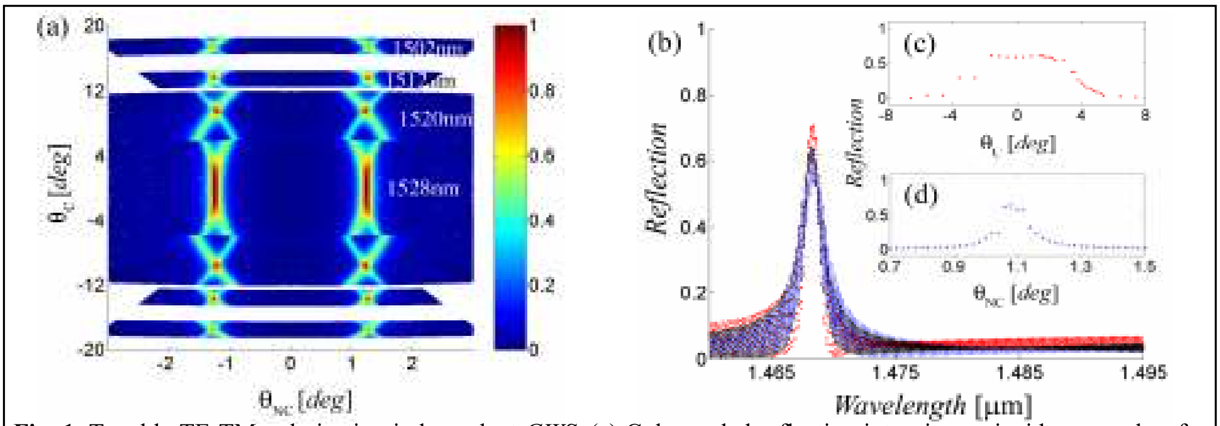

Fig. 1. Tunable TE-TM polarization independent *GWS*. (a) Color coded reflection intensity vs. incidence angles, for circularly polarized light at different wavelength. (b) Experimental e-beam fabricated *GWS*, reflection vs. wavelength at θ_{NC}=1.1°, *TE* (red), *TM* (blue) and 45° pol. (black). (c) and (d) Angular tolerance.

On the other hand, at normal incidence at TM-TM band crossing, a band gap is opened as shown in Fig. 2. A symmetric in phase ($\beta_L+\beta_R$), and an anti symmetric out of phase ($\beta_L-\beta_R$), bands are obtained and their excitation by TM incident light is dictated by symmetry. We show that similar to work done with surface plasmons[3], we can control or even close the gap by tailoring the duty cycle enabling polarization independence.

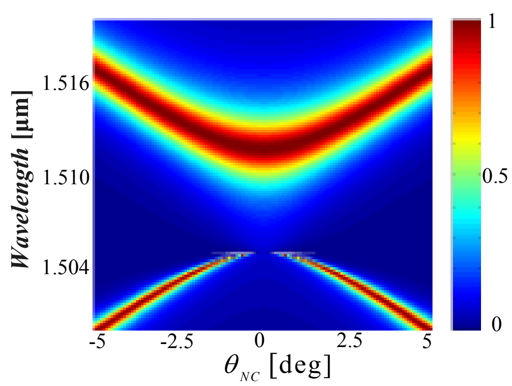

Fig. 2. Photonic band gap of TM guided modes under classical incidence for a 50% duty cycle grating.

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