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CHALLENGES IN MICRO- AND NANO-OPTICS

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Micro-optics describes a family of elements and systems fabricated by modern micromachining. Optical structures with nearly arbitrary shapes and dimensions down to the nanometer can be realized offering a large degree of freedom for the design. The progress in novel light sources, detectors, materials and technology enable new opportunities and challenges for micro-optics and nanoscale photonics.

1. Introduction

The history of micro-optics is the history of micro-fabrication of fine structures. At the beginning, the elements were simple grating structures for spectroscopy. Then, the elements became more complex. Fresnel zone plates, computer-generated holograms (CGHs), diffractive optics, microlens arrays and more recently resonant filters and photonic crystals are such elements [1-3]. With the improvement of available technology new devices and systems were proposed. The possibility to realize very small structures opened also the door to new materials. Interesting are not only static, but also dynamic elements.

The progress in the field is driven by opportunities, such as the design freedom (diffusers and beam-shaping elements), technology (nanophotonics, plasmonics), new light sources (white light sources, mid-IR lasers, frequency comb lasers), needs (parallel systems to increase the measuring speed), curiosity (negative index materials), standard platform, characterization tools, etc. A few examples will be summarized here.

2. Challenges

2.1 Design freedom - diffusers

Many years have been passed between the invention of CGHs [4] and beam shaping with plasmonic nanostructures [5]. The technique is more powerful, the features are smaller enabling a higher degree of freedom. Amplitude, phase and polarization information can be stored in planar devices and used to control the propagation of light. However, most practical applications require loss-free phase elements. For the application in illumination systems often a space-invariant response of the diffuser is required. The utilization of arrays of microlenses with adapted geometry is straight forward for this application. The lenses generate the desired angular spectrum, while the array property warrants the space invariance of the element. To use diffractive optics or CGHs has the advantage of higher flexibility for arbitrary structures. Such elements are key in illumination systems in DUV-lithography steppers [7]. A design example is shown in Fig. 1. Note that the fabrication tolerances can be improved considerably by an optimized design.

2.2 Technology - sensors

Optical sensors based on refractive index detection are attractive, because they show a high sensitivity and provide a label-free method [8]. The two most commonly used techniques are optical fiber based sensors and surface plasmon resonance technique based sensors. The progress in technology allows the realization of sensors that are able to probe extremely small volumes. However, decreasing the size of the sensor means decreasing its sensitivity proportionally to the interaction strength between light and analyte. Thus a compromise between the size of the sensor and the sensitivity has to be found. In order to study integrated sensors that can probe extremely small analyte volumes [9], metallic cavities with a slot width of 30 nm have been realized on top of a silicon waveguide (see Fig. 2). Simulations show that these devices can be used as sensors with a sensitivity of 750 nm/RIU (refractive index unit). A detailed analysis shows that an optimum resolution down to 5.8×10^{-5} RIU can be expected. These are extraordinary results for such small cavities, which are able to probe picoliter volumes.

2.3 New light sources – mid IR

Not only micromachining, but also devices and applications are important factors for the development of new domains. Quantum cascade lasers, for example, are compact light sources working in the mid-infrared (mid-IR) [10]. They are ideal light sources for sensor applications, because most of optical absorption spectral lines associated to the vibrational frequencies of gas molecules take place in the mid-IR domain of the optical spectrum. Mid-IR lasers offer also opportunities for diffractive optics, because the longer wavelength (compared to the visible spectrum) facilitates the fabrication of diffractive structures. Highly efficient binary sub-wavelength structures become attractive and feasible.

Mid-IR photonics also needs low-loss integrated waveguides. A germanium strip waveguide on a silicon substrate has been demonstrated recently, see Fig. 3 [11]. The waveguide is designed for single mode transmission of light in TM-polarization generated from quantum cascade lasers at the wavelength of 5.8 μm. The propagation losses were measured with the Fabry-Pérot resonance method. The lowest achieved propagation loss is 2.5 dB/cm.

Figure 1 : Calculated far-field of an annular shaped pattern generated by an aperture-modulated diffuser (AMD), KrF-Excimer laser at 248 nm [6].

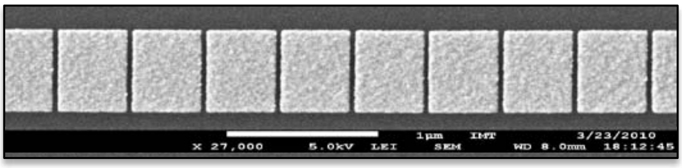

Figure 2 : Metallic slot grating on a silicon wave-guide. The slot width is 30 nm and the period 500 nm [9].

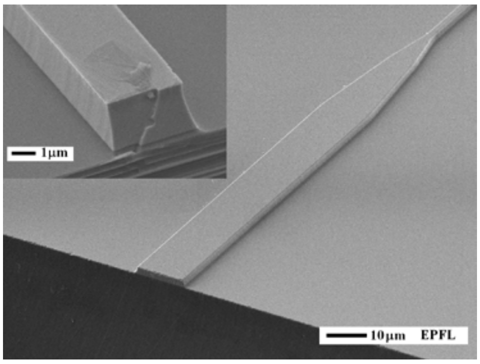

Figure 3 : SEM image of the waveguide. The coupling part is 15 μm wide and the narrower part is 2.9 μm wide. The in-set is the cross-section in the straight section. [11].

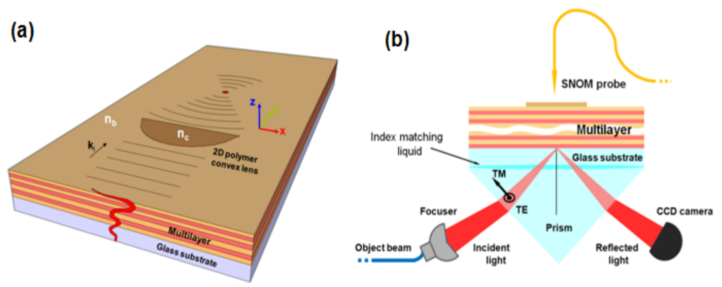

Figure 4 : (a) Concept of a 2D plano-convex lens. The field is confined at the surface of the multilayer. An ultra thin convex lens made of AZ1518 is coated on top of the platform; (b) BSWs excitation is performed in the Kretschmann configuration using a BK7-glass prism.

2.4 Standard platform – Bloch Surface Waves (BSWs)

The concept of Bloch Surface Waves (BSWs) in periodic layered media has been studied first by Yeh et al. in 1978 [12]. It has been shown that truncated dielectric multilayers can sustain surface waves under particular illumination conditions. Recently it has also been shown by Descrovi et al. [13] that these waves may be guided thanks to a dielectric waveguide on top of the multilayer. Finally, Sfez et al. [14] demonstrated the refraction of surface waves at thin waveguide structures, which opens the door for a novel 2D-platform. Different types of thin optical elements (lenses, gratings, cavities, nanostructures, …) can be arranged on the surface to realize optical systems for sensing applications. Therefore, the dielectric multiplayer is an ideal platform for 2D integrated optics.
BSWs have several interesting advantages. The dielectric materials can be chosen with very low intrinsic losses for a specific wavelength. The multilayer is wavelength scalable, i.e., the structure may be designed to sustain BSWs at any wavelength. It is possible to engineer the position of the surface mode within the forbidden bandgap. Finally, the multilayer fabrication is fully compatible with the actual fabrication technologies.

3. Conclusion

The success of micro-optics is based on the progress in wafer-scale fabrication methods. The high degree of freedom offers a wide range of possibilities that have not yet been fully explored. The progress in novel light sources, detectors, materials and technology enable new opportunities and challenges for micro-optics and nanoscale photonics.

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