F.4 Optical filters and Displacement Sensors based on Guided Resonances in Photonic Crystals

O. Kilic, S. Kim, Y.-A. Peter, S. Fan, O. Solgaard

Photonic Crystals (PCs) are artificial materials that are periodic with length scales that create forbidden energy bands for electromagnetic radiation, much like natural crystals like Silicon and Germanium do for electronic wave functions. Photonic Crystal Technology therefore provides unprecedented control over and sensitivity to electromagnetic fields on sub-wavelength dimensions and has the potential to significantly impact optical communication and sensing technology.

The focus of this project is to develop optical filters, as well as sensors and actuators that can measure and manipulate physical phenomena on the nanoscale, based on guided resonances[1] in two-dimensional PCs (Fig.1). Guided resonances enable efficient coupling to PC modes using large-aperture optics, which greatly simplifies the optical systems.

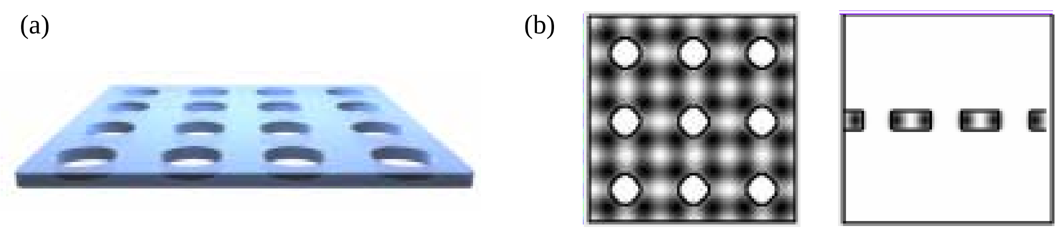

Figure 1: (a) A photonic crystal slab structure consists of a square lattice of holes introduced in a high index dielectric slab. (b) Field intensity distribution of a guided resonance on two slices that are parallel or perpendicular to the slab. Black and white represents high and low intensities, respectively.

We are currently modeling, designing, and fabricating 2-D PCs, and we are characterizing their guided resonances. We expect that these studies will verify our theoretical understanding of the guided-resonance phenomenon, and provide a fabrication base for the sensors. First, we will use the extreme sensitivity to dimensional changes in PCs to create tunable filters and displacement sensors (Fig.2) with improved sensitivity compared to interferometric systems. Displacement sensors are basic building blocks in a variety of measurement systems, including near-field probes for biological applications.[2, 3, 4]

The fabrication of PCs and related MEMS structures is, to a large extent, done using standard microfabrication technology available in the Center for Integrated Systems and the National Nanofabrication Facility at Stanford University. Single PC slabs on SOI wafers are currently fabricated for test purposes (Fig.3).

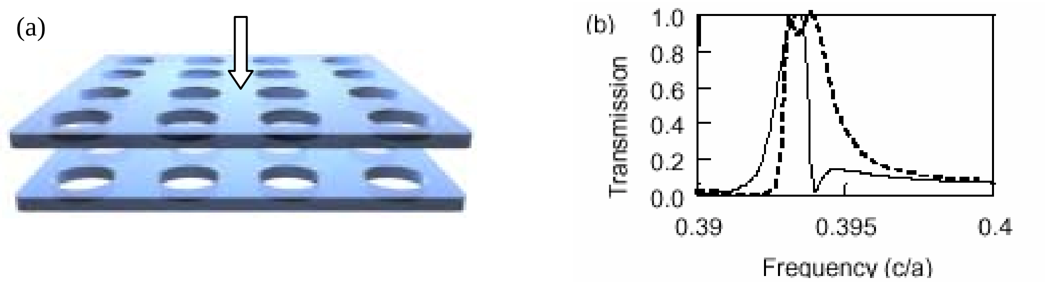

Figure 2: (a) A two-layer photonic crystal structure. (b) Transmission spectra through the structure shown in (a). The solid line corresponds to the case where the holes are aligned, while the dashed line corresponds to the case where the holes are displaced between the two layers.

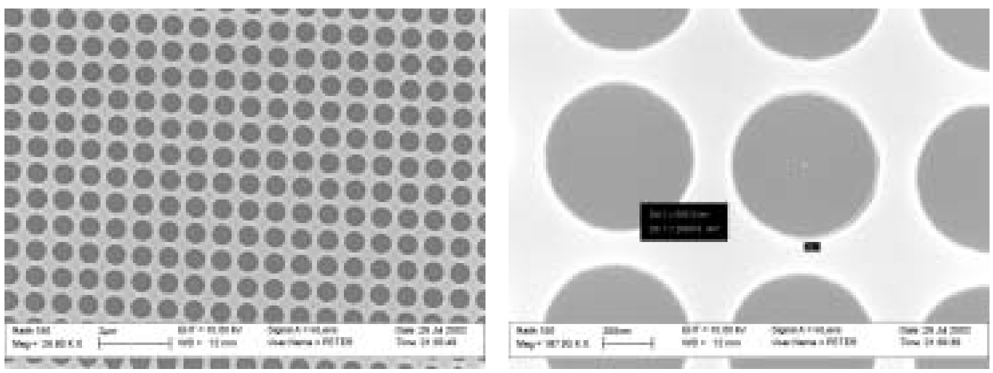

Figure 3: A photonic crystal square lattice defined on an SOI wafer. This particular example has a hole diameter of 580 nm and lattice constant 730 nm.

To fabricate the test devices with a single PC slab, we employ three main steps. In the first step we define various MEMS structures that will move the slab horizontally and vertically, and will rotate it with respect to the substrate. We are using standard photolithography to create these MEMS structures. In the second step, we protect these structures with an oxide and nitride layer, and pattern these layers from the backside. By using KOH etching, we form through holes and prism structures. Through holes are needed for direct transmission experiments, in which we shine laser light vertically on the PC slab, and measure its transmission spectrum. Prism structures, which are formed by the 54.7° angled features of the anisotropic etch, are needed for evanescent coupling experiments. By total internal reflection from the substrate surface, we can couple to specific modes of the slab, and characterize it by measuring the reflection (Fig. 4). As the last and vital step, we are defining the PC lattice with e-beam lithography to get the required lateral resolution. We use a 350 nm PMMA layer as the mask, and etch the silicon using dry etching.

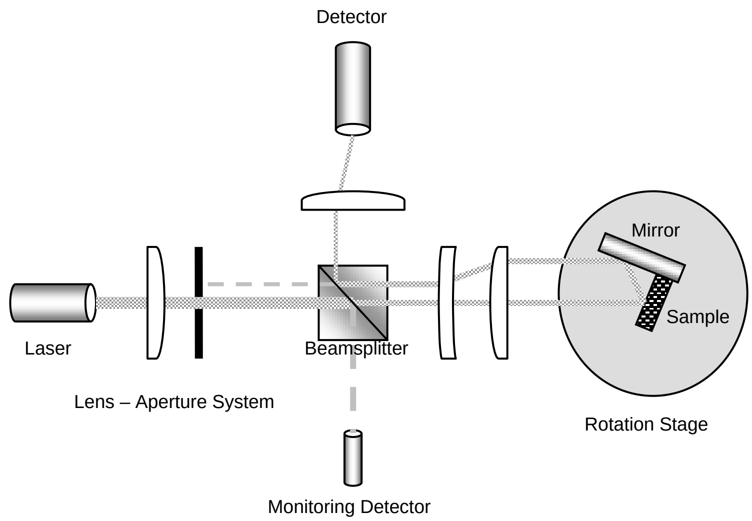

Figure 4: Experimental set-up for the prism coupling and reflection spectrum experiments. The sample is rotated on top of a stage, where the light strikes eighter the prism structure, or directly the PC slab depending on the experiment.

Photonic crystals enable extremely accurate control over electromagnetic fields on nanometer length scales, and hold the promise of very accurate optical systems for nanotechnology applications. We have identified guided resonance as a fundamental mechanism that significantly simplifies excitation and sensing of PC modes, and we develop filters and sensor systems based on this principle. We believe that the successful demonstration of these devices represent a significant step towards realizing the full potential of Photonic Crystal structures.

References:

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