16. Design and Fabrication of a Superprism Using Two Dimensional Photonic Crystals

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Project Staff:
Sheila Tandon, Chiyan Luo, Michael E. Walsh, Dr. Gale S. Petrich, Prof. Leslie A. Kolodziejski, Prof. Henry I. Smith, and Prof. John D. Joannopoulos

A superprism is an optical device similar to a conventional prism only with two enhanced properties: (1) super-dispersion and (2) ultra-refraction. Just as a conventional prism separates light into its component wavelengths, a superprism separates these wavelengths over wider angles—termed "super-dispersion." A superprism can magnify the angle of propagation of a single wavelength of light to steer the beam over wide angles—termed "ultra-refraction." Photonic crystals are responsible for the superprism effect. Superprism effects would be useful in a number of applications ranging from enhanced devices for wavelength-division multiplexing (WDM) to a new class of ultra-refractive optical elements for beam manipulation.

Our superprism consists of a 2D photonic crystal with a square lattice of cylindrical air holes in a high index material such as silicon or gallium arsenide. The top view schematic of the device shape is shown in figure 1. The device is hexagonal shaped with the photonic crystal (PC) occupying a square region in the center. The initial design has focused on realizing ultra-refraction such that an input angular sweep of approximately +/- 2 degrees is amplified to about +/- 30 degrees at the output for a wavelength of 3.2 mm. A thick low-index layer is used to minimize radiation loss into the high index substrate.

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**Figure 1: Superprism device design showing top and side views of the device.**

The feature sizes of the photonic crystal can be scaled depending on the wavelength of operation as shown in figure 1. Our desired wavelengths of 3.1mm and 1.55mm imply hole lattice constants of 750nm and 372nm, and hole radii of 300nm and 150nm. The total thickness of the
device (excluding substrate) is about 3.5 microns (460nm GaAs, 3mm $\text{Al}_x\text{O}_y$) while the top surface will have an area somewhat larger than $2\times2\text{cm}$.

The hexagonal device shape is patterned using photolithography while the photonic crystal holes are patterned using interference lithography and a tri-layer resist process. After each lithography step, patterns are etched into hard mask layers via reactive ion etching (RIE). The fully patterned hard mask layers are then used to etch the substrate material via another RIE step. Figure 2(a) is a photograph of the patterned hard-mask layers on a silicon substrate. Two hard-mask layers have been used: 50nm chromium on top of 250nm HSQ (spin-on oxide). The chromium layer is patterned with the superprism hexagonal shape while the open square area is patterned with the $\sim780\text{nm}$ period photonic crystal in HSQ. The diffraction pattern from the PC can be seen as a blue streak across the square area.

Figure 2(b) shows a microscope image (100x magnification) of the corner region of the photonic crystal area. The square grid of the PC is rotated 45 degrees with respect to the square region. The alignment accuracy between the photonic crystal orientation and the square region is critical for superprism performance. Figure 2(b) shows how a line of PC holes is aligned to the square edge with accuracy of less than one degree thus achieving our required tolerance.

Future work will include calibrating the photonic crystal hole size during the interference lithography, finding a better hard-mask layer than chromium (which leaves behind post-wet-etch residue) and reactive ion etching of the silicon substrate material.