Fabrication Techniques for Integrated-Optical Grating-Based Devices

Personnel

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Bragg gratings have widespread application in the rapidly growing field of optical telecommunications. A Bragg grating is formed by creating a periodic corrugation or refractive index modulation in an optical waveguide. Such a structure behaves as a wavelength-selective filter, reflecting a narrow band of wavelengths while transmitting all other wavelengths. Figure 13 illustrates a typical Bragg grating fabricated in an optical waveguide. Although Bragg gratings are commonly imprinted in photosensitive optical fiber, physically patterned gratings in planar waveguides offer a number of advantages. One can build Bragg gratings in non-photosensitive materials such as indium phosphide or silicon. In addition, integrated gratings can contain precise phase shifts and variations in grating strength to better achieve a desired filter response. Finally, the planar fabrication process can integrate multiple gratings with splitters, couplers, and other optoelectronic components on a single, readily manufacturable chip. This project seeks to develop the technology for building Bragg-grating devices in planar optical waveguides.

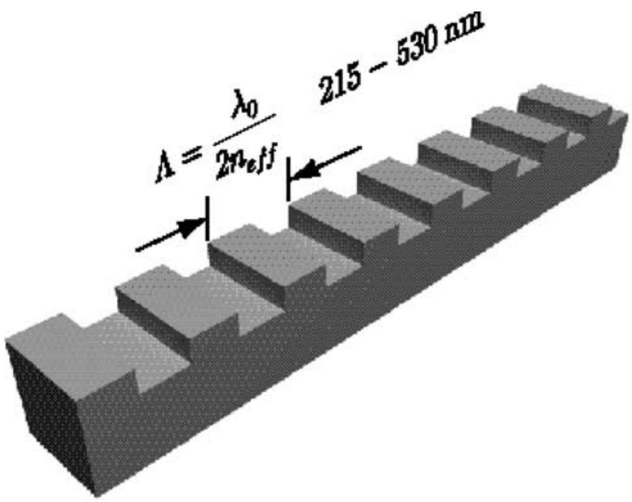

Fig. 13: Schematic of an integrated Bragg grating. A shallow corrugation is etched into the top surface of a waveguide. The Bragg grating period, L, ranges from 215 nm to 540 nm, depending on the material and waveguide design.

We use a combination of several different types of lithography to generate Bragg-grating devices. In interference lithography, two coherent laser beams are crossed, generating a standing-wave interference pattern. This standing-wave pattern is used to expose photoresist, yielding a coherent deep-submicron-period grating. This grating can be used directly as the device grating or it can serve as a precision reference for later electron-beam lithography steps.

For devices that require long Bragg gratings with engineered phase shifts or variations in grating strength, we use a technique called Spatially-Phase-Locked E-Beam Lithography (splebl), which combines the long-range spatial coherence of interference lithography with the flexibility of scanning e-beam lithography. Inherent pattern-placement errors in gratings written by standard e-beam lithography limit device performance. SPLEBL references the interference-generated grating during the e-beam exposure to minimize these placement errors.

In most cases, the techniques mentioned above are not applied directly to a device, but instead to an X-ray lithography mask. Once the mask is generated, with the appropriate gratings and alignment marks, the patterns can be repeatedly transferred to substrates using X-ray lithography.

One of the critical challenges faced by integrated Bragg gratings is that they require submicron grating structures patterned over relatively tall optical waveguides. In order to address this topography problem, we have developed a novel dual-hardmask process, depicted in Figure 14. This allows both lithography steps to be performed over essentially planar surfaces. The process can be adapted to various materials systems and waveguide designs.

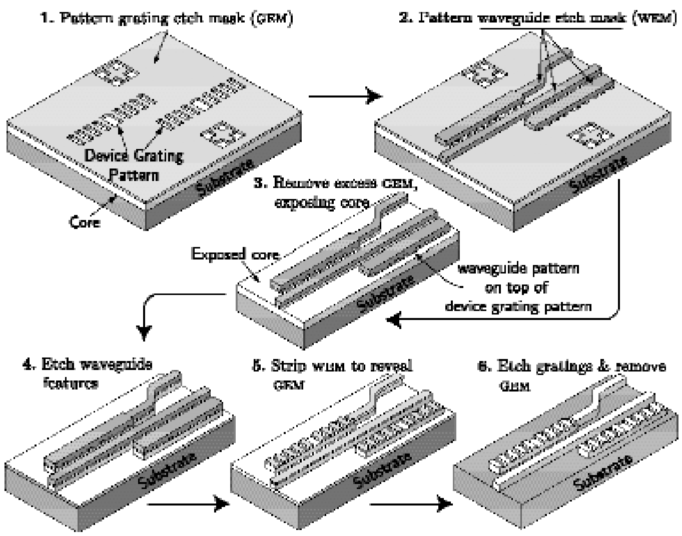

Fig. 14: Dual-layer hardmask process used to pattern fine-period Bragg gratings atop relatively tall waveguide structures. The process is designed such that all lithography steps are performed over essentially planar topography.

Figure 15 shows a quarter-wave-shifted grating in an InGaAsP waveguide fabricated by the dual-hardmask process, the subsequent InP epitaxial overgrowth, and the device's transmission spectrum. Figure 38 illustrates a WDM Add/Drop channel filter based on the Silicon-OxyNitride (SiON) materials system. A PECVD materials deposition process has been developed to achieve the appropriate refractive-index contrast between the SiON core and the SiO_2 cladding. The dual-hardmask process has been successfully adapted to these materials, and final fabrication of the device is in progress. Finally, the dual-hardmask process has been used to fabricate narrow-band filters in Silicon-On-Insulator (SOI) ridge waveguides. Figure 17 shows a cross section of such a device along with its measured optical transmission spectrum.

The combination of interference, electron-beam, and X-ray lithography with dual-hardmask planar processing allows the fabrication of complex, high-fidelity grating structures in a variety of material systems.

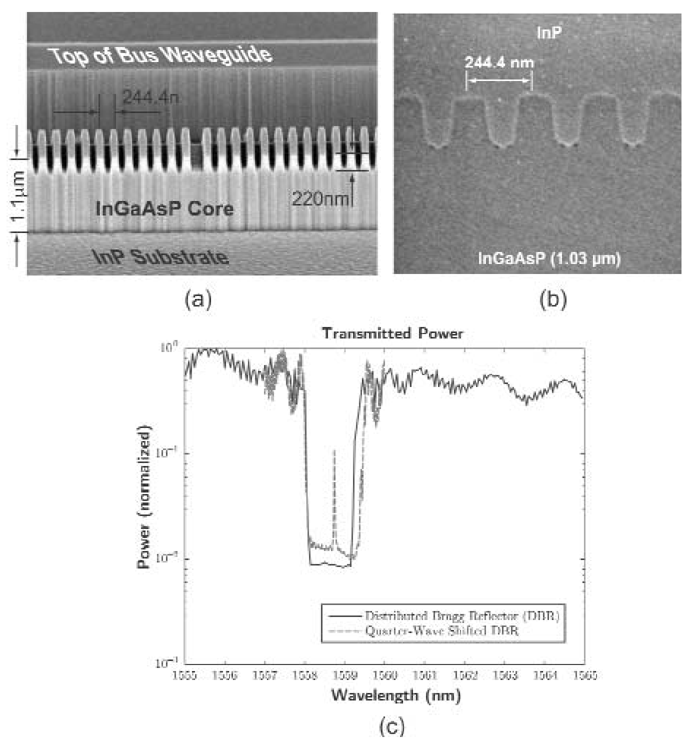

Fig. 15: (a) Scanning electron micrograph depicting a quarter wave shifted 244.4 nm period Bragg grating etched into the top surface of an InGaAsP waveguide. (b) Device grating after InP epitaxial overgrowth at Lucent Technologies. (c) Transmission spectra for uniform and quarter-wave-shifted distributed-Bragg-reflectors.

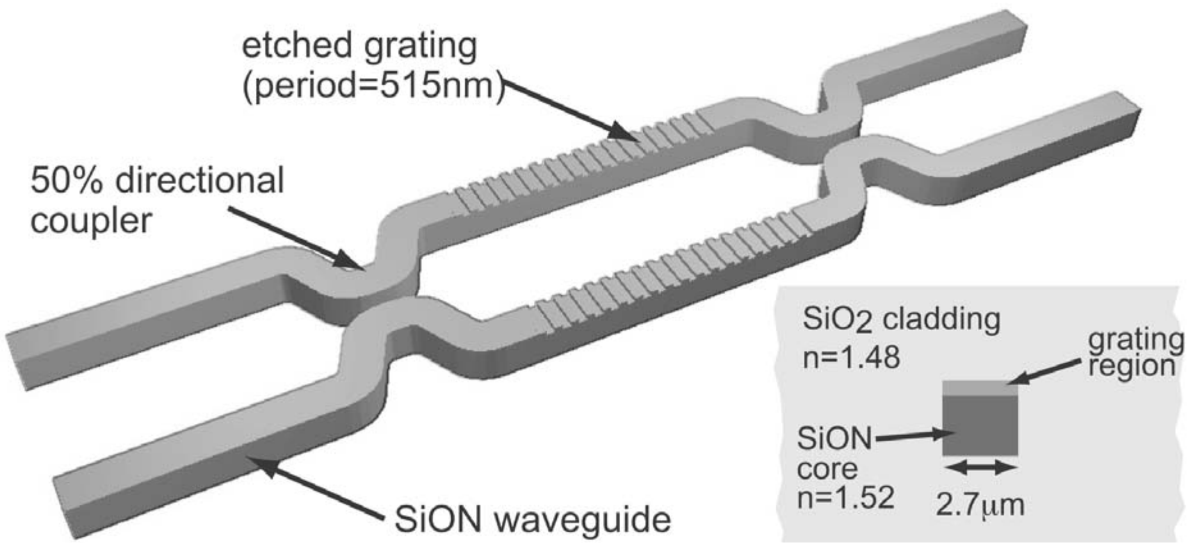

Fig. 16: Wavelength-Division-Multiplexing (WDM) channel add/drop filter currently being fabricated in silicon-oxynitride, and a cross-section of the waveguide/grating region (lower right). A number of WDM channels enter the device on the input port, a single channel is routed to the drop port while the remaining channels pass to the through port. The dropped channel can be replaced with an input on the add port.

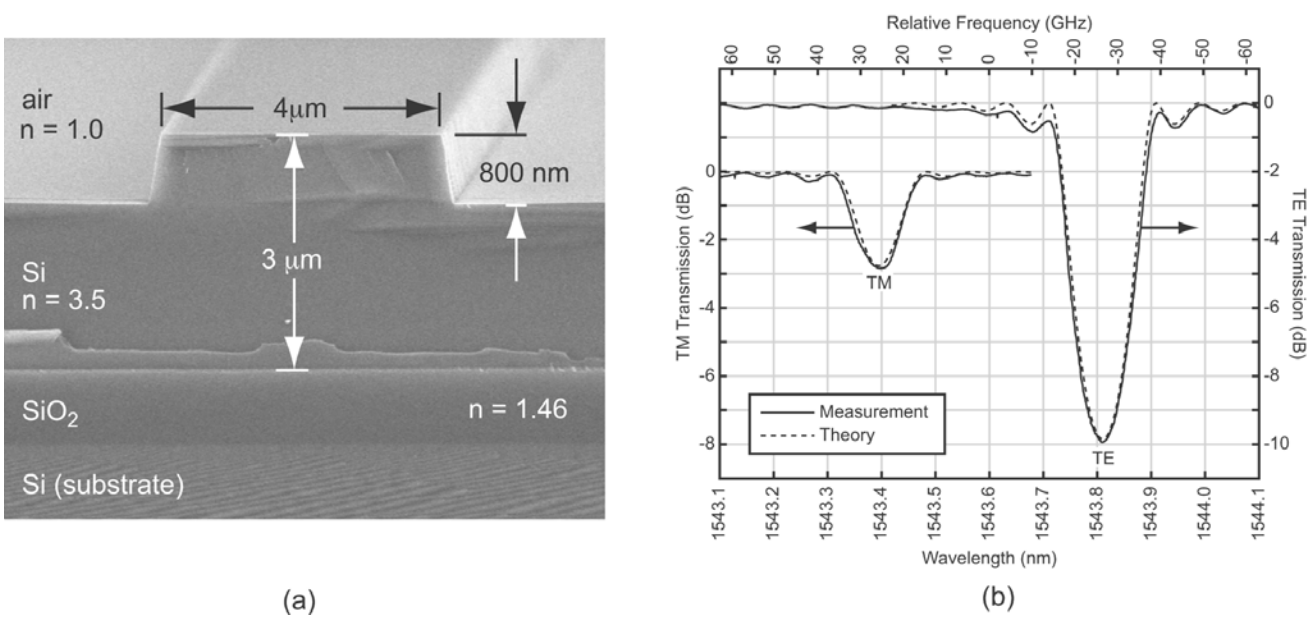

Fig. 17: (a) SEM cross-section of a typical silicon ridge waveguide. (b) TE- and TM-transmission spectra of a 4mm long grating etched 150nm deep in an SOI waveguide.