Distributed Bragg Reflectors in Ultra Low Loss Silicon Nitride Waveguides

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Abstract:

The focus of this project was to fabricate distributed Bragg reflector (DBR) structures into a silicon dioxide (SiO_2)-clad silicon nitride (Si_3N_4) waveguide. DBRs are used extensively in the standard operation of semiconductor lasers. Such gratings have the ability to reflect select wavelengths of light as a means of producing laser feedback. An efficient grating requires precise fabrication techniques as the grating features need to be very small with periods ~ 140-520 nm depending on the effective refractive index of the mode. After fabrication, it is then useful to characterize the gratings to determine their respective scattering loss, strengths, and Bragg wavelengths. Characterization was accomplished using a superluminescent light emitting diode (SLED) with an optical spectrum analyzer (OSA).

Introduction:

Though not widely known, semiconductor lasers have been one of the hallmark inventions driving the information age. Their integration as sources enabling the fiber optic networks which span the globe should not be understated. DBRs are a fundamental element for these lasers providing the wavelength selective mirror to enable an array of tightly spaced single mode lasers, often able to tune wavelengths to adjust for changes in the network. This element can also be found in other non-telecommunication applications with equally stringent requirements for wavelength selectivity.

The first objective of the project was to select reasonable grating parameters by simulating various etch depths and modal properties. The next part was to successfully fabricate the DBRs using electron beam lithography (EBL) and a dry etch process, yielding preliminary test chips (Figure 1) and a grating chip with actual waveguides.

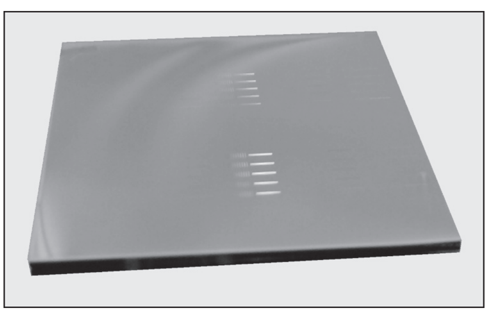

Figure 1: A chip used to test the parameters of the fabrication process.

The final part of this project was to test the fabricated DBRs by coupling light into the waveguide containing a single DBR and detecting the spectral response of the light emitted at the output. By this method, fundamental grating parameters were inferred to aid in future laser design.

Simulation:

In order to simulate the relevant grating parameters, a literature search was conducted to discover more about gratings and the equations which govern their operation [1]. A simple equation was examined which allowed for initial designs around the specifications of a 1.045 μm test laser. Further calculations were made with the aid of a MATLAB® finite difference method (FDM) mode solver program and by implementing a script representing consecutive grating periods as the product of multiple sets of 2 × 2 scattering matrixes. From these results and by selecting ideal values for the length and strength of the gratings, fabrication of the structures could begin.

Fabrication:

Electron beam lithography (EBL) is a technique with very high resolution. It uses electrons to expose the resist, as opposed to standard photolithography processes, which use light. EBL also uses a raster scan of the beam to expose select areas rather than the standard masked single exposure of a large area. EBL can require a large allotment of time as compared to standard photolithography, and therefore it is not scalable for production of large numbers of devices;

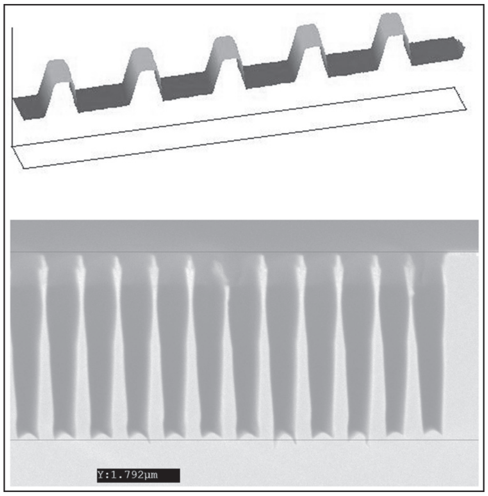

Figure 2: A 3D AFM of the fabricated gratings and corresponding SEM of the grating cross section.

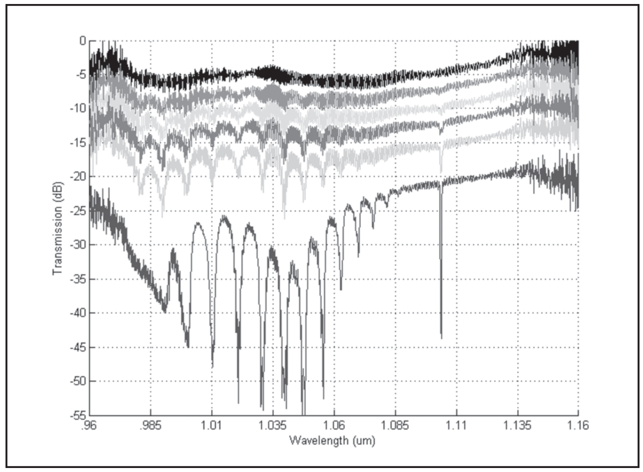

Figure 4: Transmitted power through gratings of length 55, 111, 163, 230, 380, 2000 µm from top to bottom. Each spectrum has been normalized to a straight waveguide and shifted by 2.5 dB from the adjacent spectra for ease of viewing.

however, it enables the flexibility needed to consistently create gratings with tight space wavelengths.

After patterning gratings into the resist, atomic force microscopy (AFM) images were taken to confirm the patterns as they were not visible in an optical microscope (Figure 2). Finally, a series of dry etches in inductively coupled plasma etcher using an oxide and chrome double hard-mask translated the pattern to the oxide cladding of our Si_3N_4 waveguide. The resulting profile was imaged using a scanning electron microscope (Figure 2).

Testing:

Testing the DBR gratings was prefaced by polishing the rough facets of the chip until they were mirror-like. Spectral transmission measurements were done by coupling on and off the chip, with cleave fibers using index-matching gel, a broad band SLED source with OSA. An infrared camera lens column and objective lens setup as seen in Figure 3 served to confirm that light was coupled to the waveguide and not any slab modes and to confirm a TE polarization.

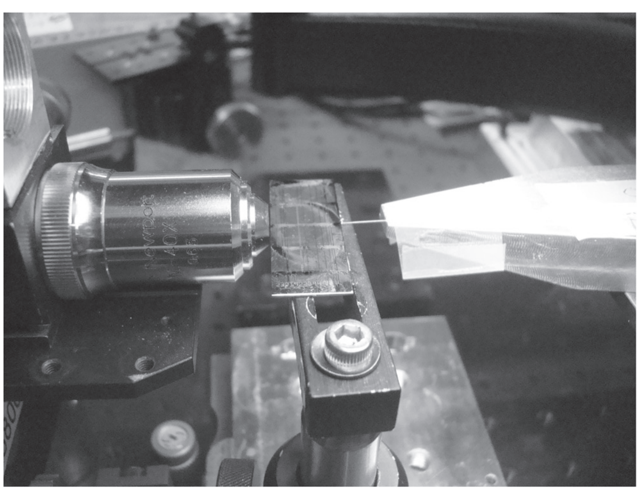

Figure 3: Test setup for measuring spectral response from the gratings.

After confirmation, the objective lens was removed and replaced with a fiber connected to the OSA allowing the spectral response to be measured. Such a response was obtained by sweeping the output wavelength of the test laser from 960-1160 nm. Outputs from grating structures were normalized to a straight waveguide without gratings and the spectra. Fitting to the simulation model failed likely due to an over etch through the cladding into the core. This is currently under investigation.

Results and Conclusion:

Complications to the project occurred during the etching portion of fabrication and resulted in structures with varied functionality. While a new chip was being fabricated, testing proceeded and spectral responses from the gratings were obtained for comparison with simulations as seen in Figure 4. At this time, new measurements are being recorded to compare against the simulation generated expectations.

This project demonstrates a comprehensive approach to understanding the principles, fabrication, and testing of distributed Bragg reflectors.

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References:

[1] Coldren, L., and S. Corzine. Diode lasers and photonic integrated circuits. Wiley-Interscience, 1995. Print.