Polarization-selective Optical Nanostructures for Optical MEMS Integration

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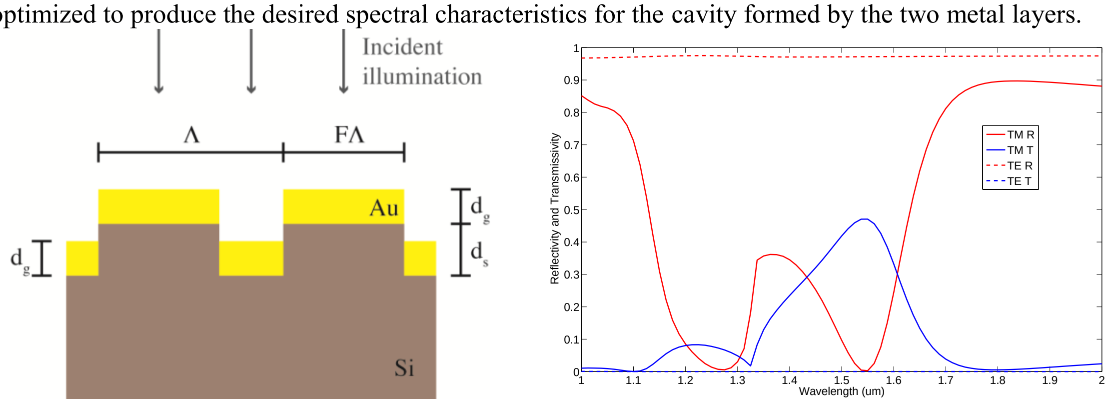
Introduction

Optical nanostructures have the potential to provide useful new functionalities, using materials and fabrication methods that are compatible with standard silicon-based processes. For example, it has been shown that a nanoscale grating coated with a metal layer produces polarization-selective reflectivity [1,2], based on the combined effects of form birefringence and a resonant cavity [3]. In this work, we adapt this design approach to develop two devices optimized to operate around 1.55 µm wavelength: a polarizing beam splitter, and a polarization-selective reflector. Such devices are of particular interest as they may provide optical properties such as polarization selectivity or enhanced reflectivity using nanostructures compatible with optical micro-electro-mechanical systems (MEMS).

Polarizing Beam Splitter

A schematic diagram of the device is shown in Fig. 1a. A nanoscale grating is first produced in the Silicon substrate, then a metallic (gold) layer is deposited, producing two metal wire-grid structures with a controlled spacing between them. The grating induces polarization selectivity through the form birefringence effect, while the layer thicknesses can be optimized to produce the desired spectral characteristics for the cavity formed by the two metal layers.



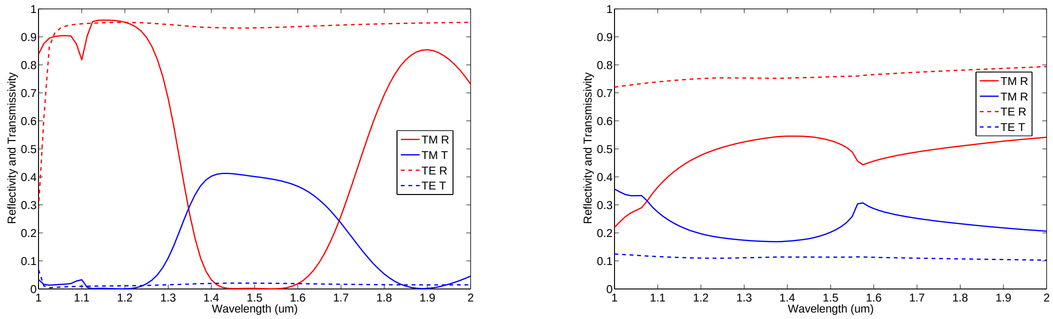
(a) (b)

Fig. 1: (a) Schematic diagram of the nanostructured polarizing beam splitter device (two periods of an infinitely periodic structure are shown); (b) reflection and transmission spectra for the device computed using RCWA.

The optical characteristics of the device are analyzed and optimized using the Rigorous Coupled-Wave Analysis (RCWA) method [4,5]. Within the parameter space investigated (limited by practical considerations for fabrication in our facilities), the optimum values for this device are found to be: $\Lambda = 0.75$ µm, $F = 0.65$, $d_g = 140$ nm, and $d_s = 215$ nm. The spectral transmission and reflection characteristics of the device computed using RCWA are shown in Fig. 1b. The device is predicted to have a TM transmissivity of almost 50%, a TE reflectivity of over 95%, and an extinction ratio exceeding 2000. This design takes into account both optimizing the performance of the device as well as minimizing the sensitivity to minor fabrication errors. Simulation work also shows that using a smaller grating period can improve the performance of the device, but this introduces additional challenges in accurate fabrication of the structure.

Polarization-selective Reflector

We also investigate a related device, optimized for the polarization extinction ratio in reflection. The structure is similar to the device shown in Fig. 1a, but with slightly different parameters: $\Lambda = 0.6$ µm, $F = 0.5$, $d_g = 90$ nm, and $d_s = 420$ nm. The spectral characteristics of the device as computed using RCWA are shown in Fig. 2a.



(a) (b)

Fig. 2: Reflection and transmission spectra computed using RCWA for (a) the polarization-selective reflector device; (b) a single layer wire-grid polarizer having the same metal thickness.

The TE reflectivity is found to be approximately 93%, and the extinction ratio in reflection (TE:TM) for this device is predicted to be over 2400. A parametric study of the various structural dimensions shows that this device has somewhat greater tolerance to fabrication errors than the previous device. For comparison purposes, a single-layer wire grid polarizer with the same metal thickness (90 nm) is optimized over approximately the same parameter space (period and fill factor). The resulting reflectivity and transmissivity are shown in Fig. 2b. It is interesting to note that the nanostructured device produces both a higher TE reflectivity and a higher reflectivity extinction ratio, as would be expected for a device having two metallic wire-grid layers instead of one. Preliminary fabrication work has been initiated on these devices, as shown in Fig. 3. This test structure has a larger grating period (800 nm), but also has a fill factor (~0.49), etch depth (~417 nm) and gold thickness (~81.7 nm) that approximately match the design parameters of the polarization-selective reflector structure.

Fig. 3: SEM image of a fabricated test grating (substrate on top, air below), having a different transverse profile (larger period), but otherwise approximately matching the design of the polarization-selective reflector.

Conclusion

Optimized designs for two polarization-selective optical nanostructures operating at 1.55 µm wavelength are presented. Both optical performance and fabrication tolerances are considered in the design process. Fabrication and characterization of these devices is ongoing. These devices are also process compatible with MEMS, and could provide enhanced functionality in an integrated micro-/nano-scale optical device.

References

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