Sub-Wavelength Gratings for Multi-Spectral Infrared Detection and Imaging

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Abstract:

Infrared spectral filtering based on Fabry-Perot etalons requires high reflectance, low loss mirrors to enable next generation infrared imaging and spectroscopy. A silicon on air (Si/air) diffraction grating was investigated as a broadband mirror in the long wavelength infrared (8-12 μm) based on the concept of high refractive index contrast sub-wavelength grating (HCG). Conventional and Bosch process reactive ion etches (RIE) were optimized and optical responses compared. The sidewall profiles obtained from the conventional RIE were non-vertical while those from the Bosch process were vertical but scalloped. Fourier transform infrared (FTIR) spectroscopy was used to characterize the gratings and the results compared to the COMSOL Multiphysics simulations. The grating reflectance was found to be insensitive to etch method differences and the suspended structure shows agreement with simulations despite bowing caused by design and fabrication processes.

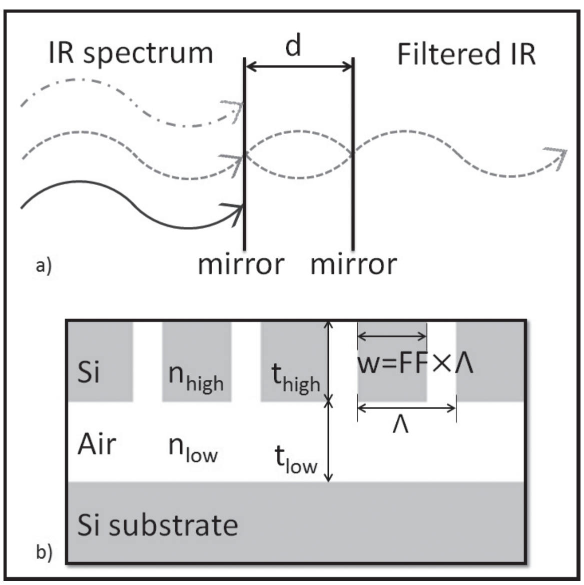

Figure 1: a) Diagram of a Fabry-Perot etalon. b) A two layer system consisting of high refractive index grating (n_{high}) on top of a low refractive index material (n_{low}). By changing the heights (t_{high} and t_{low}), period (Λ) and width (w) of the grating, the response can be tuned.

Introduction:

Thermal and long wavelength infrared (8-12 μm) imaging is used for surveillance and targeting when visibility is limited. Current imaging systems are restricted due to their intensity-based imaging method. Better object distinguishability of future systems requires spectral filtering capabilities of the long wavelength infrared (LWIR), which has further applications in spectroscopy. Fabry-Perot (FP) etalons use two low-loss high reflectance mirrors separated by a multiple of a half wavelength of the desired frequency to filter light, as seen in Figure 1a. The resonant wavelength transmits, while the other wavelengths destructively interfere. Higher mirror reflectance yields a narrower transmittance band and correspondingly a more selective filter. Distributed Bragg reflectors (DBRs) are conventionally used as low loss mirrors for lasers and spectral filters, however, fabrication of layer thicknesses required for the LWIR is difficult to reliably achieve due to wafer uniformity and curvature issues.

High refractive index contrast sub-wavelength gratings (HCGs) can be used as alternative broadband low loss mirrors in FP etalons requiring only two dielectric layers. HCGs consist of a high refractive index grating on top of a low refractive index layer. The grating dimensions are smaller than the wavelengths of the LWIR spectrum. HCGs are attractive candidates for broadband high reflectance mirrors required for effective FP etalon filtering.

Experimental Procedure:

Figure 1b depicts the silicon on air (Si/air) HCG investigated. These materials have minimal loss in the LWIR and have a high index contrast (3.4/1.0). The gratings were fabricated on a silicon on insulator (SOI) wafer using standard photolithography, two methods of reactive ion etches (RIEs), a hydrofluoric (HF) etch, and critical point drying. The conventional RIE used a hydrogen bromide (HBr) plasma etch and an oxygen plasma clean to remove the photoresist. The second RIE used the Bosch process based on sulfur

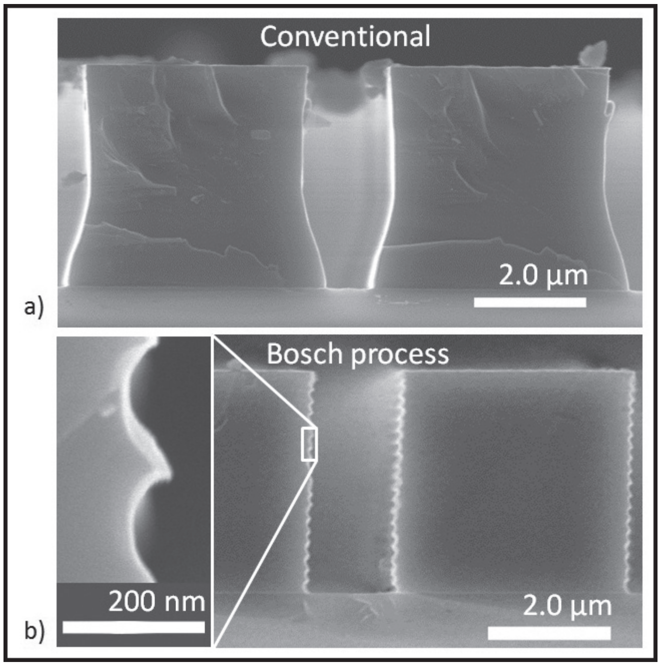

Figure 2: Cross-sectional SEM images showing; a) smooth but beveled conventional RIE sidewall profiles, and b) straight but scalloped Bosch process RIE sidewall profiles.

hexafluoride (SF_6) as the etch gas, octafluorocyclobutane (C_4F_8) as the passivation gas, and an oxygen plasma clean.

The HF etch was used to remove the sacrificial silicon dioxide (SiO_2) from the SOI providing the suspended structure. A critical point dryer was subsequently used to minimize adhesion affects between the grating and the substrate.

Using a scanning electron microscope (SEM), cross-sectional images allowed for sidewall profile comparisons for etch optimization. The reflectance and transmittance of each grating were measured using Fourier transform infrared (FTIR) spectroscopy before and after the HF etch. Measurements were taken from three different locations on each sample.

Results:

The SEM images show smooth, but beveled, sidewall profiles for the conventional RIE, whereas scalloped, but vertical, sidewalls for the Bosch process, as seen in Figure 2. The optical responses of the two gratings showed little difference before the sacrificial layer was removed. After the HF etch, the gratings bowed and touched the substrate 150 μm from the edge of the grating due to gravity and adhesion. By reducing the suspension length, this problem can likely be mitigated. Figure 3 shows the similar optical responses of the two etch processes with the Bosch process response red shifted, possibly as a result of different heights of the air gap. The reflectance measurements at the edges gave good agreement with COMSOL Multiphysics simulated responses, as seen in Figure 4.

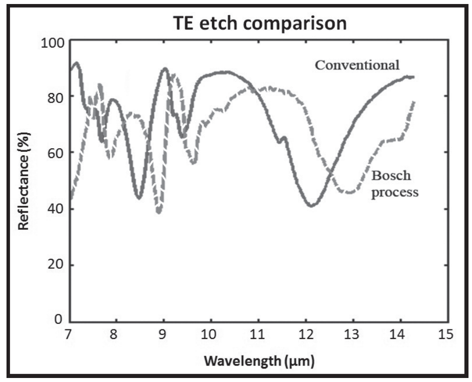

Figure 3: Optical responses of gratings produced by conventional and Bosch process RIEs are similar with the response from the Bosch process red shifted.

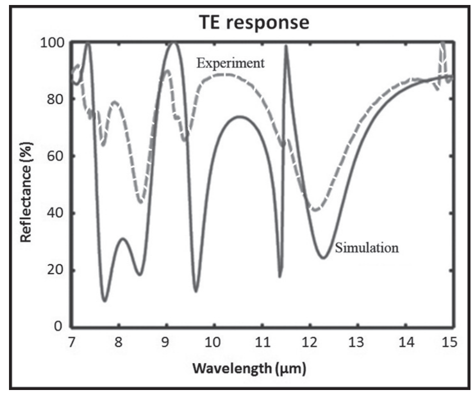

Figure 4: Experimental and simulated structure responses with peak agreement.

Conclusions:

Si/Air HCGs were fabricated using conventional and Bosch process RIEs. The measured IR response seems insensitive to etch process differences and shows agreement with the simulated response. By further optimizing the suspended length, it is likely the bowing that was witnessed will be resolved.

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References:

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