Non-periodic sub-wavelength gratings fabricated by helium ion beam lithography

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Sub-wavelength dielectric gratings (SWGs) have promised applications in free-space optical filtering and sensing with their broad spectral range and high reflectivity. Recently our group discovered a remarkable property of high-index-contrast gratings: a carefully designed non-periodic SWG pattern allows full control of the phase front of the propagated light while maintaining a high reflectivity [1]. This new feature opens up possibility of creating miniature optical elements that can be fabricated in thin planar dielectrics with low cost and high volume for integrated photonics and other commercial optics applications. We used that property to fabricate an amorphous silicon focusing mirror [1], and a silicon binary tilting mirror that mimics a blazed diffraction grating [2], using electron beam lithography (EBL). However, the device experimental results were not ideal comparing to the design targets largely due to the strong proximity effect that limits the patterning of carefully chosen, non-periodic gratings for local phase tuning.

Recently the helium ion microscope was introduced at Hewlett Packard Labs. Helium ion beam lithography (HIBL) has several advantages comparing to EBL, including smaller beam spot size, higher sensitivity and very low proximity effect [3]. This can be readily applied to creating the non-periodic sub-wavelength gratings. We chose a compact 10-μm by 10-μm TM polarized grating coupler as an initial attempt to validate our design.

Grating coupler has been used for out-of-plane coupling between a standard single-mode fiber and a waveguide in integrated photonics, Fig. 1, to enable wafer-scale testing. Contrary to the traditional shallow TE grating coupler, here the TM grating coupler needs to be etched deeply enough for stronger scattering of the vertical E filed. However the deep grooves also result in large back-reflection, so the width of the air grooves need to be adiabatically adjusted with narrow gap at the entrance of the gratings and increasing the gap slowly. FDTD simulations are carried out to minimize the back-reflection while maintaining high out-of-plane coupling efficiency. The optimized non-periodic design has grating periods varying from 616 nm to 732 nm, and gap duty cycle (DC) from 16% to 45%. Comparing to uniform gratings, such a non-periodic structure can reduce the back-reflection from 6.8% to 1%, while increasing the efficiency from 55% to 63%.

The device is fabricated on a SOI wafer with 250 nm silicon and 3 μm buried oxide. The TM grating coupler and the waveguide are patterned in the same lithography step in 100 nm thick hydrogen silsesquioxane (HSQ) using a Carl Zeiss Orion Plus helium ion microscope equipped with a Raith ELPHY pattern generator. After developing HSQ, the patterns are etched to 200 nm deep in silicon using HBr/O2 plasma in RIE. Fig. 2 shows the SEM image of the etched non-periodic TM grating coupler. The gap/line dimensions are measured and plotted on top of the designed structure, Fig. 3. As we can see, the fabricated gratings faithfully reproduce the design. Measurement results are to be followed.

In conclusion, we demonstrate the superior proximity reduction capability of HIBL. This feature is crucial in enabling non-periodic sub-wavelength grating based applications. More complicated device such as focusing lens using 2-D gratings will be fabricated using HIBL.

[1] D. Fattal, et al, “Flat dielectric grating reflectors with focusing abilities”, *Nature Photonics*, vol. 4, pp. 466-470, July 2010.

[2] Z. Peng, et al, “Reflective silicon binary diffraction grating for visible wavelengths”, *Optics Letters*, vol. 36, no. 8, pp. 1515-1517, Apr. 2011.

[3] D. Winston et al, “Scanning-helium-ion-beam lithography with hydrogen silsesquioxane resist,” JVST B, 27(6), pp.2702-2706 (2009)

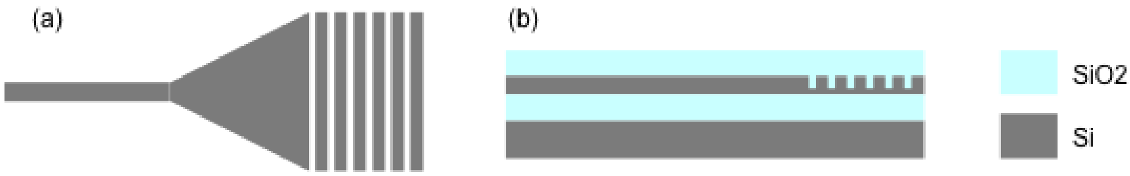

Fig.1 (a) top view and (b) cross-section of a grating coupler connected to a waveguide.

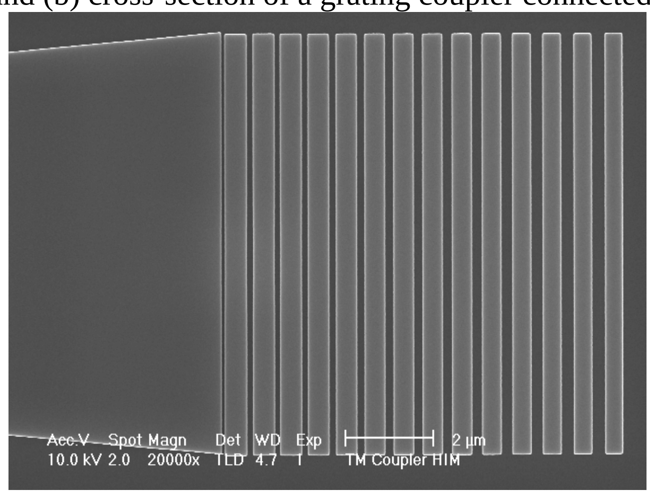

Fig.2 SEM pictures of etched TM grating coupler.

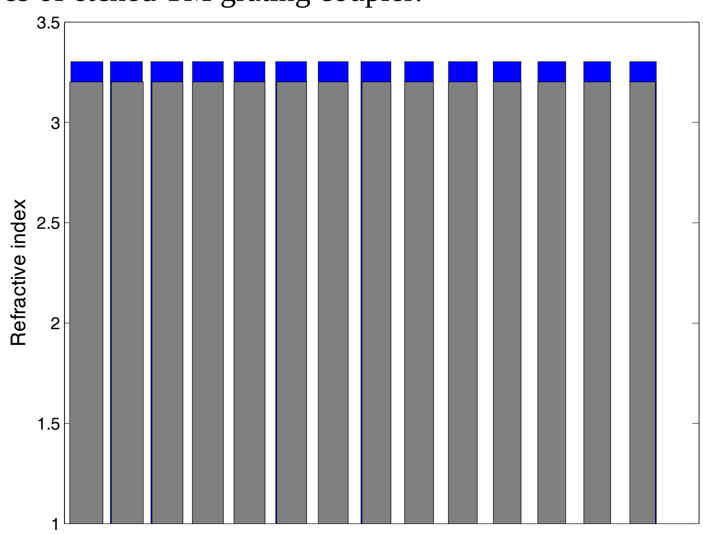

Fig. 3 Design (blue) and measured (grey) grating structure, period 616 nm to 732 nm, DC 16% to 45% from left to right.