Focused ion beam nano-structuring of Al_2O_3 dielectric layers for photonic applications

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Active integrated optical components such as waveguide amplifiers and lasers are being studied with increasing interest. Being Si-technology compatible, rare-earth-ion-doped amorphous dielectric layers have attracted special attention. Taking a successful step in that direction, we have recently reported on realization of low-loss Al_2O_3 channel waveguides grown on thermally oxidized silicon substrates [1]. In order to enable full integration of such a technology, high quality micro- and nano-structuring processes aiming at the development of on-chip resonator structures are to be achieved.

In this work we report on development and realization of sub-μm-period surface-relief reflection gratings on Al_2O_3 channel waveguides by using focused ion beam (FIB) patterning. A Nova 600 dual-beam FIB machine was used in the experiments. The acceleration voltage was set to 30 kV and the milling current was chosen to be 93 pA. In order to avoid charging of the structures a Cr layer with thickness ranging from 10 to 40 nm was sputtered on top. The length of the gratings was about 23 μm and waveguides with widths between 2.0 and 3.8 μm were used. The period of the grating was about 550 nm and the milled depths varied between 150 and 200 nm. The initial thickness of the Al_2O_3 channel waveguides was ~550 nm. In order to obtain uniform and smooth sidewalls of the grating structures, a study for minimisation of the redeposition effects was performed. The dwell time and number of loops were varied while keeping the total dose constant to achieve similar milling depths. Figure 1(a) shows the cross-section profile of a grating structure obtained with a dwell time of 0.1 ms and 8 loops and in Fig. 1(b) the corresponding profile obtained with a dwell time of 0.001 ms and 800 loops is depicted. The deteriorating effects of redeposition are clearly identified in the first case, dictating that the fabrication process can be optimized by using small dwell times and higher number of loops, thus smoothing out the effects of redeposition. Previous results [2] show that these findings may depend on both the milled geometry and material used. The gratings were realized using a predefined mask file (stream file) that contains milling time, pixel information, and pixel sequence for the desired geometry. The flexibility provided by the stream-file-based patterning allows us to choose the pathway by which the grating is defined on the waveguide. Figures 1 (c) and 1 (d) depict the cross-sectional profiles of two different gratings obtained by performing the beam scan along x and y axes (as indicated in the insets of the figures), respectively. When the scanning is done along the x-axis, i.e. perpendicular to the grating grooves, the cross-sectional profile is distorted due to redeposition effects and the inter-groove space is also milled, resulting in sinking of the entire grating structure. Furthermore, when the thickness of the Cr layer, used for elimination of the charging effects, is increased to about 40 nm, the Cr layer also acts as a sacrificial layer which prevents the rounding of the upper corners in the grating structures, as seen in Figs. 1 (b) & (d).

By optimizing FIB milling parameters such as ion current, dwell time, loop repetitions, scanning strategy, and applying a top metal layer for reducing charging effects and improving sidewall definition, reflection gratings on Al_2O_3 channel waveguides with smooth and uniform sidewalls were fabricated. A successful realization of a reflection grating is depicted in Fig. 2 (a) and the transmission spectrum of the device with a stop band with an on-off ration of ~14 dB is given in Fig. 2 (b). Fig. 3 shows the use of FIB milling for polishing the end-facets of the waveguides, removing the need for additional polishing steps. Currently, optimization of the grating parameters together with a study on effects of Ga ion implantation on Al_2O_3 grating structures is in progress.

[1] K. Wörhoff, J.D.B. Bradley, F. Ay, and M. Pollnau, *Conference on Lasers and Electro-Optics*, Technical Digest 2007 (Optical Society of America, Washington, DC 2007), paper CMW5.

[2] W.C.L. Hopman, F. Ay, W. Hu, V.J. Gadgil, L, Kuipers, M, Pollnau, and R.M. de Ridder, *Nanotechnology 18*, 195305 (2007)

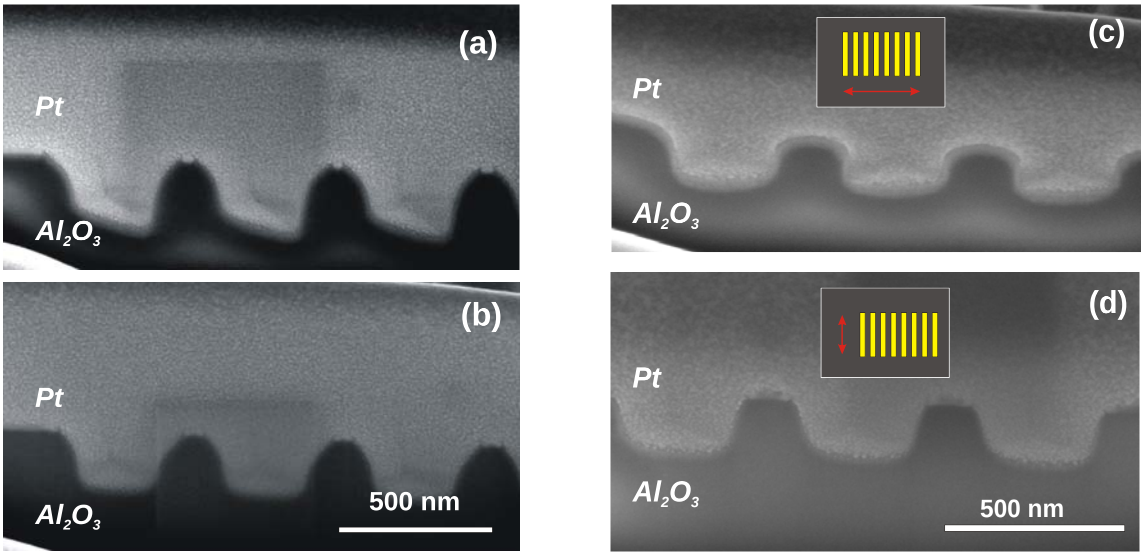

Fig. 1. The cross-section profiles of the grating structure obtained (a) with a dwell time of 0.1 ms and 8 loops, (b) with a dwell time of 0.001 ms and 800 loops, (c) by performing the beam scan along x-axis (perpendicular to the grooves), and (d) when the scanning is done along the y-axis (parallel to the grooves) and having thicker Cr layer on top.

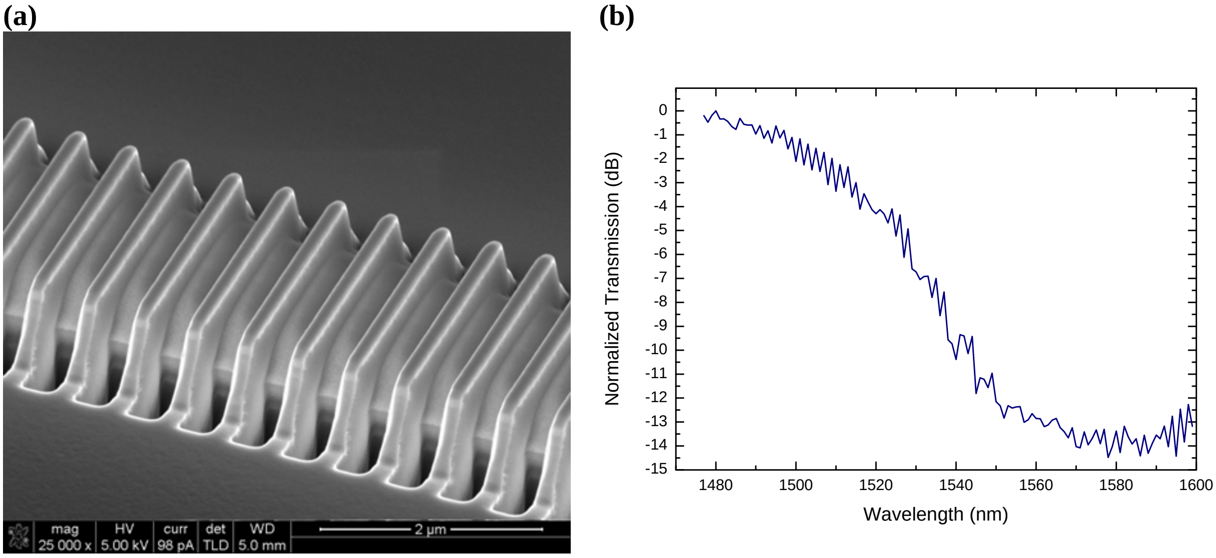

Fig. 2. (a) Reflection grating with the optimized FIB parameters. (b) Optical transmission spectrum of the grating device with a stop band with an on-off ration of ~14 dB.

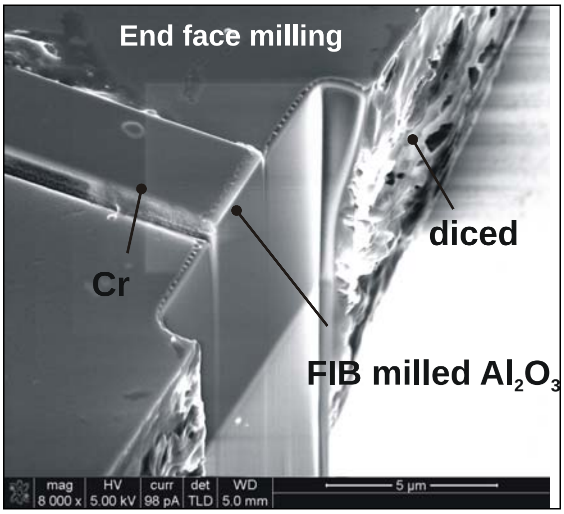

Fig. 3. End-face-polishing of the Al_2O_3 channel waveguides by FIB milling