Focused Ion Beam Nano-structuring of Bragg Gratings in Al_2O_3 Channel Waveguides

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We report our recent results on an optimization study of focused ion beam (FIB) nano-structuring of Bragg gratings in Al_2O_3 channel waveguides. 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 with smooth and uniform sidewalls were achieved.

Introduction

The increasing interest in the patterning of materials in the nano-scale range stimulates the development of innovative techniques and technologies but also provides major challenges. Focused ion beam (FIB) milling has been used for more than a decade mostly in microelectronics industry. The attractiveness of the method in the area of photonics has only recently been recognized. The main motivation for using this technology comes from need for nanostructuring - with features much smaller than the wavelength of light- in the novel field of nanophotonics (including photonic crystals and plasmonics). Several of these applications involve materials or material combinations that are hard to etch using more conventional chemical methods. In comparison to other technologies for nanofabrication, such as those based on e-beam lithography, FIB has the advantage of enabling fast prototyping, considerably reducing the design-fabrication-characterization cycle time.

Here we report our recent results on an optimization study of FIB nano-structuring of Bragg gratings in Al_2O_3 channel waveguides. The sub-µm-period surface-relief reflection gratings on dielectric channel waveguides were realized by use of a FEI Nova 600 dual-beam FIB machine. The acceleration voltage was set to 30 kV and the milling current was chosen to be 93 pA.

Cross sectioning

In order to analyze the effect of milling parameters on the sub-µm grating structures, the technique for creating cross-sections of the milled structures was optimized. This cross-sectioning is done in situ using the same FIB machine that produced the grating structure. The optimized method starts with local FIB-induced deposition of a layer of Pt on top of the region of interest, in order to prevent redeposition while milling the cross-section. The next step is to mill a large-area hole with a sloped angle to avoid long milling times. Finally, a line-by-line scan (termed cleaning cross-section) is applied at a lower current (28 pA) to facilitate a high contrast image, as depicted in Fig. 1.

The analysis of the cross-sectional profile of the grating structures is done by use of SEM. Since the electron beam and the ion beam are arranged at a fixed angle of 52°, SEM photos at an angle can be made of the cross-section without rotating the specimen holder stage.

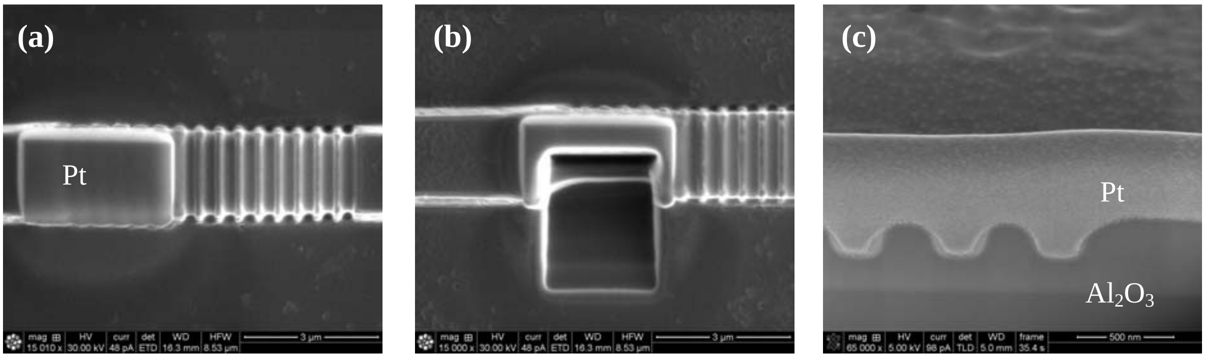

Fig. 1: *Illustration of the cross sectioning procedure: (a) deposition of the Pt layer on top of the grating(top view), (b) milling of a deep sloped hole (top view), (c) final cross-sectional view (at an angle of 52°).*

Optimization of the milling process

In order to obtain uniform and smooth sidewalls of the grating structures, a study for minimization 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. In order to avoid charging of the structures a Cr layer with thickness ranging from 10 to 40 nm was sputtered on top. The grating lengths were about 23 μm and waveguides with widths between 2.0 and 3.8 μm were used. The grating period 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 about 550 nm [1].

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. Figure 2(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. 2(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 show that these findings may depend on both, the milled geometry and material used [2].

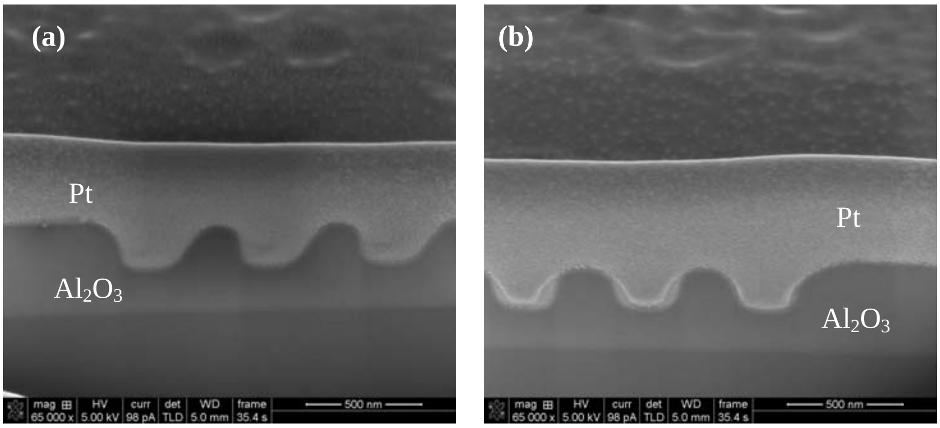

Fig. 2: *Cross-section profiles of grating structures obtained with (a) a dwell time of 0.1 ms and 8 loops , (b) a dwell time of 0.001 ms and 800 loops.*

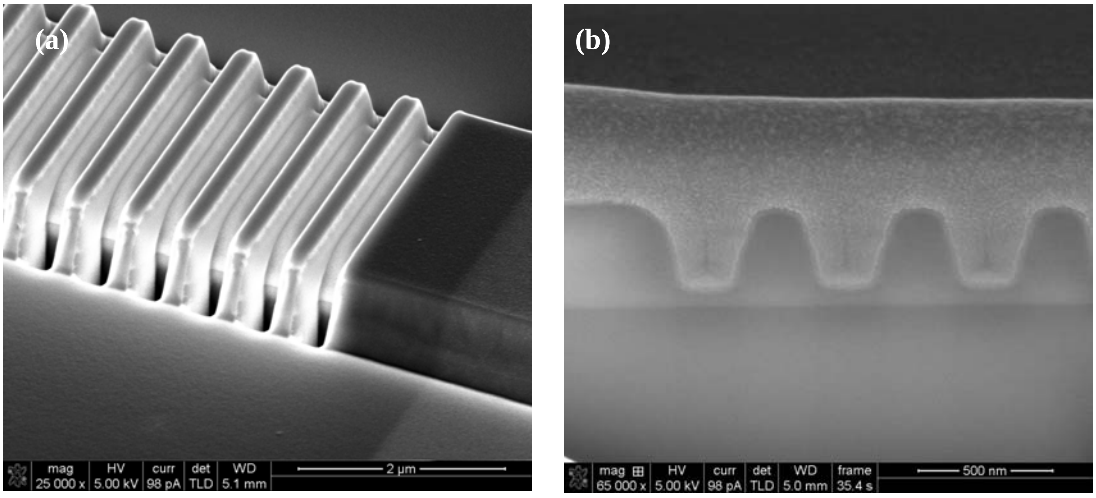

Fig. 3: *(a) Grating device realized with optimized parameters; (b) cross-sectional profile of the optimized grating structure.*

When the scanning is done along a direction 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. A successful realization of a reflection grating when applying optimized milling parameters is depicted in Fig. 3.

Conclusions

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.

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References

[1] J.D.B. Bradley, F. Ay, K. Wörhoff, and M. Pollnau, *Appl. Phys. B* **89**, 311-318 (2007).

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