FOCUSED ION BEAM (FIB) FOR THE FABRICATION OF GRATING COUPLERS IN SI_3N_4 WAVEGUIDES.

Anna Vilà[1], *Kirill Zinoviev*[2], *Carlos Domínguez*[2]

[1] *EME/CeRMAE/CEMIC, Electronics Department, University of Barcelona,*
Martí i Franqués 1, E-08028-Barcelona, Spain.
[2] *Instituto de Microelectrónica de Barcelona CNM-CSIC, Campus UAB,*
E-08193-Cerdanyola, Barcelona, Spain
anna@el.ub.esT

Diffraction gratings are very convenient elements for coupling out-of-plane light in planar waveguides of sub-micronic thickness. They have been investigated in dielectric [1] and high-index waveguides [2], and a platform for modeling has been created [3], but technology should still be improved for giving gratings efficient and simple as modeled. Standard methods like reactive ion etching through a photoresist mask, done with electron beam lithography or optical holography, give errors due to the initial surface roughness and to inaccurate corrugation control, and can not be used on micromechanical delicate structures. Focused Ion Beam (FIB) has been shown as a versatile powerful direct-write nanotechnology technique able to solve many of these problems [4]. It allows depositing and milling a variety of materials with nanometer resolution without masks nor sacrificial photosensitive layers. So, an important advantage of this technique is the ability of making sub-micron structures as the diffraction grating couplers onto chips with fragile elements, thus completing the technology.

In this work, planar waveguide diffraction grating couplers in Si_3N_4 rib waveguides fabricated by FIB are presented. The samples were obtained by standard thermal oxidation, silicon nitride LPCVD, UV photolithography and reactive ion etching, defining 40 µm large and 140 nm high waveguides. Next, a FEI DB-235 Strata FIB machine with Ga^+ ions at 30 keV and currents of about 230 pA was used for milling the gratings. AFM has been used for imaging the resulting structures, as well as the SEM system available in the FIB machine.

A primary grating relatively deep was made in order to test the technology. Its quality is shown in figure 1, which shows the frequency spectrum of its depth profile obtained from the AFM measurement (image in the inset). The grating depth is 100 nm and period 312 nm, and its spectrum is similar to that of a rectangular train, suggesting quite vertical walls and flat bottom for the grating and demonstrating the suitability of the proposed technology. Following the same procedure, three other depths depending on ion dose (table I) have been provided to gratings 50 µm long, giving also good quality and uniformity as can be seen in figure 2, which presents the SEM image of a grating of the deepest type, viewed at an inclination of 52º.

Coupling experiments have been performed by focusing He-Ne laser onto the grating coupler placed on a rotation stage at an angle of maximum coupling efficiency. Coupling efficiency was lower than expected. Light entering the grating does not reach the non-corrugated zone because of high absorption, induced, apparently, by Ga implantation as concluded already for other types of high index waveguides [5]. Auger spectroscopy experiments have confirmed Ga presence up to 50 nm depth. The length of light coupling out of the waveguide was estimated, but the measured lengths are significantly shorter than the expected ones.

In conclusion, the feasibility of diffraction grating couplers by FIB is demonstrated, but the influence of implanted Ga^+ ions onto the optical properties of the resulting structure needs further investigation.

References:

[1] J. Canning, D.J. Moss, M. Faith, P. Leech, P. Kemeny, C.V. Poulsen and O. Leistiko, Electron. Lett., **32** (1996) 1479.

[2] T.E. Murphy, T. Hastings and H.I. Smith, J. Lightwave technol. **18** (2000) 1402.

[3] R. Petit, Electromagnetic theory of gratings, Springer-Berlag, Berlin (1980).

[4] A. Romano-Rodríguez, A. Vilà, J.R. Morante and J. Samitier, Communic. To XXI Reunión de la Sociedad de Microscopía de España, Cádiz (2003).

[5] D.J. Moss, V.G. Ta'eed, B.J. Eggleton, D. Freeman, S. Madden, M. Samoa, B. Luther-Davies, S. Janz and D.-X. Xu, Appl. Phys. Lett., **85** (2004) 4860.

Figures:

Ga^+ dose (ions per line)	Period (nm)	Corrugation depth (nm)
$7.19 \cdot 10^{12}$	320	20
$4.31 \cdot 10^{12}$	316	8
$2.88 \cdot 10^{12}$	310	5

Table I. Data on grating parameters.

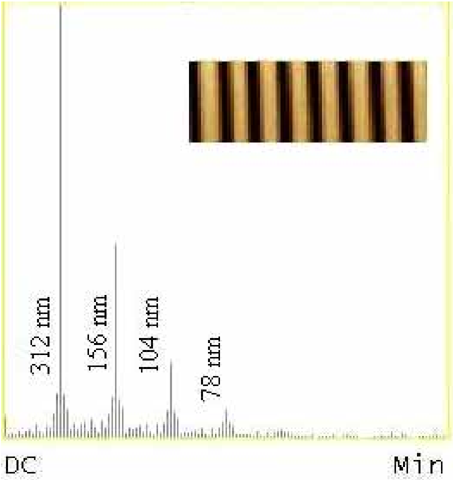

Fig. 1. Spectrum of spatial frequencies obtained from Fourier transform of the grating profile measured by AFM. At the inset a fragment of the AFM image of the grating.

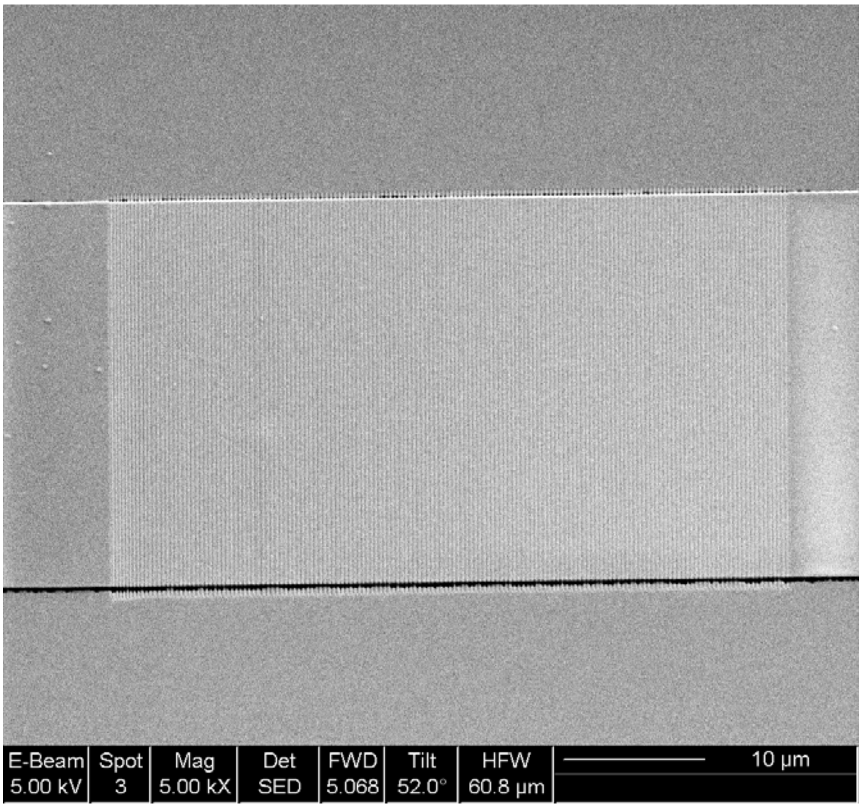

Fig. 2. SEM image of the grating fabricated at highest Ga^+ dose, viewed in situ in the FIB system at 52° of inclination.