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Ultramicroscopy 106 (2006) 771–774
ultramicroscopy
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# Transmission properties of hydrogen and helium ion implantation induced waveguide grating structures and potential application

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Received 11 September 2005; accepted 6 December 2005

**Abstract**

Optical waveguides in fused silica have been manufactured by $H^+$ implantation, which shows significantly improved transmission properties after implantation. The relationship between the transmission property and the thickness of the cladding layer after surface etching has also been investigated. Grating structures in waveguides have been made by additional $He^+$ implantation with a periodic metal mask covering the surface. The transmission of such grating structures is leveled throughout the measured wavelength range. This observation suggests a new method to make variable optical attenuators (VOAs) to equalize optical powers of different channels.


*PACS:* 85.40.R; 42.65.D; 78.20.C

*Keywords:* Ion implantation; Optical transmission; Fused silica; Grating structures

## 1. Introduction

There are several conventional techniques for fabricating optical waveguides including ion exchange, metal diffusion, and epitaxial growth. These techniques increase the refractive index of the surface layer up to a few microns, and this high index layer is surrounded by the low index of air and substrate to form an optical waveguide. Ion implantation, a surface modification technique by which ions are accelerated to a target at energies high enough to bury them below the target's surface, can modify the optical properties of an insulator surface, thereby changing the refractive index, luminescence, thermoluminescence, reflectivity, birefringence, and optical dispersion curves [1]. In the current project, we are interested in changing the refractive index near the projected range of the implanted ions. This approach can be used to fabricate optical waveguides, and further, induce grating structures in the guiding layer for filters, mode converters and sensor applications. Ion implantation has some unique advantages compared to other traditional waveguide fabrication methods. Accurate dose control is possible by beam current measurement. Any desired impurity profile can be achieved by choosing the proper ions, energy and dose. Chemical solubility limitations do not apply.

Fused silica is an important material for the manufacture of optoelectronic components, and is also commonly used in fiber networks. It is compatible with established Si processing techniques. There is significant interest in ion implantation modified fused silica for numerous applications in the telecommunication area.

We report on waveguides fabricated by hydrogen ion implantation in fused silica, and grating structures in the guiding area that are obtained by subsequent helium implantation with a metal mask covering the surface in a periodic fashion. The transmission properties of the waveguides were measured by the end-fire coupling [2].

## 2. Experimental details

Samples of fused silica were implanted with hydrogen ions ($H^+$) at room temperature with a 1.7 MV Tandetron Accelerator at the University of Western Ontario. We chose a dose of $5\times10^{14}$ ions/cm$^2$. With the implantation

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doi:10.1016/j.ultramic.2005.12.013

energy at 350 keV, the range of the implanted ions is about 3.4 μm according to simulation by SRIM, a Monte Carlo program that calculates the trajectories of the ions involved in the irradiation [3]. The actual depth profile of the implanted ions has been measured by Cameca IMS-3f secondary ion mass spectrometry (SIMS) using a negative oxygen beam and monitoring positive secondary ions of interest. The surface of the sample has been coated with a thin layer of gold (~20 nm) before the analysis by SIMS to increase conductivity.

Grating structures in waveguides were fabricated by additional ion implantation with a periodic metal mask (period of 350 μm; slot width of 180 μm). Helium ions with an energy of 1 MeV were implanted at room temperature with a dose of $5 \times 10^{14}$ ions/cm$^2$. The energy is chosen such that the helium ions reach the same depth as the previously implanted hydrogen ions. During implantation, the sample normal was tilted 7° off the beam direction. The procedures for manufacturing the grating structures are illustrated in Fig. 1.

The transmission properties of the waveguide made by ion implantation were measured by the end-fire coupling. The waveguide cross-sections have been polished before measurement. Focused visible light was guided into the front cross-section. The transmitted light was collected with an OceanOptics HR4000 spectrometer at the other end. The waveguide holding stage is adjustable to maximize the transmission.

The surface of the fused silica has been visualized by LEO 1530 field-emission scanning electron microscopy (FE-SEM).

## 3. Results and discussion

Fig. 2 shows the depth profile of hydrogen ions in fused silica investigated by SIMS. Note the measured depth includes the thin layer of gold. The peak of implanted $H^+$ ions is about 3.52 μm below the fused silica surface (without the gold coating), in good agreement with the SRIM simulation. The big tail in the depth profile may be attributed to the damage retention in the distorted/stressed region.

Fig. 3 shows the transmission spectra of the sample in the visible wavelength (400–700 nm) before and after $H^+$ implantation. The transmission is significantly improved after ion implantation because a guiding layer is formed inside the fused silica. Fused silica is compacted at the end-of-range due to the ions which undergo nuclear scattering interactions with the atoms, and, to a less extent, due to electronic interaction effects. The density change leads to an increase in refractive index near the projected range of the implanted ions; this zone then constitutes the light guiding layer of the waveguide [1].

The relationship between the transmission and the thickness of the cladding layer after etching is shown in Fig. 4. Buffered hydrofluoric acid (HF) was used to etch the cladding layer of the waveguide. With the initial erosion of the surface layer, the transmission is lowered, reaching a minimum after 60 s. Thereafter the transmission gradually increases with further etching. We suggest the following explanation: with the thinning of the surface cladding layer, scattering is increased due to an increasing roughness caused by the surface etching process, which in turn leads to lower transmission. After further etching, the cladding layer is completely removed and a new waveguide is formed with air as the cladding layer. The transmission increase at that point may be due to a reduction in roughness due to a difference in etching rate for the cladding layer compared with the layer compacted by the ion beam.

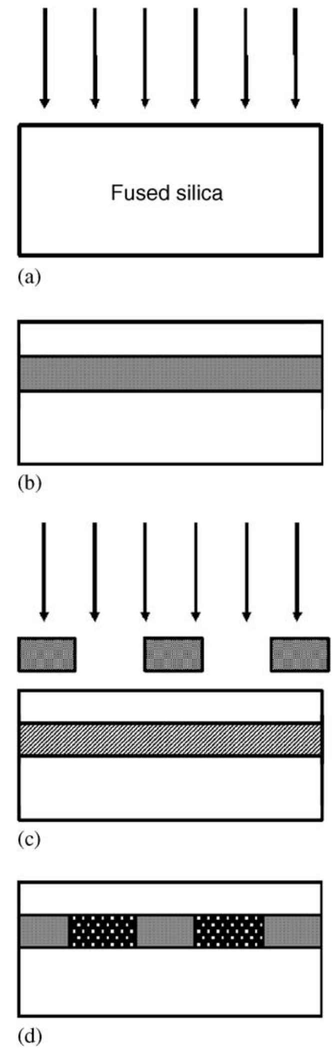


Fig. 1. Manufacturing procedure: (a) $H^+$ ion implantation in fused silica, (b) a new waveguide is formed, (c) additional $He^+$ implantation with a periodic metal mask covering the surface and (d) grating structures are formed.

Grating structures in waveguides have been made by additional $He^+$ implantation with a metal mask covering the surface periodically. Fig. 5 shows the SEM image of the surface of such a modulated sample. Periodic structures are highlighted by arrows: note that the entire sample has been