Fabrication of long-period optical fiber gratings by use of ion implantation

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We report the fabrication of long-period optical fiber gratings by use of a refractive-index increase induced by ion implantation. Helium ions were implanted in an optical fiber core through a metal mask that had a 170-μm-pitch grating with spacing of 60 μm. We obtained a wavelength-dependent effective transmission loss by use of the grating.

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Long-period optical fiber gratings formed by periodic refractive-index changes with periods of 100 μm to 1 cm in the core of an optical fiber work as narrow-band optical filters, mode converters, sensors, etc. by coupling two copropagating fiber modes.[1–5] Currently, these gratings are formed by refractive-index changes induced by ultraviolet photon irradiation.[1] To fabricate high-performance devices requires a high refractive-index change of ~0.001. However, standard optical fibers usually do not have enough photosensitivity for fabricating effective devices. Therefore, special fibers, e.g., high-Ge-concentration Ge-doped silica core fibers, are used to produce high-performance devices.[6] If fabricating the gratings in standard optical fibers is required, the fibers have to be sensitized by H_2 loading.[7,8] However, there still exist several kinds of optical fiber, such as pure silica-core fibers, that do not show sufficient photosensitivity even after sensitization.

It has been well known that relatively high refractive-index increases of as much as ~0.01 can be obtained by ion implantation in almost all silica-based glasses[9] and that the refractive-index increases are due mainly to compaction of the glasses.[9,10] Therefore, ion implantation makes it possible to fabricate optical fiber gratings in almost all kinds of silica-based optical fiber. In this Letter we report the successful fabrication of long-period cladding-mode-coupled gratings by implantation of He ions in an optical fiber.

The optical fiber used in the experiment was a Corning SMF-28 single-mode telecommunication fiber. The core of the fiber was Ge-doped silica glass of $97SiO_2{:}3GeO_2$ and had a diameter of 9 μm. The core was embedded in a cladding of pure silica glass with a diameter of 125 μm. The fiber was implanted with He^{2+} ions at room temperature in a vacuum of 10^{-6} Torr through a metal amplitude mask by use of the 1.7-MV tandem accelerator at the Université de Montréal. The acceleration energy of the He ions was 5.1 MeV, the maximum attainable. The mask was made of Ni:Co and had 29 periods of 170-μm-pitch grating with 60-μm spacing. Figure 1 shows a schematic of the alignment of the mask and the fiber. The transmission spectra of the fabricated gratings were observed with a spectrum analyzer (Hewlett-Packard 70951A).

Figure 2(a) shows a photograph of white light transmitted through the cross section of the He-ion-implanted optical fiber. The bright circle at the center is the light guided by the core of the fiber. The luminous arc across the fiber indicates the region in which the implanted He ions induced a significant refractive-index increase. As shown in Fig. 2(b), the depth of the arc from the optical fiber surface is ~24 μm, which corresponds to the projected range of the 5.1-MeV He ions in silica glass. Since ions must reach the core of the optical fiber to produce gratings in the core, we etched the cladding of the optical fiber with hydrofluoric acid (10% HF in H_2O) for 7 h and prepared an optical fiber with a cladding diameter of ~53 μm, as shown in Fig. 2(c). Figure 3 shows the transmission spectrum of the grating fabricated by the ion implantation with a dose of 20×10^{15} He^{2+}/cm^2. Very sharp and effective transmission loss owing to the coupling of the fundamental guided mode to a cladding mode was observed at 1410 nm.

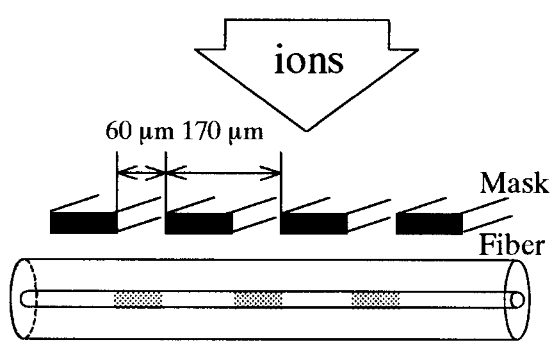

Fig. 1. Schematic of the alignment of the mask and the fiber.

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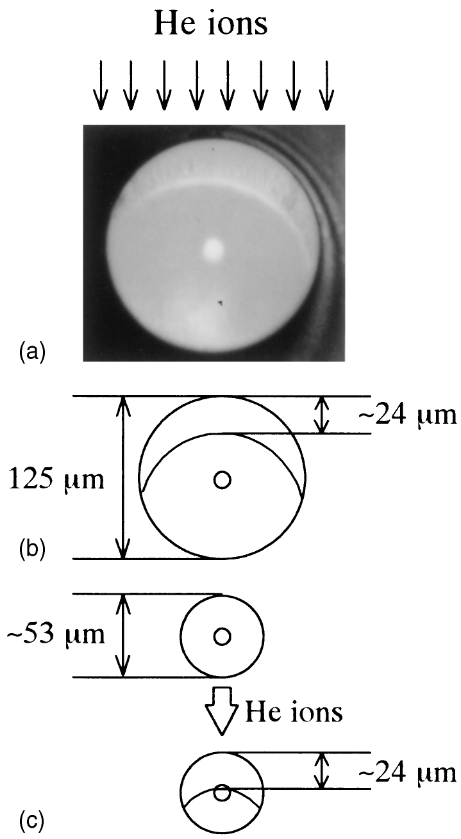

Fig. 2. (a) Photograph and (b) schematic of white light transmitted through the cross section of the He-ion-implanted optical fiber. (c) Schematic of the cross section of the optical fiber that was etched with hydrofluoric acid.

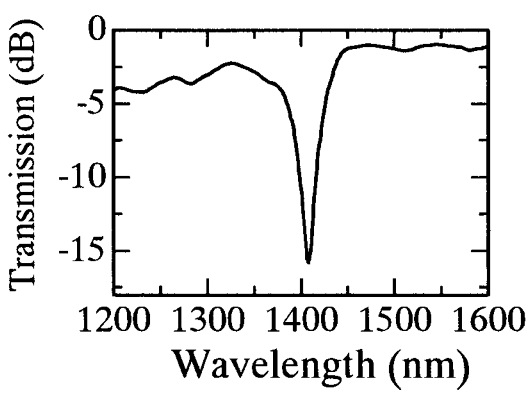

Fig. 3. Transmission spectrum of the grating fabricated by use of ion implantation.

As shown in Fig. 2, the induced refractive-index increase, indicated by the arc, was not only in the core but also in the cladding. This is so because the ion implantation induced a quite-high refractive-index increase even in pure silica glass. The refractive-index increase in the cladding causes a problem for the practical use of the gratings, because the fundamental guided mode can couple not only to the symmetric cladding modes but also to unsymmetrical ones, which results in high background loss, as can be seen in Fig. 3. However, this loss can be removed by use of a mask with narrow spacing, through which ions are implanted only in the core of the optical fiber. Furthermore, with a mask that has $\sim$1-μm-pitch gratings, this method can be applied to the fabrication of Bragg gratings[11] in optical fibers.

In summary, we have shown that long-period optical fiber gratings can be fabricated by use of ion implantation. This method makes it possible to fabricate these gratings in almost all kinds of optical fiber.

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