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Gratings in Polymeric Waveguides

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ABSTRACT

Laser-induced formation of polymer Bragg grating filters for Dense Wavelength Division Multiplexing (DWDM) applications is discussed. Acrylate monomers halogenated with both fluorine and chlorine, which possess absorption losses less than 0.25 dB/cm and wide choice of refractive indices (from 1.3 to 1.5) in the 1.5 μm telecom wavelength region were used. The monomers are highly intermixable thus permitting to adjust the refractive index of the composition within ±0.0001. Moreover they are photocurable under UV exposure and exhibit high contrast in polymerization. These properties make halogenated acrylates very promising for fabricating polymeric waveguides and photonic circuits.

Single-mode polymer waveguides were fabricated on silicon wafers using resistless contact lithography. Submicron index gratings have been written in polymer waveguides using holographic exposure with He-Cd laser beam (325 nm) through a phase mask. Both uniform and apodized gratings have been fabricated. The gratings are stable and are not erased by uniform UV exposure.

The waveguide gratings possess narrowband reflection spectra in the 1.5 μm wavelength region of 0.4 nm width, nearly rectangular shape of the stopband and reflectivity $R > 99\%$. The fabricated Bragg grating filters can be used for multiplexing/demultiplexing optical signals in high-speed DWDM optical fiber networks.

Keywords: fluorinated polymers, polymer waveguides, submicron index gratings, Bragg grating filters

1. INTRODUCTION

The advent of DWDM technology permits propagation of dozens of optical channels across a single-mode fiber with bit rates up to 40 Gbits/s per channel and channel spacing at 200, 100 and 50 GHz. It results in the necessity of developing Optical Add/Drop Multiplexers (OADM's) for 1.5 μm telecom wavelength region capable of extracting or adding a specified channel from/to a dense multichannel stream. OADM's must possess narrowband reflection/transmission spectra (0.4 – 1.6 nm width), high reflectivity ($R > 99\%$), rectangular shape of the reflection/transmission band and must be cost-effective in large-scale production. Polymer-based OADM's can meet these requirements.

The well-known technical approaches for fabricating optical multiplexers/demultiplexers include utilization of narrowband wavelength-selective filters on the basis of single-mode quartz fibers with photoimprinted refractive index gratings,[1] side-polished fibers with embedded relief gratings,[2-4] and

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single-mode channel waveguides with relief or index gratings.[5-9] Since uniform gratings with constant coupling coefficient can not provide rectangular-shaped reflection/transmission spectra due to the sidelobes outside the stopband, it was suggested to use apodized gratings or gratings with phase shifts.[10-13]

We present the results on the design and fabrication of narrowband optical filters for DWDM applications on the basis of single-mode polymer waveguides with submicron apodized index gratings. The polymer waveguides were fabricated on silicon substrates using resistless contact lithography. The index gratings were written in the waveguides using UV holographic exposure through a phase mask. Bragg grating filters have nearly rectangular shape of the stopband with 0.4 nm width and peak reflectivity $R > 99\%$. The filters can be used for multiplexing/demultiplexing optical signals in high-speed DWDM fiber networks.

2. FABRICATION OF POLYMER BRAGG GRATING FILTERS

Polymer technologies are now penetrating into many areas of telecommunications including polymer fibers and planar photonic circuits due to ease of fabrication, cost-effectiveness and compatibility with other materials. Among polymeric materials halogenated olygomers and monomers are now considered as the most promising, since they have high optical transparency, wide range of refractive indices and improved environmental stability.[14]

To fabricate polymer waveguides, we have used two compositions on the basis of halogenated acrylic monomers CH_2=CH-COO-CH_2-$(CF_2)_4$-H_2C-OOC-HC=H_2C and CH_2=CF-COO-CH_2-CCl_3 with low and high refractive indices. These liquid monomers have absorption losses less than 0.25 dB/cm around 1.5 μm, with refractive indices of $n_D = 1.379$ and $n_D = 1.459$ respectively. High miscibility of the two monomers permits to adjust the refractive index of each composition within ±0.0001. The compositions are in liquid form and do not contain a solvent, and therefore an evaporation step prior to exposure is not required.

The single-mode polymer waveguides were fabricated on silicon wafers using resistless contact lithography. Due to low viscosity of the compositions, spin coating is not an option. The multistep process used here involves the deposition and lithographic patterning of three polymer layers. First, a buffer layer using the low refractive index composition was fabricated on the Si substrate by depositing a few droplets of the composition on the precleaned Si wafer and placing a quartz plate on above. The thickness of the buffer layer is adjusted by placing spacer bands on the Si substrate prior to deposition of composition droplets. The composition is then cured with UV light. The quartz plate also prevents oxygen from reaching the polymer surface during cure process. This procedure was repeated to obtain a waveguiding layer of high index on the buffer layer. Here, using a second step, the array of rectangular cores with high refractive index and with thickness of 8 μm was produced by UV exposure through a photomask. The high photosensitivity of the composition results in UV dose requirements of only few tens of mJ/cm^2 at Hg I-line (365 nm). The pattern is then developed by conventional wet etch of unreacted material using standard organic solvents (isopropyl alcohol, methanol, acetone etc.). Finally, using a third step, the cores were covered with polymer cap layer of low refractive index.

The contact lithography allows the definition of polymeric waveguides with dimensions ranging from 2 to 10 μm due to high contrast of our halogenated compositions. The photograph of the waveguide array is shown in Figure 1, which illustrates the capability of the method. Note the well-defined straight waveguides with smooth sidewalls. Waveguides with cross sectional dimensions of $2x2\ \mu m^2$ to $8x8\ \mu m^2$ have been fabricated using this approach.

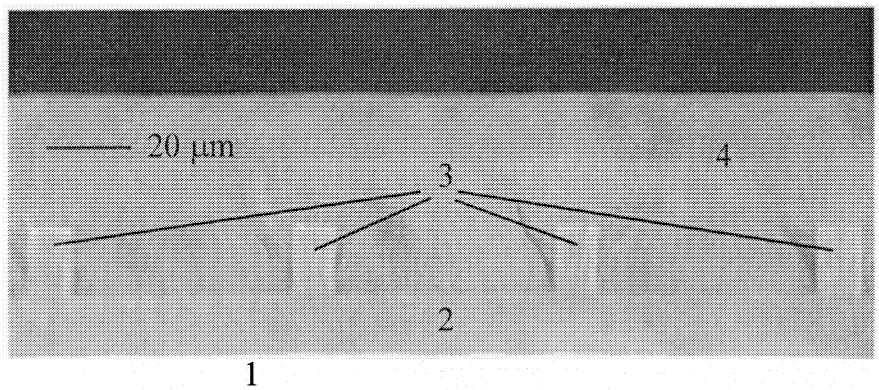

Figure. 1. Array of single-mode polymeric waveguides, fabricated using resistless contact lithography. 1 – silicon substrate, 2 – polymer buffer layer, 3 – polymer waveguide cores, 4 – polymer cap layer.

Submicron index gratings with period $d \approx 0.53\ \mu m$ were written in polymeric waveguides by holographic UV exposure through the phase mask. This was done using 325 nm line of a He-Cd laser. The phase mask was fabricated by stamping a polymeric replica from a master grating in InP material itself obtained by holographic exposure by UV light in an etchant solution, Figure 2. The incident beam had Gaussian envelope thus resulting in apodized shape of the laser-induced index grating through the phase mask.

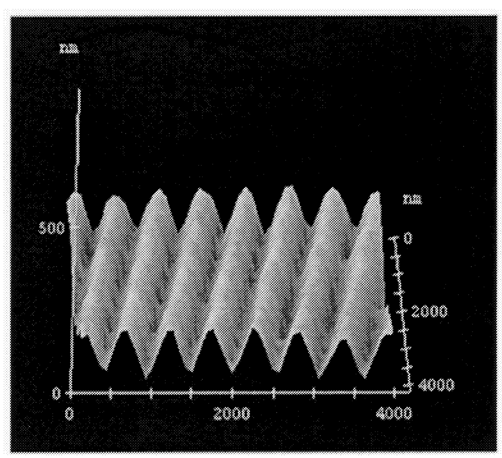

Fig. 2. AFM photograph of polymeric phase mask.

The fabricated index gratings are stable and can not be erased by uniform UV exposure. We suggest that the physical mechanism for grating growth is laser-induced mass transfer in solid polymer material. In the suggested process, an index variation can be photoinduced by causing the spatial separation of non-reacted monomers with different indices.

3. REFLECTION AND TRANSMISSION SPECTRA OF BRAGG GRATING FILTERS

The spectral characteristics of polymer Bragg grating filters were measured using a tunable diode laser, Newport 2010A. The typical reflection/transmission spectra are presented in Figure 3. The spectra are nearly rectangular-shaped due to the apodization of the grating. The width of the reflectivity stopband at $\lambda_{Br} \approx 1.56$ μm is 0.4 nm and the amplitude of the reflectivity peak is $R >$ 99%. The radiation losses in transmission on the short-wavelength side of the Bragg resonance are small because the grating has equal strength in the core and cladding regions due to the suspected laser-induced mass transfer mechanism.

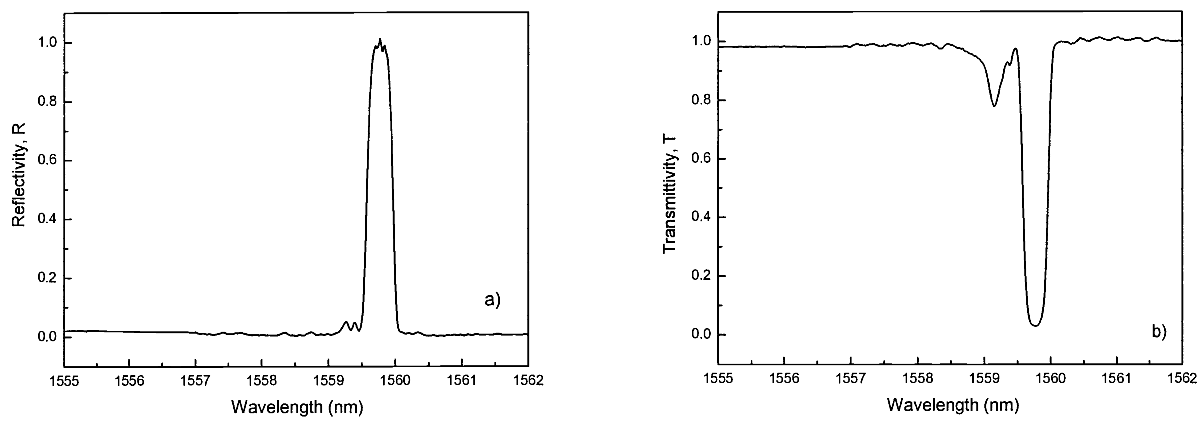

Fig. 3. Reflection (a) and transmission (b) spectra of Bragg grating filter on the basis of single-mode polymer waveguide with laser-induced apodized index grating.

4. CONCLUSIONS

The wavelength-selective optical filters for DWDM applications on the basis of single-mode polymer waveguides with laser-induced submicron index gratings are fabricated. The filters have nearly rectangular reflection spectra with stopband width 0.4 nm and peak reflectivity $R >$ 99% in the 1.5 μm telecom wavelength region. The filters can be used for multiplexing/demultiplexing optical signals in high-speed DWDM fiber networks.

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