Long-Period Waveguide Gratings

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Abstract: Polymeric long period waveguide gratings (LPWGs) were fabricated and characterized. A maximum attenuation of –18dB and a minimum bandwidth of 6nm were measured, and the grating length is as short as 1 cm.

Keywords: waveguide gratings, long period gratings, polymeric waveguides.

Introduction

Long-period grating (LPG) devices are useful for both telecommunication and sensor arenas. Many LPG devices have been demonstrated in recent years, such as band-rejection filters [1], gain flattening elements for erbium-doped fiber amplifier (EDFA) [2], optical sensors [3], wavelength selective polarizing elements [4], sensing elements/demodulators [5], and codirectional coupler filters [6]. Up to now, most of the LPG devices have been realized in optical fiber. Long period waveguide grating (LPWG) is attractive because of its small size, low cost, simple process, and potential integration with other components on the same substrate.

Polymeric optical waveguides and Bragg grating filters based on a negative tone epoxy novolak resin (ENR) have been fabricated recently using electron-beam direct writing [7, 8]. In this work, we report the fabrication and characterization of ENR polymeric LPWG.. The temperature property of the polymeric LPWG is also investigated.

Experiments

The LPWG was fabricated using standard cleanroom processing steps: 1) UV photolithography to pattern the photoresist grating on Si wafer, 2) reactive ion etching (RIE) to transfer the grating pattern onto the surface of the Si wafer, 3) thermal oxidation to form the buffer SiO_2 layer, and 4) spin coating and UV photolithography to form the ENR polymeric waveguide. Fig.1 shows the schematic diagram of the fabrication process of the polymeric LPWG.

An amplitude mask was used to expose a grating pattern on Si substrate, and the periodicity varies from 370μm to 450μm. The substrate area was ~3cm x 1cm. The grating pattern was then transferred to the Si surface by RIE using a mixture of O_2 and SF_6 gases. The grating depth is ~150nm, and the grating length L_g is ~1.7cm which is shorter than the values used for LPFGs. In general, the LPFG length is longer than 2.5cm [1,4]. After etching, the Si substrate surface was thermally oxidized, and ~1.5μm thick silicon dioxide (SiO_2) layer was used as the lower cladding layer. The refractive index of ENR polymer is ~1.575 at 1.55μm and is higher than that of SiO_2. The polymeric channel waveguide was formed on the grating embedded SiO_2/Si substrate by spin-coating and ultraviolet (UV) exposure. ENR polymer was spun at 4500 rpm for 180 s, and a pre-exposure bake of 3 min at 90°C was carried out. The polymer was exposed using a Karl Suss Mask Aligner having a highly pressurized mercury lamp with 350W power and 365nm exposure wavelength. The exposure time was 60 s. After exposure, a post-exposure bake time of 3 min at 90°C was carried out before development in propylenglygol-monomethylether-acetate (PGMEA) for 15s. The sample was then rinsed in fresh PGMEA again.

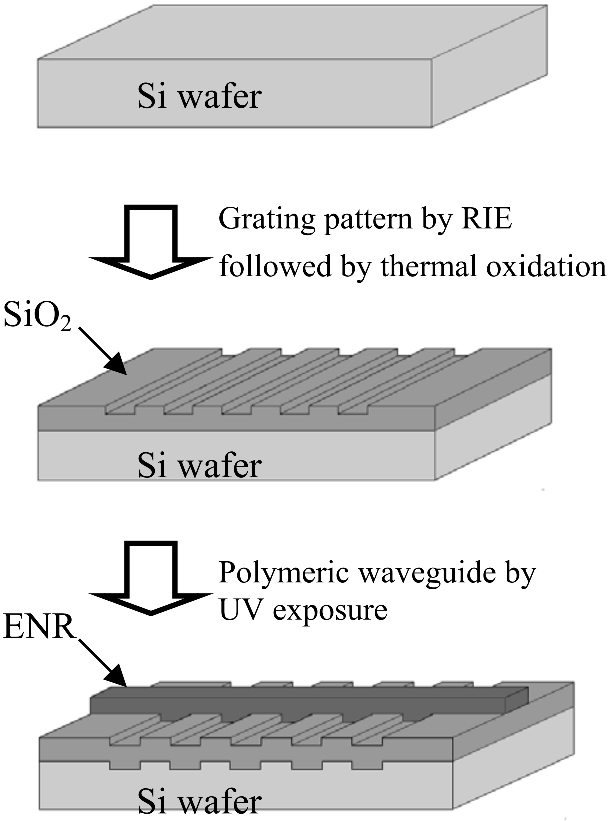

Fig. 1 Schematic diagram showing the fabrication process of polymeric LPWG

The width and height of the waveguide are 6μm and 2.2μm, respectively, and the grating pattern appears as bottom surface corrugations. The grating depth is controlled by the RIE etching time, and the designed amplitude mask determines the grating period.

Discussion and results

The transmission spectrum of the LPWG was obtained by coupling the output light from a broadband source, either an EDFA (1.5 μm wavelength band) or a superluminescent light emitting diode (SLED, either1.3 μm or1.4 μm wavelength band), into one of the cleaved ends of the device. The output light of the device was collected using a single mode fiber and analyzed using a HP8210A optical spectrum analyzer (OSA), and index matching fluid was used to minimize Fresnel reflections during the measurements. Fig. 2 shows the dependence of transmission peak wavelength on grating period. As expected, a linear relationship is obtained in accordance to the phase matching condition, and Δn_{eff}, defined as the effective index difference between the guided and radiation modes, corresponds to the slope of the straight line. From Fig. 2, the slope is ~3.9×10^{-3}. In Fig. 3(a), a transmission peak of ~ –10dB at 1.3μm wavelength was observed, corresponding to > 90% attenuation, and in Fig. 3(b), a transmission peak of ~ –13dB at 1.5μm wavelength was observed, corresponding to an > 95% attenuation. The bandwidths are ~6nm in both cases. The sidelobes, -1dB and –3dB, that appear in the spectra in Fig 3(a) and Fig. 3(b), respectively, are similar to those reported in [4] and [6], indicating that there is some non-uniformity in the LPWG. As shown in Fig. 3(c), by optimizing the fabrication processes and the structure, a transmission peak of ~ –18dB at 1.4μm wavelength with negligible sidelobes was observed, corresponding to >98% attenuation. The grating length and depth in this case are ~1cm and ~400nm, respectively, and the bandwidth is ~13nm. Compared to LPFG the attenuation in LPWG is similar (> -10dB), the L_g is shorter (<2cm), and the 3dB bandwidth is narrower (<13nm). LPWG offers many advantages, because of its compact size and possible integration with other components on the same substrate.

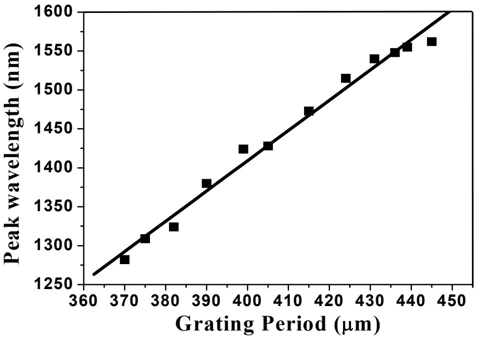

Fig. 2. Transmission peak wavelength as a function of grating periodicity

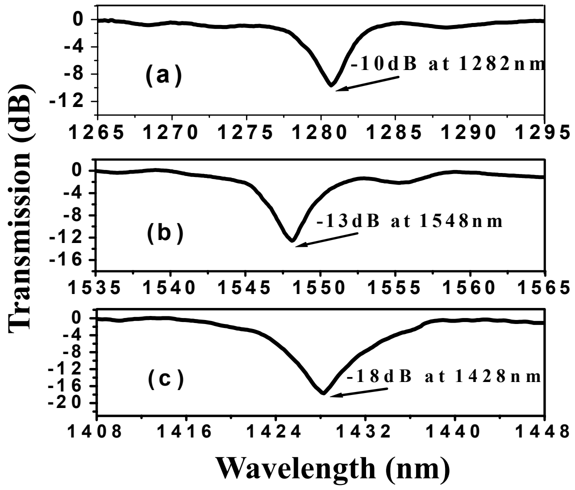

Fig. 3. Transmission characteristics of LPWG at (a) 1.3μm wavelength, (b) 1.5μm wavelength and (c) 1.4μm wavelength

The temperature characteristic of the LPWG was investigated, and the change in peak wavelength versus temperature $d\lambda/dT$ is found to be ~ –0.165nm/°C. This value is similar to those measured in LPFGs, which exhibit temperature sensitivity in the range of 0.05-0.16nm/°C [3,9]. The insertion loss of the LPWG device was also measured, and is in the range 9-10dB which is similar to that reported in [10]. This high value is due to the mode mismatch, the propagation loss, and the end-face scattering loss between the waveguide and the fiber. Polishing the two end faces can reduce further the insertion loss.

Conclusion

In conclusion, LPWG has been demonstrated in ENR polymeric waveguide using standard cleanroom fabrication processes. Experimental results show a linear relationship between the grating period and the transmission peak wavelength. The grating depth and period can be controlled easily in the fabrication steps. The LPWG exhibits high attenuation transmission (up to -18dB), narrow bandwidth (down to 6nm), and short grating length (less than 2cm). In addition, the temperature characteristic of the LPWG was also measured, and is similar to those reported for LPFGs. LPWG is attractive because of its small size, low cost, and potential integration with various optical components and functional devices on the same SiO_2/Si substrate.

Acknowledgment

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