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UV-written long-period waveguide grating coupler for broadband add/drop multiplexing

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ABSTRACT

We demonstrate a UV-written polymer long-period waveguide grating (LPWG) coupler, which offers a bandwidth of ~20 nm, a maximum coupling efficiency of ~80% and ~60% for the TE and TM polarizations, respectively, and a wavelength-tuning range over the (S + C + L)-band (~140 nm) with a temperature control of ~25 °C. The LPWG coupler has the potential to be developed into a practical broadband add/drop multiplexer for coarse wavelength-division-multiplexing applications.

1. Introduction

Optical add/drop multiplexers (OADMs) are critical components in the development of wavelength-division-multiplexed (WDM) transmission networks. A conventional fiber-optic OADM consists of a fiber Bragg grating and two optical circulators [1] and is an expensive and bulky device. Much more compact OADMs with different configurations based on planar optical waveguides have been proposed, which include, for example, Bragg-grating assisted couplers [2,3], Mach–Zehnder interferometers [4,5], arrayed waveguide gratings [6], and X-crossing vertical couplers [7]. All these OADMs can provide a narrow bandwidth to satisfy the channel-spacing requirement (0.4 nm or 0.8 nm) of dense WDM (DWDM) systems. On the other hand, compact broadband OADMs for coarse WDM (CWDM) systems, which require a channel spacing of 20 nm, have not received much attention, regardless of the fact that CWDM systems are widely considered as the desired solutions for short-distance access networks, such as FTTH and LAN applications [8]. In this paper, we demonstrate a compact broadband OADM based on the configuration of two parallel long-period waveguide gratings (LPWGs), which was fabricated with polymer waveguides by using a simple UV-writing technique.

LPWG [9] is the waveguide counterpart of the well-known long-period fiber grating (LPFG) [10]. Such a grating enables strong light coupling from the core mode to selected cladding modes at specific resonance wavelengths and is intrinsically a band-rejection filter. The flexibility of the optical waveguide technology allows a wider range of devices, especially tunable devices, to be realized with LPWGs. In fact, a number of widely tunable LPWG devices, such as band-rejection filters [11], band-pass filters [12], variable attenuators [13,14], and OADMs [15], have been demonstrated experimentally. The LPWG OADM demonstrated [15] consists of two parallel, coupled LPWGs, where light on resonance is coupled from the launching core into the cladding of the composite structure through the grating in the launching core and then coupled into the neighboring core through the other grating [16]. As the optical power transfer between the two cores in such a coupler is achieved purely by the grating effect, the spatial separation between the two cores can be large [16], which can simplify the design work and relax the fabrication tolerance. The first demonstrated OADM of this kind was fabricated by the conventional microfabrication process, where the gratings were etched into the cores of the waveguides. It gave a maximum coupling efficiency up to 34% [15]. The rather low coupling efficiency was due to the difficulty in the prediction of the corrugation depth required and the geometric asymmetry in the fabricated device. In the conventional microfabrication process, the cladding of the composite structure is applied after the gratings have been formed, which means that the grating pitch can only be predicted from the assumed cladding characteristics. On the other hand, the LPWG coupler presented in this paper was fabricated by a simple UV-writing technique [17], which allows the grating to be formed after the waveguide has been fabricated and characterized and, therefore, can provide a more accurate control of the grating

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characteristics. In addition, we employ a UV-insensitive epoxy as the cladding material [17], which makes possible the writing of the gratings into the cores of the coupler. The UV-written coupler offers a bandwidth of ~20 nm and a wavelength-tuning range of ~140 nm with a maximum coupling efficiency as high as ~80% and ~60% for the TE and TM polarizations, respectively.

2. Device fabrication

Fig. 1a shows a schematic diagram of our LPWG coupler, which consists of two parallel gratings LPWG-1 and LPWG-2. The gratings are formed in two well separated cores made of benzocyclobutene (BCB) and embedded in a common epoxy cladding. Light launched into one of the cores is coupled to the cladding mode of the entire structure by the grating in the launching core. Simultaneously, the cladding mode is coupled into the parallel core by the other grating. The output spectra from the two cores show complementary band-rejection and band-pass characteristics. Evanescent-field coupling between the two cores is negligible because of the large core separation [16].

To fabricate the coupler shown in Fig. 1a, we first formed a layer of 1.9-μm thick BCB (Dow Chemical Co.) on a SiO_2–Si substrate (the SiO_2 layer was 3 μm thick) by spin-coating and thermal curing. We then patterned and etched the BCB film into two identical 3-μm wide cores with a separation of 20.5 μm by photolithography and reactive ion etching (RIE). Finally, we spin-coated a 10.7-μm thick epoxy (OPTOCAST 3505 from Electronic Materials Inc.) film on the whole waveguide structure and etched it into a cladding with a nominal width of 45 μm by photolithography and RIE again. The refractive indexes of the BCB and epoxy films for the TE polarization, measured by a prism-coupler system (Metricon 2010) at 1536 nm, were 1.5397 and 1.5085, respectively. The dimensions of the waveguide structure were determined by a surface profiler (Ambios XP-2). An SEM image of the cross-section of a fabricated waveguide is shown in Fig. 1b. We can see from Fig. 1b that the structure is not perfectly symmetrical. The distances from the cladding walls to the left and right cores are 9.2 and 9.8 μm, respectively. The small offset (0.6 μm) was caused by the alignment tolerance and/or the error in the mask aligner during the alignment of the cores with the cladding, which was limited by the facilities available in our laboratory.

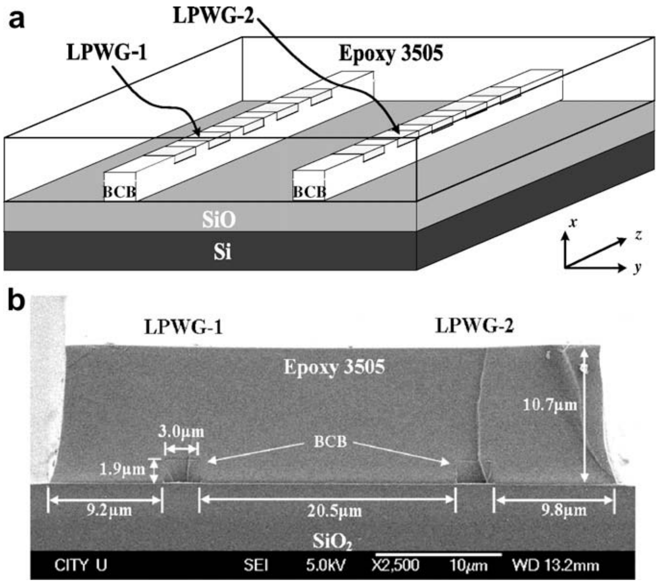

Fig. 1. (a) The LPWG coupler consists of two parallel gratings (LPWG-1 and LPWG-2) formed in the BCB cores embedded in a common epoxy cladding. (b) SEM image of the cross-section of the fabricated LPWG coupler.

The photosensitivity characteristics of BCB and epoxy OPOCAST 3505 in thin-film form have been investigated using a UV lamp (Novacure 2100) as the irradiation source [17]. It has been shown that the refractive index of a BCB film can be increased irreversibly by as much as ~0.01 after a long exposure to the radiation of the UV lamp, while the refractive index of an epoxy film remains unchanged. Therefore, to form the gratings directly in the cores, it is only necessary to expose the composite waveguide structure to the radiation from the UV lamp through a suitable amplitude grating mask over a period of time. In our experiments, the output power density of the UV lamp was set at 2000 mW/cm^2 and the total exposure time was 28 min. The amplitude mask used was a chromium mask, which contained a grating pattern that was 10 mm long and had a pitch of 103 μm. It should be mentioned that the resonance wavelength of the gratings shifted to the longer wavelength during the writing process (because of UV-induced index change in the cores). The grating pitch chosen already took that into account and was expected to produce resonance wavelengths at ~1500 nm for both polarizations. In general, the resonance wavelength of a polymer LPWG can be tuned thermally over a wide range [11,12,14,15]. Therefore, the accuracy in the determination of the grating pitch needs not be too high.

3. Experiment results and discussion

We measured the transmission spectra of the UV-written LPWG coupler with a broadband source and an optical spectrum analyzer. We placed a heat pump below the substrate to control the temperature of the device. Fig. 2a and b show the normalized transmission spectra measured at 39.4 °C for the TE and TM polarizations, respec-

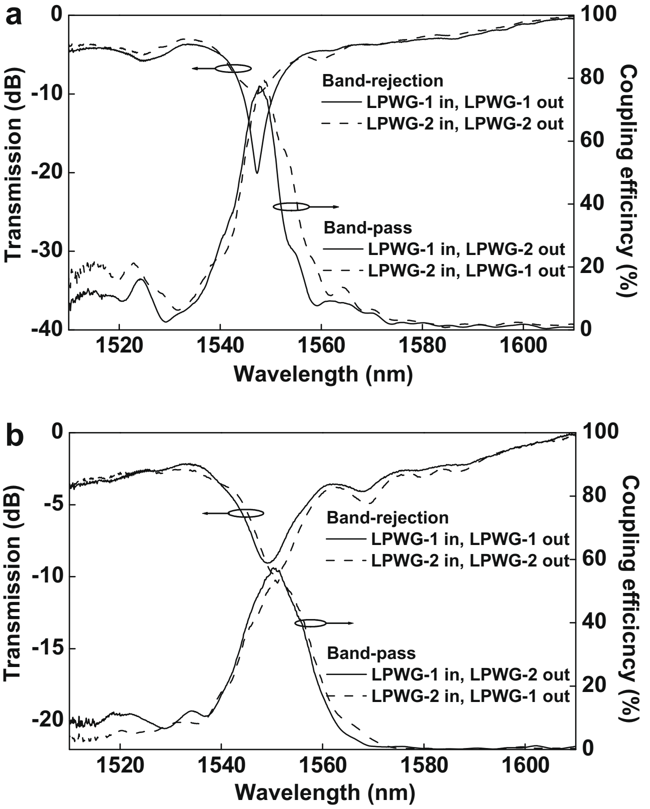

Fig. 2. Normalized transmission characteristics of the LPWG coupler measured at 39.4 °C for (a) the TE polarization and (b) the TM polarization.