Polymeric Bidirectional Wavelength Filter Based on Multimode Interference

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***Abstract* - We proposed and demonstrated a polymer-based wavelength division multiplex filter based on multimode interference for 1.31/1.55-µm bidirectional operation. The design of the filter chip was optimized by simulation based on the beam propagation method.**

I. Introduction

The fiber-to-the-home (FTTH) networks have been considered as a final broadband access network solution to business or home customers by optical communication service. The wavelength division multiplexing (WDM) filter is one of the key components for the bidirectional module in the FTTH system because the WDM technology can be used to increase information capacity in optical fiber communication [1]. Several integrated optics schemes have been proposed to perform this function, including asymmetric Mach-Zehnder interferometer (MZI), conventional directional coupler (DC), thin film filter (TFF), asymmetric Y-branching devices, and multimode interference (MMI) devices [2]-[3]. Among them, the WDM filter based on MMI has attracted increased interest in recent years because of important advantages such as compact size, low excess loss, wide bandwidth, polarization independence, and relaxed fabrication tolerance [4]. Several groups have reported the design and fabrication of WDM filter for 1.31/1.55-µm bidirectional operation. However, these devices were all made by planar lightwave circuit (PLC) technology. Compared with the complex fabrication process and corresponding high cost of silica-based MMI filter chips such as PLC devices, polymer-based MMI filter chips using nano imprint lithography (NIL) are attractive because they are relatively simple to process and have shown promise for use in low-cost devices [5]-[6]. Nano imprint techniques, such as hot embossing technique and Ultraviolet (UV)-embossing are powerful tools for producing a large volume of waveguides. Especially, the hot embossing technique is appropriate to fabricate high-precision polymer microstructures for optical components.

In this paper, we proposed a polymer-based WDM filter chip, fabricated using a hot embossing process, and based on MMI for 1.31- and 1.55-µm bidirectional operation. The MMI device functions either as a multiplexer or demultiplexer, depending on the direction of light propagation with a sufficient optical crosstalk and insertion loss.

II. Simulation and Fabrication

The proposed MMI wavelength division multiplexer/ demultiplexer is schematically shown in Fig. 1. The WDM filter consists of three parts: a single mode input waveguide section, a wide multimode waveguide section, and two separate single mode output waveguides section. The operating principle of the MMI multiplexer is based on the self-imaging effect in a multimode section [7]. The transmission characteristics of the WDM filter chip was simulated by using BeamPROP, a software based on the beam propagation method (BPM).

The refractive indices of the polymer used for core and cladding were 1.4916 and 1.4804, respectively, with an index difference (Δ) of 0.75%. The size of the single mode channel waveguides for input and output channel was 6 µm × 6 µm. The width (W_{MMI}) and length (L_{MMI}) of the MMI region was 14 µm and 3756 µm, respectively.

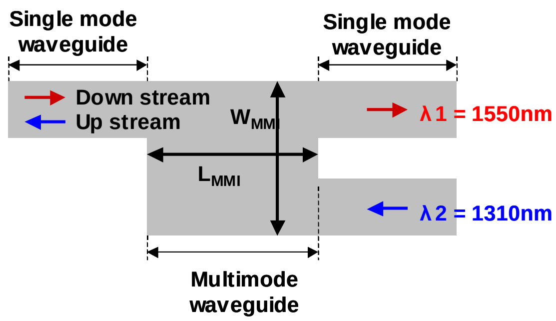

Fig. 1. Schematic view of WDM filter chip based on multimode interference.

Fig. 2 (a) shows a photograph of the quartz master for embossing process of MMI structure on polymer was fabricated using a deep reactive ion etching (DRIE) process and (b) shows an SEM picture of fabricated polymer based MMI device.

Using the quartz master, MMI structure was embossed in one-step on the PMMA sheet by the hot embossing process. A PMMA sheet was heated above its glass transition temperature (Tg) and a master was pressed into the sheet with pressure. After an adequate embossing time (holding time), the polymer was cooled down below its Tg and then the mold is lifted up. The embossed structure was filled with UV-curable optical adhesives, whose refractive index was 1.4916. Then, the core material was cured with a 365 nm UV light for 10 minutes in N2 atmosphere. After the core material curing, an over-clad PMMA was coated and then cured under the same conditions as the core.

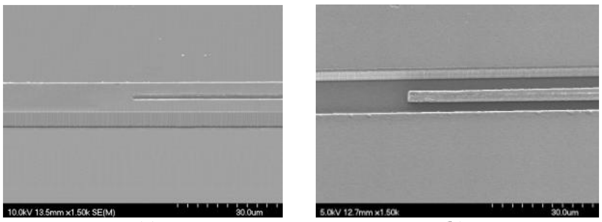
(a) (b)

Fig. 2. Schematic view of WDM filter chip based on multimode interference.

The sidewall roughness of polymeric MMI waveguide channel fabricated by these embossing process was about 20nm (RMS) measured by a WYKO interferometer.

Fig. 3 (a) and (b) show the beam propagation method simulation of the two wavelengths propagating signal along the waveguide. The MMI waveguide acts as a cross-coupler and as a bar-coupler at 1.31 and 1.55-μm wavelengths, respectively. From these two figures, it is obvious that the proposed MMI waveguide performs the multiplexing/demultiplexing operation.

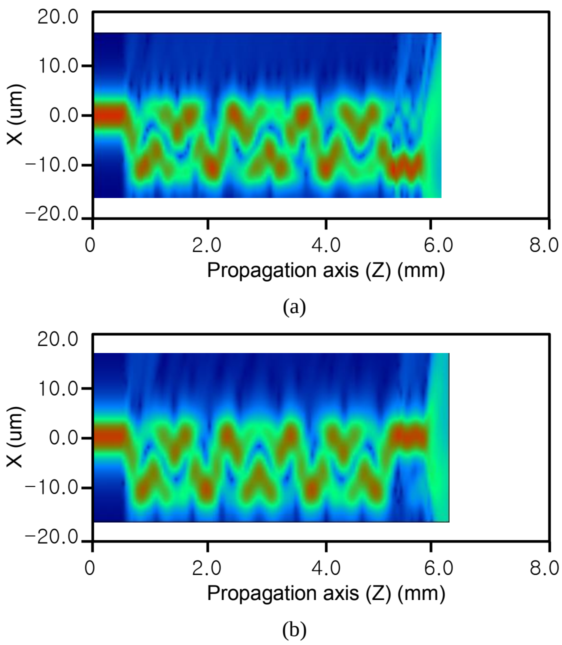

Fig. 3. Beam propagation method simulation of the MMI-based WDM filter for bidirectional operation : (a) the cross state at wavelength 1.31 μm and (b) the bar state at wavelength 1.55 μm.

Fig.4 shows the simulated and measured results of the polymeric WDM filter chip in terms of spectral response. For the measurement setup, the light beams produced by a tunable laser source in the range of 1.2 μm ~ 1.6 μm wavelengths were focused on the cleaved facet at the input waveguide using a single mode fiber. Optical crosstalk of the 1.55 μm downstream port to the 1.31 μm upstream port was about -35 dB, with corresponding insertion losses of WDM filter chip of about 5.3 dB and 5.1 dB, respectively. Here, the insertion losses included input and output coupling losses of about 1.0 dB/point between the WDM filter chip and the optical fiber.

We also measured the contrast of WDM filter chips, which was used as a measure of device performance. Referring to Fig. 4, we define the contrast at 1.31 μm and

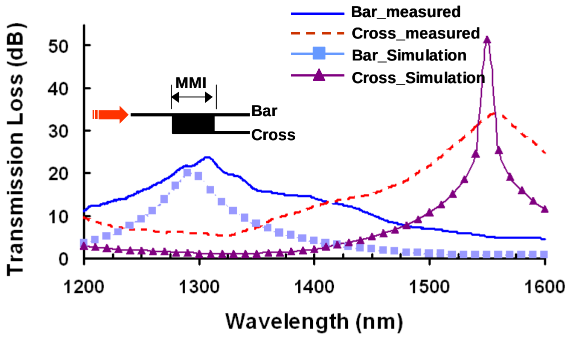

Fig. 4. Spectral response characteristics of the WDM filter chip based on MMI. Scattered dots lines are measured results. Solid and dashed lines are BPM simulated results.

1.55 μm wavelengths as being $|10\mathrm{Log}(P_{bar}/P_{cross})|$. In this case, the optical contrasts of the 1.31 μm and 1.55 μm signals were demonstrated about 17.9 dB and 28.1 dB, respectively.

III. Conclusion

We have demonstrated a polymeric WDM filter chip based on multimode interference using a hot embossing process. The device functions either as a multiplexer or a demultiplexer, depending on the direction of light propagation. The design of the WDM chip was optimized by simulation using the beam propagation method. At optimized MMI length and the MMI width, contrast of 17.9 dB and 28.1 dB and insertion losses of 5.3 dB and 5.1 dB are obtained at 1.31- and 1.55-μm. This technology enables the reduction of fabrication costs and can be used to realize various photonic integrated circuits in polymers.

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