Polymeric flat focal field arrayed waveguide grating using electron-beam direct writing

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Received December 29, 2003

A four-channel 400-GHz spacing flat focal field arrayed waveguide grating (AWG) demultiplexer is designed based on polymeric optical waveguide. The waveguide core-layer material is a newly developed negative tone epoxy Novolak resin (ENR) polymer with ultravoilet (UV) cured resin Norland optical adhesive 61 (NOA61) as the cladding layer. The device is fabricated using electron-beam direct writing, which has less processing steps than the reported polymeric AWGs. The experimental result is presented.

OCIS codes: 250.5460, 060.1810, 130.3120.

Arrayed waveguide grating (AWG) is one of the most promising devices for multiplexer/demultiplexer in future wavelength division multiplexing (WDM) system because of its low insertion loss, high stability, and low cost[1,2]. Polymeric AWG multiplexers have attracted much attention due to their low cost possibility and easy fabrication that can be compared to silica-based ones[3−6]. Polymeric optical waveguide devices may be fabricated in many ways, such as direct photolithography, reactive ion etching (RIE), molding, and embossing[7]. Electron-beam direct writing has the advantages of allowing rapid prototyping without mask and allowing writing complex structure with nanometer pattern flexibly. This letter describes an AWG demultiplexer fabricated on a newly developed negative tone epoxy Novolak resin (ENR) polymer using electron-beam direct writing.

ENR is a cross-linkable polymer, having high refractive index, negative tone property, large hardness, and glass transition temperature (T_g) of $>$ 200 °C for full cross linking[8]. The crucial factor for electron-beam direct writing is that ENR is an electron-beam-sensitive polymer. The saturation dosage is 3.8 μC/cm^2 at 50 keV on the silicon substrate. It is 100 times more sensitive than conventional polymethyl-methacrylate (PMMA)[8,9]. Therefore, the writing speed is more than 100 times faster.

A single-mode polymeric waveguide using ENR (Microchem Corp.) as the core-layer is designed as shown in Fig. 1. The cladding layer is ultraviolet (UV) cured resin Norland optical adhesive 61 (NOA61). At 1550-nm wavelength, the refractive indices of ENR and NOA61 are 1.575 and 1.54, respectively, giving a high refractive index contrast between the core and cladding of 2.2%. A new-type four-channel 400-GHz spacing flat focal field AWG demultiplexer, with the focal signals of all operating wavelengths focusing along a straight line[10,11], is designed based on the polymeric waveguide. The design parameters of the demultiplexer are listed in Table 1.

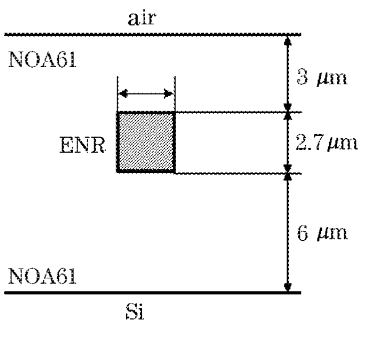

Fig. 1. Schematic diagram of the single-mode polymeric waveguide.

Table 1. Design Parameters of the Flat Focal Field AWG Demultiplexer

Parameter	Value
Central Wavelength	1550 nm
Free Spectral Range	12.8 nm
Diffraction Order	121
Effective Index of Channel Waveguide	1.5554
Effective Index of slab Waveguide	1.5646
Spacing of Arrayed Waveguide	9 μm
Spacing of Input and Output Waveguides	20 μm
Focal Length of Slab	723.0 μm
Grating Waveguide Number	37
Chip Size	7×3 mm^2

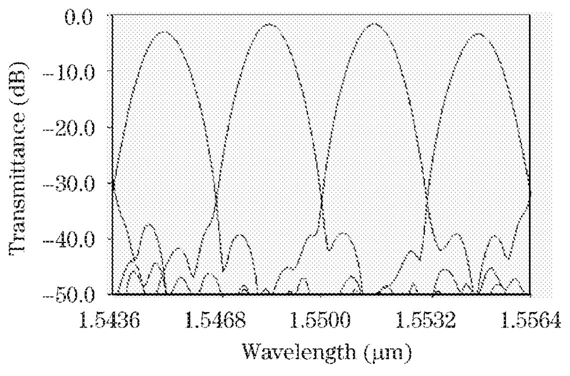

Fig. 2. Transmission spectra of four-channel 400-GHz spacing flat focal field AWG demultiplexer.

The waveguide structure ensures strong confinement of the light in the waveguide and allows low-loss bend with radius as small as 2 mm. The transmission spectra are simulated using beam propagation method (BPM), the results are shown in Fig. 2.

The AWG demultiplexer is fabricated on a 4-inch silicon wafer. 6-μm-thick NOA61 is firstly spin coated on the substrate as the bottom cladding layer and cured for 30 minutes using UV light at 365-nm wavelength and 350-W power. To further improve the adhesion, the sample is baked at 50°C for 12 hours in an oven. 2.7-μm-thick ENR is then spin coated on as the waveguiding layer. A prebake time of 5 minutes at 90°C is applied before exposure. The pattern exposure is performed using Leica EBL-100L nanowriter system at 50 keV, and the electron-beam spot diameter is 70 nm. The postexposure bake time is 3 minutes at 90 °C. After postexposure baking, the resist is developed for 20 s in propylenglygolmonomethylether-acetate (PGMEA), and then rinsed in fresh PGMEA again to form the slab and channel waveguides. No other subsequent process is required. Then, the pattern is covered with 3-μm-thick UV-cured NOA61 upper cladding layer.

Figure 3 shows the magnified (×200) image of a section of the AWG demultiplexer where tapered arrayed waveguides, with taper-end width of 8 μm and taper angle of 2°, meet the slab region. Figure 4 shows the scanning electron microscope (SEM) image of the cross-section of the channel waveguide.

Light from a wide-band erbium-doped optical fiber amplifier (EDFA) (1528 – 1563 nm) is butt-coupled into the input waveguide through standard single-mode fiber (SMF). The input and output waveguides are tapered and the taper-end widths are optimized for more efficiently butt-coupling with SMFs. The signals from the output waveguides are magnified (×20) by lens and received by infrared vidicon camera. Four clear mode images are observed on the monitor, as shown in Fig. 5.

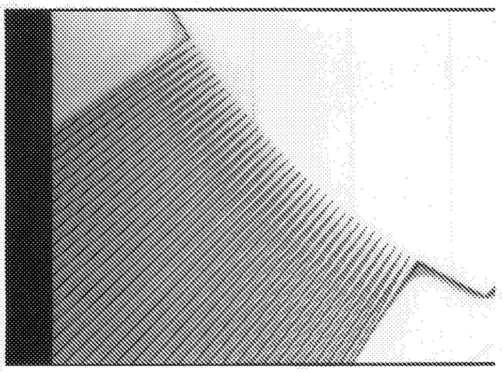

Fig. 3. Magnified (×200) image of region where tapered arrayed waveguides meet slab.

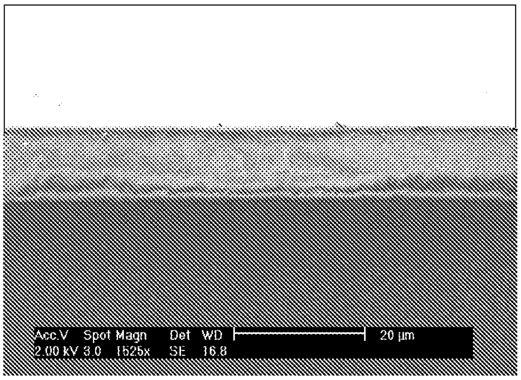

Fig. 4. SEM image of the cross-section of the channel waveguide.

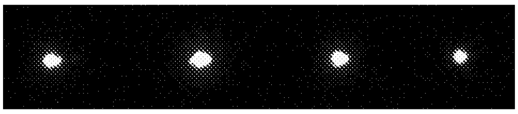

Fig. 5. Output of the 1×4 flat focal field AWG demultiplexer.

In conclusion, a 1×4 new-type flat focal field AWG demultiplexer is fabricated based on a newly developed ENR polymer using electron-beam direct writing. Four clear mode images from the output waveguides are observed. Further fabrication and experiment are underway.

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References

1. M. K. Smit, Electron. Lett. **24,** 385 (1988).
2. Y. L. Chu and H. Y. Zhang, Chin. Opt. Lett. **1,** 196 (2003).
3. H. Takahashi, I. Nishi, and Y. Hibino, Electron. Lett. **28,** 380 (1992).
4. Y. Hida, Y. Inoue, and S. Imamura, Electron. Lett. **30,** 959 (1994).
5. M. B. J. Diemeer, L. H. Spiekman, R. Ramsamoeji, and M. K. Smit, Electron. Lett. **32,** 1132 (1996).
6. Y. H. Min, M. H. Lee, J. J. Ju, S. K. Park, and J. Y. Do, IEEE J. Sel. Top. Quantum Electron. **7,** 806 (2001).
7. L. Eldada and L. W. Shacklette, IEEE J. Sel. Top. Quantum Electron. **6,** 54 (2000).
8. W. H. Wong and E. Y. B. Pun, J. Vacuum Science and Technology B **19,** 732 (2001).
9. R. Waldhausl, B. Schnabel, E. B. Kley, and A. Brauer, Electron. Lett. **33,** 623 (1997).
10. D. Y. Wang, G. F. Jin, Y. B. Yan, and M. X. Wu, J. Lightwave Technol. **19,** 279 (2001).
11. S. Lu, W. H. Wong, E. Y. B. Pun, Y. B. Yan, D. Y. Wang, D. E. Yi, and G. F. Jin, Opt. and Quantum Electron. **35,** 783 (2003).