Polymeric 32-channel arrayed waveguide grating multiplexer using fluorinated poly (ether ether ketone)

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In wavelength division multiplexing (WDM) systems, an arrayed waveguide grating (AWG) multiplexer is a key component. A polymeric AWG multiplexer has recently attracted much attention due to its low cost processing and a potential of integration with other devices. Fluorinated poly (ether ether ketone) (FPEEK) is excellent material for fabrication of optical waveguides due to its low absorption loss at 1.55-μm wavelength and high thermal stability. A 32-channel AWG multiplexer has been designed based on the grating diffraction theory and fabricated using newly synthesized FPEEK. During the fabrication process of the Polymer/Si AWG device, spin coating, vaporizing, photolithographic patterning and reactive ion etching (RIE) are used. The AWG multiplexer measurement system is based on a tunable semiconductor laser, infrared camera and a Peltier-type heater. The device exhibits a wavelength channel spacing of 0.8 nm and a center wavelength of 1548 nm in the room temperature.

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The wavelength division multiplexing (WDM) system has become the preferred technology for further increasing the capacity of the optical fiber telecommunication infrastructure[1,2]. An arrayed waveguide grating (AWG) multiplexer is a key component for WDM systems because both add-drop multiplexing and wavelength routing require its use[3]. AWG multiplexers have been fabricated using silica[4], semiconductor (InP)[5], and polymer[6,7]. Among them, a polymeric AWG multiplexer has recently attracted much attention due to its easy fabrication, a low cost possibility and a potential of integration with other devices such as polymer thermo-optic switches for an add-drop multiplexer etc.

Key issues in the polymer waveguide materials include a low propagation loss at 1550-nm wavelength[8], a high thermal stability[9], a small birefringence, and easy control of the refractive index. Fluorinated poly (ether ether ketone)(FPEEK), is developed for interlayer dielectric materials and represents good candidate materials for optical waveguide devices because of their excellent thermal stability, mechanical properties and low moisture absorption in the near-infrared region.

In this paper, an AWG multiplexer is described, in which a newly synthesized cross-linkable FPEEK is used. We are able to control the refractive index of polymers from 1.455 to 1.531 by varying the composition ratio of monomers.

Figure 1 shows a schematic waveguide layout of the multiplexer. The AWG multiplexer consists of 32 input waveguides, 32 output waveguides, two focusing slab waveguides, and an arrayed waveguide grating, all of which are integrated on the same substrate. Multiplexed light input from a fiber is launched into one of the input waveguides. The light is diffracted in the slab and coupled into the arrayed waveguide. Every arrayed waveguide is located on a circle whose center is the end of the center input waveguide. The radius of the circle is the focal length of the slab. The diffracted light enters the arrayed waveguide with the same phase. The arrayed waveguides are separated with no coupling between them. The lengths of any two adjacent waveguides differ by constant. Each light propagates individually in the waveguide, thus attaining a phase difference at the waveguide exit. This results in wavelength-dependent wavefront tilting. The light from the arrayed waveguide grating is focused in the vicinity of the output waveguides by the output slab waveguide. The position of the input/output waveguides, slab waveguide and arrayed waveguide is based on the Rowland circle construction in the same way as a conventional concave reflection grating system. The focal position depends on the wavelength because of the wavelength-dependent phase shift caused by the path difference in the arrayed waveguide. Finally, the light is demultiplexed into the respective output waveguides[10,11]. Based on the grating diffraction theory, the AWG design parameters are listed in Table 1[12].

When synthesizing our new polymer for the AWG multiplexer, the following four important aspects are focused on: 1) Low intrinsic absorption loss in the near infrared

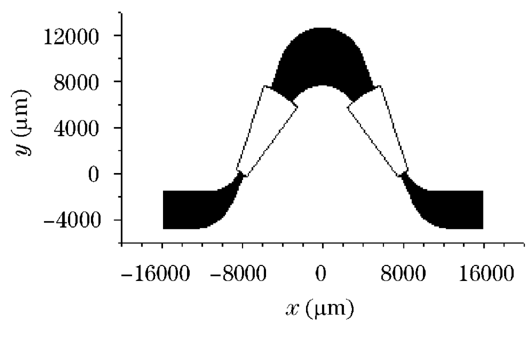

Fig. 1. Schematic waveguide layout of the 32-channel AWG.

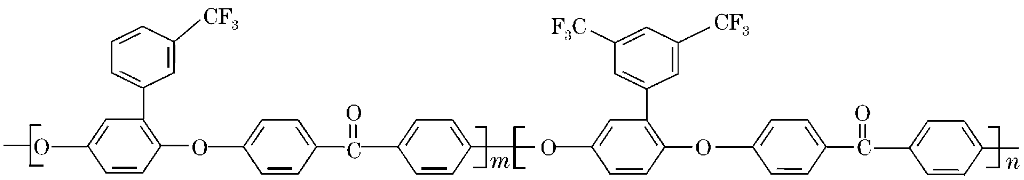

Fig. 2. Chemical structure of copolymer 3F-PEEK and 6F-PEEK.

Table 1. Design Parameters of the 32×32 AWG Multiplexer

Center Wavelength	1550 nm
Wavelength Spacing	0.8 nm (100 GHz)
Waveguide Thickness	4 μm
Waveguide Width	4 μm
Refractive Index of Waveguide Core	1.499
Refractive Index of Waveguide Cladding	1.487
Effective Refractive Index of Arrayed Waveguide	1.490
Effective Refractive Index of Slab Waveguide	1.495
Group Index	1.500
Diffraction Order	56
Pitch of Adjacent I/O and Arrayed Waveguide	15 μm
Length Difference of Adjacent Arrayed Waveguide	58.28 μm
Focal Length of Slab Waveguide	7458 μm
Free Spectral Range	27.6 nm
Number of Arrayed Waveguide	201

region, 2) high thermal and environmental stability, 3) high refractive index controllability, and 4) small birefringence. Many polymers have high optical loss in the infrared region due to carbon-hydrogen (C-H) bond vibrational absorption. By modifying a molecule via the substitution of fluorine or deuterium for hydrogen in the C-H may reduce greatly optical loss.

We use a copolymer of two kind of FPEEK, synthesized from (3-trifluoromethyl)phenyl hydroquinone (3F-PH) with 4,4'-difluorobenzophenone and (3,5-ditrifluoromethyl)phenyl hydroquinone (6F-PH) with 4,4'-difluorobenzophenone, as waveguide materials[13]. Varying the composition ratio of the 3F-PH and 6F-PH can control the refractive index of polymers from 1.455 to 1.531. The copolymer molecular structures are shown in Fig. 2.

In experiment, a 32-channel AWG multiplexer using the FPEEK is fabricated. The fabrication processes are as following: First, an under-cladding and core are spin-coated on a Si substrate and cured at 360 °C for 2 hours, respectively. Then the aluminum film with the thickness of 10−30 nm is vaporized on the surface of the core layer. Next, the AWG multiplexer pattern is formed on the Al film by conventional photolithography and wet etching. By etching the Al film, AWG multiplexer pattern is transferred onto the core surface. Then the core ridges are formed by O_2 gas reactive ion etching using the Al as a mask. Finally, after removing the Al mask, the core ridge is covered with an over-cladding layer by spin coating. Figure 3 is a schematic diagram of the fabrication process. Figure 4 shows an atomic force microscopy (AFM) photograph of the core ridge of the waveguides.

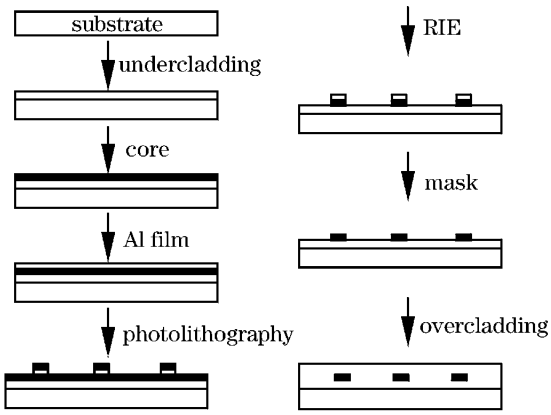

Fig. 3. Schematic diagram of the fabrication process for the arrayed waveguide grating (AWG) multiplexer.

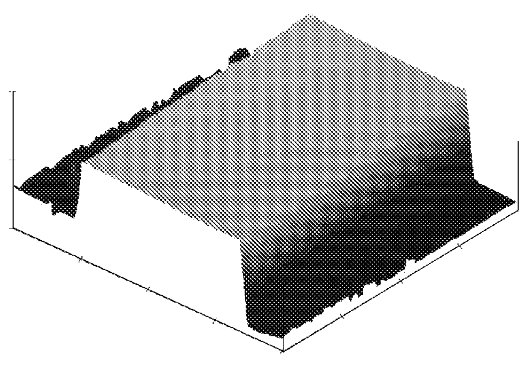

Fig. 4. Atomic force microscopy (AFM) photograph of the cross-section of core ridge formed by RIE.

The ridge wall is smooth and almost vertical.

The AWG multiplexer measurement system is based on a tunable semiconductor laser, the single mode fiber and infrared camera. A 1.55 μm light from the tunable semiconductor laser is coupled into the input waveguides of AWG with the single mode fiber, and the output near-field mode patterns at the output channels are observed with an infrared camera after being magnified by a $\times 10$ microscopic objective lens. The output wavelength region of the tunable semiconductor laser is about 1510−1590 nm and center wavelength at 1550 nm. The AWG multiplexer is placed on the Peltier-type heater, which can accurately control the temperature of the AWG multiplexer. In order to enhance the coupling efficiency, the core of the single mode fiber is tapered to 5 μm, which is obtained from the above-mentioned calculation. In addition, to decrease the reflecting loss, the antireflection coating is vaporized on the end of the tapered fiber, which makes the transmission efficiency enhanced to 90%.

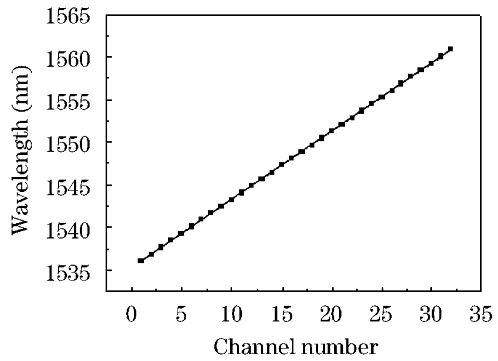

Fig. 5. The measured pass wavelength of FPEEK AWG multiplexer at room temperature.

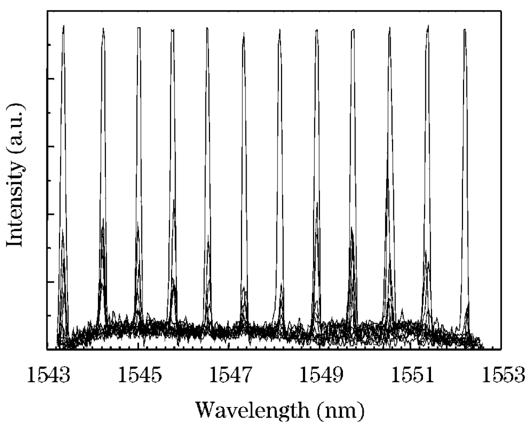

Fig. 6. The intensity curve of AWG output signal.

Figure 5 shows the measured pass wavelengths of the AWG multiplexer. The slope is 0.8 nm/channel and the center wavelength is 1548 nm. The center wavelength has a little excursion, which can be adjusted to 1550 nm using Peltier-type heater. The near field patterns at center position are transformed to the intensity distribution of corresponding wavelength, as shown in Fig. 6. The output power over the channels is almost uniform.

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