Thermo-optically tunable arrayed-waveguide-grating made of polymer/Si*

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A 33×33 thermo-optically tunable arrayed-waveguide-grating (AWG) has been fabricated by using the poly (2,3,4,5,6-pentafluorostyrene-co-glycidylmethacrylate) (PFS-co-GMA). The technological process of the fabrication of the device is described, and the measured results are presented. The measured spacing of the wavelength channel is about 0.81 nm, the 3-dB bandwidth is about 0.35 nm, the crosstalk is about −20 dB, and the insertion loss is between 10.4 dB for the centre port and 11.9 dB for the edge port. The measured thermo - optical tunable shift is about −0.12 nm/K. The measured center wavelength is 1545.21−1551.81 nm in the temperature range from 10℃ to 65℃, and the tuning range is 6.6 nm.

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In the future, optical communication systems will use more exceptional optical fiber with high bandwidth. Dense wavelength division multiplexing (DWDM) is considered as a promising solution to the demand for transporting terabits of information via fibers[1]. Arrayed waveguide gratings (AWGs) are key devices in DWDM systems in which they can serve as multiplexers, demultiplexers and wavelength routers[2].

AWGs have been developed commercially using various types of materials such as SiO_2/Si, InP and polymer[3]. Polymer AWG devices possess some excellent particular features including easier fabrication, easier control of the refractive index, better transparency, and easier vertical integration compared with other kinds of AWG multiplexers[4]. The wavelength bands used in DWDM systems are mainly within the range of 1530-1610 nm. Recently, in order to increase the work wavelength range of AWG, and some research groups have designed and fabricated tunable AWG devices using many thermo-optical materials[5,6]. We use thermo-optic (TO) effect in polymer waveguide to obtain the tunability of the polymer AWG. In our experiment, in order to decrease the insertion loss of AWG, we utilize the fluorinated poly (2,3,4,5,6-pentafluorostyrene-co-glycidylmethacrylate) (PFS-co-GMA) as waveguide material. Furthermore, we present the design parameters, details of fabrication process, and the measurement results of the tunable polymer AWG.

The PFS-co-GMA is chosen as the cladding material, and the styrene (St) is used to regulate the PFS-co-GMA to form the core material with higher refractive index. Fig. 1 shows the molecular formula of the material. The core refractive index can be easily controlled from 1.461 to 1.555 through regulating the mol percent of St. In this paper, we select the refractive index of the polymer guide core to be $n_1 = 1.4704$, and that of the polymer cladding surrounding the guide core to be $n_2 = 1.463$. So the refractive index difference between the core and the cladding is about $\Delta = (n_1 - n_2)/n_1 = 0.5\%$. Based on these polymer materials, a 33×33 AWG multiplexer with 0.8 nm (100 GHz) channel spacing is designed. The AWG multiplexer is shown schematically in Fig. 2, and the optimized values of the parameters are listed in Tab. 1.

Tab. 1 Optimized parameter in the design of the polymer AWG

Central wavelength	$\lambda_0 = 1.550\,918$ μm
Wavelength spacing	$\Delta\lambda = 0.8$ nm
Thickness of core	$b = 5$ μm
Width of core	$a = 5$ μm
Refractive index of core	$n_1 = 1.4704$
Refractive index of cladding	$n_2 = 1.463$
Diffraction order	$m = 56$
Pitch of adjacent I/O and arrayed waveguides	$d = 15.5$ μm
Length difference of adjacent arrayed waveguide	$\Delta L = 59.29$ μm
Focal length of slab waveguide	$f = 7838.22$ μm
Free spectral range	$FSR = 27.58$ nm
Number of I/O channels	$2N+1 = 33$
Number of arrayed waveguides	$2M+1 = 151$

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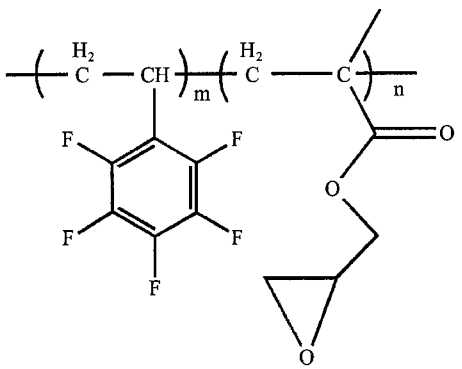

Fig. 1 Molecular formula of PFS-co-GMA

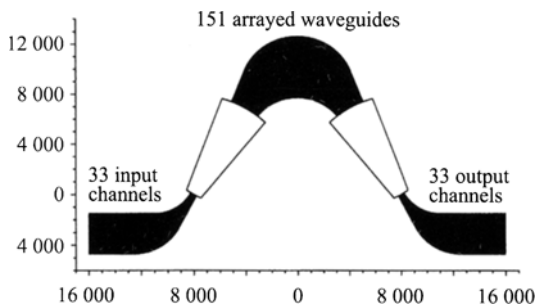

Fig. 2 Schematic layout of the designed AWG device

The guide core is buried in the cladding. The schematic diagram of the fabrication procedures is drawn in Fig. 3, which includes (a) spin-coating the lower cladding and core layer in turn, (b) depositing metal mask, (c) photolithography, (d) RIE, and (e) spin-coating the upper cladding. And we spin-coat at 3000 rmp and thermally cure the core material after an initial thermal curing of the lower cladding; and each curing of which is at 120℃. We estimate the optimized thickness of the Al mask to be 50 nm. We dry-etch square waveguide patterns using RIE process. In order to avoid side-etching we select the optimized velocity of oxygen flow and etching power as 40 SCCM and 40 W, respectively. Fig. 4 shows a scanning electron microscope (SEM) micrograph of an input-channel. The section of this channel is 5×5 μm^2, which corresponds with theoretical value.

The propagation loss of a 5. 7-cm-long waveguide with identical core diameter is measured by a cut-back technique[7], which is about 0. 68 dB/cm at 1 550 nm. The measured transmission spectrum of the fabricated AWG is presented in Fig. 5. From this figure, we can see that the crosstalk is about −20 dB, and the insertion loss of our device is between 10. 4 dB for the central port and 11. 9 dB for the edge ports, the wavelength spacing is about 0. 81 nm, and the 3-dB bandwidth is about 0. 35 nm. Fig. 6 gives the near-field photograph of the demultiplexing spectrum at the output ports of the output channels. Therefore, we can conclude from Figs. 5 and 6 that the presented AWG device exhibits good transmission characteristics.

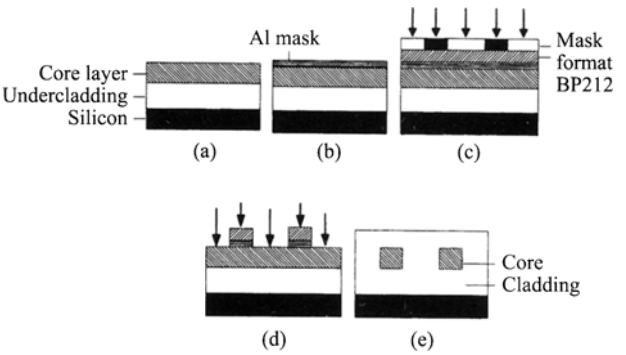

Fig. 3 Process steps of the fabrication of AWG: (a) Spin-coating the lower cladding and core layer in turn; (b) Depositing metal mask; (c) Photolithography; (d) RIE; (e) Spin-coating the upper cladding

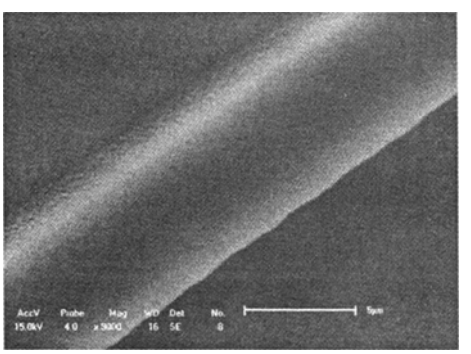

Fig. 4 SEM micrograph of an input channel waveguide after reactive core etching

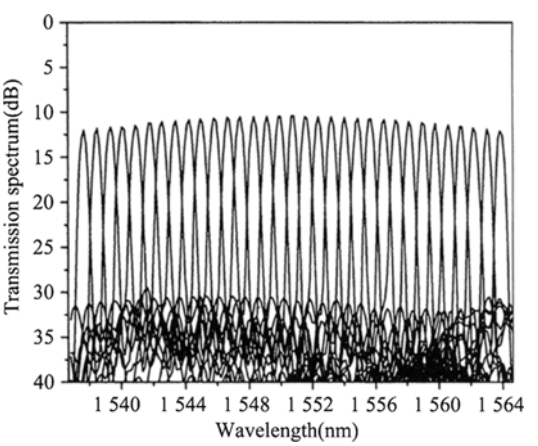

Fig. 5 Measured transmission spectrum of the fabricated AWG. at 18 ℃

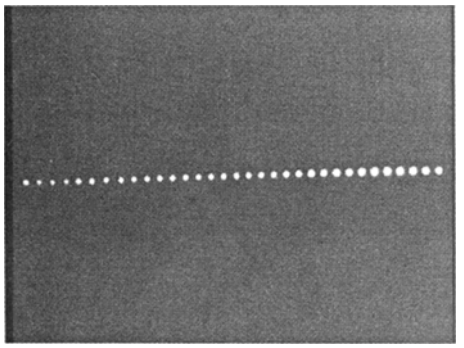

Fig. 6 Near-field photograph of the demultiplexing spectrum

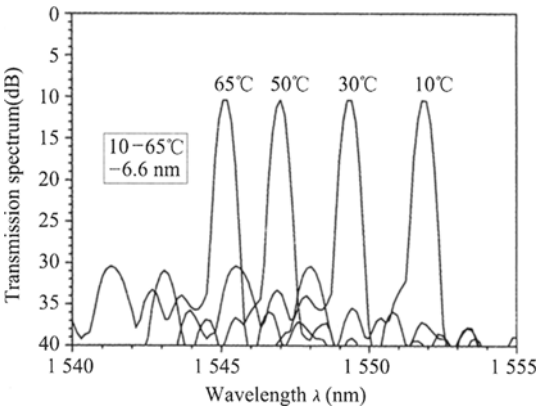

Fig. 7 Measured TO tuning characteristic of the polymer AWG

In our experiment, the measured TO coefficient of the fluoroacrylate polymer waveguide is equal to -1.16×10^{-4}/K, which is much larger than that of silica. Therefore, the TO effect of the polymer AWG is mainly determined by the polymer waveguide. Channel spacing $\Delta\lambda$ is a constant, which is independent of the waveguide effective refractive index n_e, so we only give the representative thermal behavior of the AWG at the central wavelength λ_0 in this paper. The TO effect of the AWG at the central wavelength can be expressed by:

$$\frac{d\lambda_0}{dT}=\frac{\Delta L}{m}\frac{dn_e}{dT}$$

where ΔL is the length difference of adjacent arrayed waveguide, m is the diffraction order, and dn_e/dT is the TO coefficient of the polymer waveguide. From the above equation we can see that the AWG exhibits a theoretical negative wavelength/temperature shift rate of −0.12 nm/K. The TO effect of the AWG is investigated by placing the AWG on a thermo-controller. Fig. 7 shows the temperature effect on the shift of the central wavelength of the AWG in the temperature range of 10℃～65℃. We can observe that the polymer AWG exhibits a large wavelength/temperature shift of −6.6 nm in the temperature range of 10℃～65℃, i. e. a shift rate of −0.12 nm/K.

In summary, we have fabricated a 33×33 thermo-optical tunable polymer AWG device through RIE process, of which the crosstalk is below −20 dB, insertion loss is between 10.4 dB and 11.9 dB, and TO tuning rate is −0.12 nm/K. The AWG is tuned over a wide range of 6.6 nm by changing the device temperature (10−65℃). Currently, we are devoting ourselves to further increase the TO tuning range of the polymer AWG device to make this device with longer work wavelength.

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