Vol. 31, No. 1 Journal of Semiconductors January 2010

A novel fabrication approach for an athermal arrayed-waveguide grating

Zhou Tianhong(周天宏)† and Ma Weidong(马卫东)

(Accelink Technologies Co, Ltd, Wuhan 430074, China)

Abstract: A novel method for fabricating an athermal AWG is proposed, using a unique apparatus for ITU-T center wavelength adjustment and optical coupling of two cut-parts. UV adhesive or sticky gel is applied into the gap between the cut-elements and the alignment base substrate by capillary infiltration. The spectrum profiles are almost the same as those of the original chip state, and no deterioration is observed resulting from athermalization. Flat-top athermal AWG modules of 100 GHz × 40 ch are fabricated. Over a temperature range of −40 to 85 °C, the center wavelength shift is ±22 pm, and the insertion loss change is less than ±0.11 dB.

Key words: AWG; optical waveguide filter; planar lightwave circuit; wavelength division multiplexing
DOI: 10.1088/1674-4926/31/1/014005 **PACC:** 4280L; 4280S; 4285D

1. Introduction

The recent explosion in demand for internet and broadband services has moved dense wavelength-division-multiplexing (DWDM) systems beyond backbone use into metropolitan and access networks. Arrayed-waveguide gratings (AWGs) play an important role as multiplexers/demultiplexers in DWDM systems. Because the output wavelength of a silica-based AWG is temperature dependent, it is common practice to control its temperature using Peltier elements or heaters, to keep the AWG chip at a constant operating temperature of 70 °C or above. But this causes problems of power consumption and adhesive degradation. Furthermore, with WDM-PON applications being passive there is no power supply. In addition, VMUX and ROADM have been used in metropolitan networks widely. In these two devices heat and power consumption are critical problems. Use of an athermal AWG can resolve the two problems easily.

Athermal AWGs have been studied extensively at home and abroad. Various athermalizing approaches have been reported[1−11], such as waveguide movement technology, resin-filled technology, athermal polymer or hybrid waveguide structure, and the piezo-optic effect. But to allow their use in actual DWDM systems, the cost and reliability of the module are critical. The method based on slab-waveguide movement is extensively used because of its simple fabrication process and low cost. Currently, athermal AWG products using the method have obtained commercial large scale application. Among all the athermalizing technologies based on slab-waveguide movement, the ITU-T center wavelength is adjusted by temperature change. The center wavelength adjustment precision is poor, and recycling of the chip is a fatal disadvantage when disassembly is needed, and the cost is higher. So we design a unique apparatus for ITU-T center wavelength adjustment and optical coupling of two cut-parts. This would allow the achievement of 1 pm wavelength adjustment precision. We have developed 100 GHz 40 ch athermal AWG commercial modules with flat-top spectra using the novel method. The modules have passed reliability and stability testing based on Telcordia GR-1209 and GR-1221.

2. Principle of athermalization

The center wavelength of AWG is represented by

$$\lambda_c = \frac{n_{\text{eff}}\Delta L}{m}, \tag{1}$$

where λ_c is the center wavelength, n_{eff} is the effective refractive index of the arrayed waveguide, ΔL is the optical path length difference of adjacent arrayed waveguides, and m is the order of diffraction.

Differentiating Eq. (1) by temperature T, we can represent the temperature dependence of the center wavelength by

$$\frac{\mathrm{d}\lambda_c}{\mathrm{d}T} = \lambda_c\left(\frac{1}{n_{\text{eff}}}\frac{\mathrm{d}n_{\text{eff}}}{\mathrm{d}T} + \alpha_{\text{sub}}\right), \tag{2}$$

where $\mathrm{d}n_{\text{eff}}/\mathrm{d}T$ is the temperature dependence of the refractive index of silica, and α_{sub} is the linear coefficient of expansion of the silicon substrate instead of the silica waveguide.

According to the linear dispersion of an AWG, when the center focus point is defined as C and the distance between C and D is defined as x (shown in Fig. 1), the relation between λ and x may be represented by

$$\frac{\mathrm{d}x}{\mathrm{d}\lambda} = \frac{L_f\Delta L}{n_s d\lambda_c}n_g, \tag{3}$$

where L_f is the focal length of the slab waveguide, n_s is the effective refractive index of the slab waveguide, d is the distance

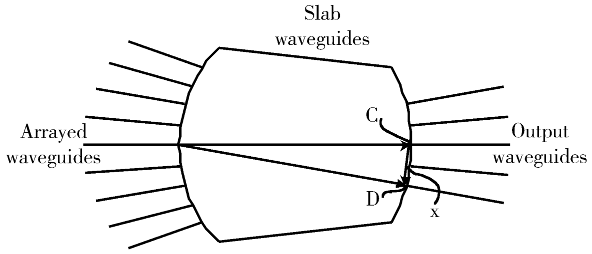

Fig. 1. Linear dispersion of the output slab waveguide.

---

† Corresponding author. Email: tianhong.zhou@accelink.com

Received 16 April 2009, revised manuscript received 15 July 2009

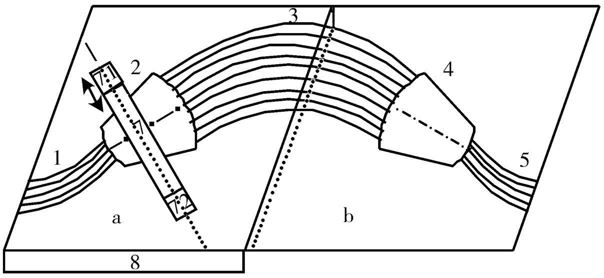

Fig. 2. Principle of the athermal AWG.

between adjacent arrayed waveguides, and $n_{\rm g}$ is the group refractive index of the arrayed waveguide.

From Eq. (2), we know the wavelength change $\Delta\lambda_{\rm c}=\frac{{\rm d}\lambda_{\rm c}}{{\rm d}T}\Delta T$ because of ambient temperature change ΔT, and from Eq. (3) we obtain the wavelength change $\Delta\lambda_{\rm c}^{1}=\frac{{\rm d}\lambda}{{\rm d}x}\Delta x$ because of the focus point shift Δx. Thus we can realize athermalization of the AWG if $\Delta\lambda_{\rm c}$ is equal to $\Delta\lambda_{\rm c}^{1}$. Figure 2 shows operation mechanism of the athermal AWG. The AWG chip is cut into two parts (one larger and one smaller part) at one of the slab waveguides, and the two parts are connected by a compensating rod made of aluminum. As the temperature changes, the aluminum rod expands or contracts, causing relative displacement between the two parts. If the length of the compensating rod is optimal, $\Delta\lambda_{\rm c}$ can be equal to $\Delta\lambda_{\rm c}^{1}$. Thus the light wavelength from the same output waveguide remains constant.

Now the length L can be calculated using the following equation:

$$\frac{{\rm d}\lambda_{\rm c}}{{\rm d}T}\Delta T=\frac{n_{\rm s}{\rm d}\lambda_{\rm c}}{L_{\rm f}\Delta L n_{\rm g}}\alpha L\Delta T, \tag{4}$$

where α is the linear coefficient of expansion of aluminum, and L is the optimal length of aluminum rod. From Eq. (4) we know that the suitable length is dependent on the structural parameters of the AWG.

The optimal length of aluminum rod can be calculated simply as follows. Here we take the chip structure parameters used by us as an example. For a 100 GHz AWG, the difference in the output wavelength between adjacent output channels $\Delta\lambda$ is 0.8 nm. The distance between adjacent output channels Δx is 23.74 μm. That is to say, the wavelength of the same output channel will change by 0.8 nm if aluminum rod moves 23.74 μm. So the optimal length can be expressed as

$$\frac{{\rm d}\lambda}{{\rm d}T}\Delta T=\frac{\Delta\lambda}{\Delta x}\alpha L\Delta T. \tag{5}$$

Taking $\frac{{\rm d}\lambda}{{\rm d}T}=11$ pm/℃, $\Delta\lambda$ = 0.8 nm, Δx = 23.74 μm, and α = 23 $\times 10^{-6}$ ℃$^{-1}$ in Eq. (5), we can obtain L = 11 × 25 / (0.8 × 23) = 16.3 mm. The effect is the same as that using Eq. (4). The error of the suitable length can be 0.2 mm, well within manufacturing tolerance.

3. Fabrication process

The center wavelength of the AWG must be matched to the ITU-T grid wavelength. All the reported methods change the curing temperature of the heat-curable adhesive which is used to connect the compensating rod with the chip. Wavelength adjustment precision with the changing temperature method is poor. Now we propose a novel approach to ITU-T center wavelength adjustment and optical coupling of two cut-parts. Employing the proposed approach to adjust the center wavelength can obtain 1 pm of adjustment precision. During the course of the fabrication process many new methods are adopted. Figure 3 shows the fabrication process.

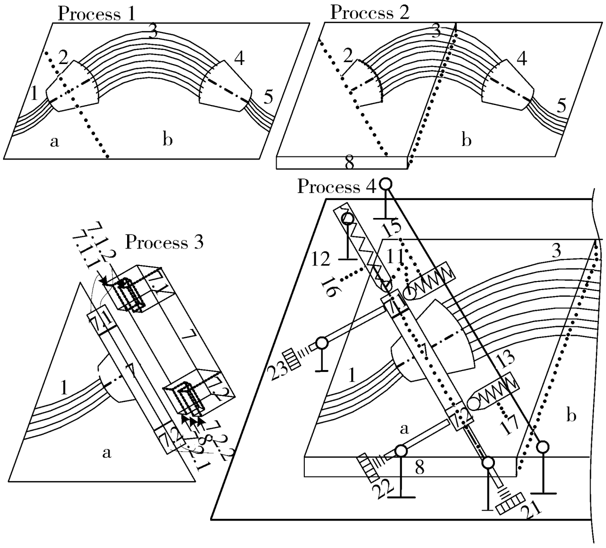

Fig. 3. Fabrication steps of the athermal AWG.

Process 1: the chip is cut into parts a and b at one of the slab waveguides.

Process 2: an alignment base substrate 8 is connected to the bottom surface of part b by adhesive.

In the process, a groove with 0.5 mm width and 0.5 mm depth is formed at the alignment base substrate 8. Part b is put onto substrate 8, and then a filament smeared with adhesive is pulled up and down through the groove. The adhesive spreads to the gap between the two contacted surfaces through capillary infiltration.

Process 3: the compensating rod is connected to part a by UV adhesive.

Two small pieces of glass with a groove are connected to the ends of the aluminum rod respectively. Note that the fixed location is 7.1.1 only.

Process 4: parts a and b are coupled, then the ITU-T center wavelength is adjusted.

The proposed apparatus has three spring structures and three subtle handwheels. Two of the spring structures and two of the handwheels are used to fine-tune the distance between parts a and b in order to ensure the same coupling spectrum as the original chip. The other spring structure and handwheel are employed to adjust the center wavelength. It is well known that optical coupling of a passive device is very time-consuming, but here only several minutes are spent on the coupling of part a and part b.

Process 5: testing parameters and curing compensating rod.

Matching oil is applied between the two interfaces of parts a and b. Then on-line testing is carried out. The compensating rod is fixed by UV-curable adhesive after all the parameters have been qualified. Note that the fixed location is 7.2.2 only.

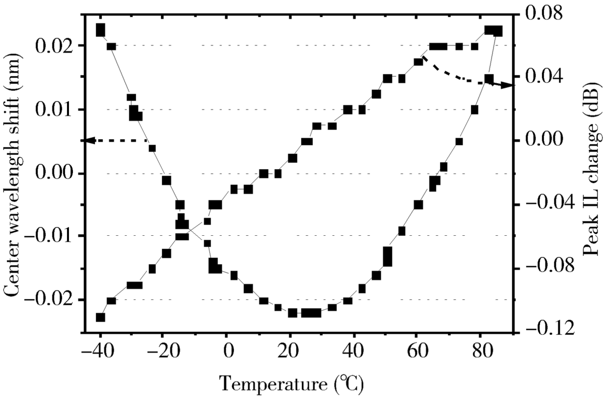

Fig. 4. Temperature dependence of center wavelength and insertion loss.

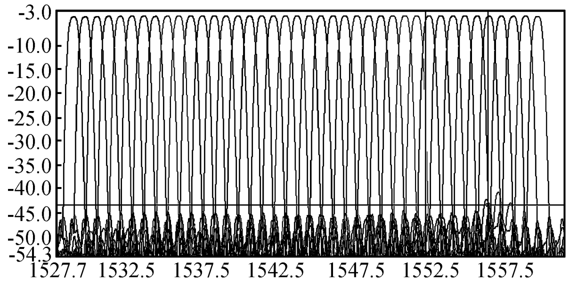

Fig. 5. Spectrum of the 100 GHz × 40 ch flat-top athermal AWG module.

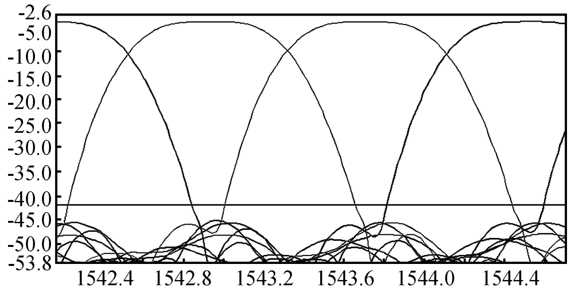

Fig. 6. Enlarged spectrum for the part channels.

4. Experimental results and discussion

Using the method described above, we have fabricated flat-top athermal AWG modules of 100 GHz × 40 ch. Figure 4 shows the temperature dependence of the center wavelength and insertion loss. Over a temperature range from −40 to 85 °C，the center wavelength shift is less than ±22 pm, and the insertion loss change is less than ±0.11 dB.

Figure 5 shows the tested spectrum over all channels of the athermal AWG module. It is substantially the same as the original chip, and no deterioration is found resulting from athermal realization. Figure 6 shows the enlarged spectrum for the part output channels. Figure 7 is a photo of the athermal AWG module. The package size is 100 × 45 × 8 mm^3.

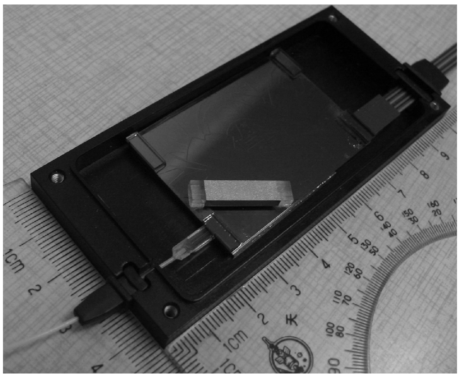

Fig. 7. Photo of the athermal AWG module.

5. Conclusion

A novel fabrication method for a flat-top athermal AWG has been proposed. We use the proposed apparatus to realize flexible coupling and high wavelength adjustment precision. On all output channels, over −40 to 85 °C the athermal AWG module has a center wavelength shift of less than ±22 pm and an insertion loss change of less than ±0.11 dB. The other spectral characteristics are almost the same as the chip state over the operation range of −40 to 85 °C. The modules have passed reliability and stability testing.

References

[1] Itoh M, Kamei S, Ishii M, et al. Ultra small 100 GHz 40 ch athermal AWG module using 2.5%-δ silica-based waveguides. ECOC, 2008, Mo.4.C.4

[2] Zhu Daqing, Xu Zhene. Study on a temperature-insensitive arrayed waveguide grating. Acta Optica Sinica, 2004, 24(7): 907

[3] de Peralta L G. Control of center wavelength in reflective-arrayed waveguide-grating multiplexers. IEEE J Quantum Electron, 2004, 40(12): 1725

[4] Huang Huamao, Liu Wen, Huang Dexiu. Analytical solutions for the temperature stability of central wavelength in arrayed waveguide gratings. Acta Optica Sinica, 2007, 27(10): 1725

[5] Inoue Y, Kaneko A, Hanawa F, et al. Athermal silica-based arrayed-waveguide grating multiplexer. Electron Lett, 1997, 33(23): 1945

[6] Soole J B D, Schlax M, Narayanan C, et al. Athermalisation of silica arrayed waveguide grating multiplexers. Electron Lett, 2003, 39(16): 1182

[7] Kamei S, Inoue Y, Kaneko A, et al. Recent progress on athermal AWG wavelength multiplexer. Proc SPIE Active and Passive Optical Components for WDM Communications V, 2005: 60140H

[8] Kanelo A, Kamei S, Inoue Y, et al. Athermal silica-based arrayed-waveguide grating (AWG) multi/demultiplexer with new low loss groove design. Electron Lett, 2000, 36(4): 318

[9] Bosc D, Loisel B, Moisan M, et al. Temperature and polarization insensitive Bragg gratings realised on silica waveguide on silicon. Electron Lett, 1997, 33(2): 134

[10] Kashihara K, Nara K, Nekado Y, et al. Arrayed waveguide grating type optical multiplexer/demultiplexer. US Patent, No. 6668116, 2003

[11] Kashihara K, Nara K, Tanaka. Arrayed waveguide grating optical multiplexer/demultiplexer and method for manufacturing the same. US Patent, No. 6735364, 2004