行政院國家科學委員會專題研究計畫　成果報告

矽基片上積體抗諧振反射光波導(ARROW)陣列波導光柵(AWG)元件在 DWDM 光通訊系統應用之研製(II)

計畫類別：個別型計畫
計畫編號：NSC91-2215-E-009-060-
執行期間：91 年 08 月 01 日至 92 年 07 月 31 日
執行單位：國立交通大學電子工程學系

計畫主持人：黃遠東

報告類型：精簡報告

處理方式：本計畫涉及專利或其他智慧財產權，1 年後可公開查詢

中　華　民　國 93 年 2 月 5 日

The Influence of Temperature Variation on the Performance of Arrayed-Waveguide Grating Based on ARROW Structures

Kun-Zong Lin, Shih-Hsin Hsu, and Yang-Tung Huang
Department of Electronics Engineering and Institute of Electronics
National Chiao Tung University
1001 Ta-Hsueh Road, Hsinchu, Taiwan, Republic of China
TEL: (03) 5712121 x 54138, FAX: (03) 5724361, E-Mail: huangyt@cc.nctu.edu.tw

(NSC 91-2215-E-009-060)

Abstract — The influence of temperature variation on the performance of AWG based on ARROW structures is discussed. Design of temperature-insensitive ARROW-based AWG devices is reported. The passband shift can be reduced to 0.002 nm/K.

Index terms: integrated optics, antiresonant reflecting optical waveguide, arrayed-waveguide grating, wavelength-division multiplexing, temperature variation.

1. Introduction

Wavelength multi/demultiplexers are key components in wavelength-division-multiplexing (WDM) systems. Among various configurations, arrayed-waveguide grating (AWG) multi/demultiplexers are attractive owing to easy fabrication, mass production, small size, and the ability of integration [1]. In contrast to conventional waveguide structures, antiresonant reflecting optical waveguides (ARROW's) utilizing antiresonant reflection as guiding mechanism instead of total internal reflection can perform low-loss single mode propagation with relatively large core size [2]. ARROW-based AWG demultiplexers have been proposed, but the temperature effect on their performance has not yet been discussed.

In this presentation, the influence of temperature variation on the performance of AWG based on ARROW structures is investigated. In order to reduce the temperature dependence, an overlay with a negative temperature coefficient is introduced, since the temperature coefficient for the original structure is positive. The improved design of temperature-insensitive ARROW-based AWG devices is reported.

2. Temperature Dependence of the ARROW-based AWG Performance

The 3-D Si-based ARROW structure used for AWG devices is shown in Fig. 1. It is a multi-layered structure with an ARROW configuration in the vertical direction (x) and a conventional waveguide structure along the lateral direction (y). The material of the core and the second cladding layer is SiO_2 ($n_c = n_l = 1.45$) and the high-index first cladding layer is poly-Si ($n_h = 3.50$). The free-space operating wavelength λ_0 is 1.55 μm. To attain a low insertion loss for the ARROW-based AWG devices, whose optical path length is usually several centimeters, the thickness of the core layer is chosen to be 7.00 μm to keep the propagation loss of the vertical ARROW structure acceptably low. The thickness of the first and second cladding layers are found to be 0.12 and 3.50 μm respectively, by satisfying the transverse antiresonant condition [2]

$$d_i = \frac{\lambda_0}{4n_i}\left[1 - \left(\frac{n_c}{n_i}\right)^2 + \left(\frac{\lambda_0}{2\,n_i\,d_{c,core}}\right)^2\right]^{-1/2} \cdot (2Q+1); \qquad Q = 0; 1; 2; \cdots; \tag{1}$$

where $i = h; l$, and $d_{c,core}$ is the thickness of the core layer. For single-mode operation in the lateral y-direction, the thickness of the core layer in the lateral cladding regions $d_{c,clad}$ is chosen to be 4.80 μm. The effective index method (EIM) is used to analyze the 3-D waveguide structure.

To investigate the temperature dependence of the ARROW-based AWG performance, the temperature coefficient of the refractive index of SiO_2 film ($dn/dT = 7.93 \times 10^{-6}/K$ [3]) and Si ($dn/dT = 160 \times 10^{-6}/K$ [4]) are introduced into the analysis. Fig. 2 shows the effective index of the fundamental mode of the vertical 2-D ARROW structure in the core region versus temperature. The slope of the curve dN_{eff}/dT can be found to be $7.96 \times 10^{-6}/K$, which is relatively close to the temperature coefficient of the refractive index of the core layer. As for the 3-D structure, the width of the core region $W = 7$ μm, which will be the width of array waveguides, is considered. The analyzed results show that the effective index N_{eff} is 1.4445, propagation loss is 0.077 dB/cm, and the temperature dependence dN_{eff}/dT is $7.966 \times 10^{-6}/K$.

The temperature dependence of the ARROW-based AWG performance, which can be described by the dependence of the pass wavelength on the temperature, could be expressed as

$$\frac{d\lambda}{dT} = \lambda_c \cdot \left(\frac{1}{N_c}\frac{dN_c}{dT} + \frac{1}{\Delta L}\frac{d\Delta L}{dT}\right) = \lambda_c \cdot \left(\frac{1}{N_c}\frac{dN_c}{dT} + \alpha\right); \tag{2}$$

where λ_c is the central wavelength in free space, N_c is the effective index of the array waveguides, ΔL is the optical path length difference between adjacent array waveguides, and α is the thermal expansion coefficient of ΔL defined as

$$\alpha = \frac{1}{\Delta L}\frac{d\Delta L}{dT}. \tag{3}$$

Since the thickness of the substrate is usually much greater than that of waveguide layers, the thermal expansion coefficient α is mainly determined by that of the Si substrate ($\alpha_{Si} = 2.63 \times 10^{-6}$/K [3]). Introducing the previous found values and the central wavelength $\lambda_c = 1.55\ \mu m$ into Eq. (2), the temperature dependence of the pass wavelength of the proposed ARROW-based AWG is obtained as

$$\frac{d\lambda}{dT} = 1.26 \times 10^{-5}\ \mu m/K = 1.26 \times 10^{-2}\ nm/K. \tag{4}$$

This value is quite near the temperature dependence of a conventional AWG (1.2×10^{-2} nm/K [1]).

3. Design of Temperature-Insensitive ARROW-based AWG

The temperature dependence of the ARROW-based AWG must be reduced or eliminated to prevent the use of power-consuming temperature controllers. From Eq. (2), the athermal (temperature-insensitive) condition can be obtained if

$$\alpha_{sub} + \frac{1}{N_{eff}}\frac{dN_{eff}}{dT} = 0, \tag{5}$$

where α_{sub} is the thermal expansion coefficient of the substrate. Since Si substrate has a positive thermal expansion coefficient, it's required to find a negative value of dN_{eff}/dT to satisfy the above equation. For this purpose, an additional overlay with a negative value of dN_{eff}/dT is added on the original structure, as shown in Fig. 3. Here, silicone polymer is chosen and its refractive index and temperature coefficient are 1.50 and -370×10^{-6}/K [1], respectively. To have a negative value of dN_{eff}/dT and maintain low propagation loss, it can be found that the thickness of the silicone overlay $d_{add} = 0.60\ \mu m$ is suitable and then dN_{eff}/dT of the vertical 2-D ARROW structure in the core region becomes -5.09×10^{-6}/K. Since the vertical 2-D structure in the core region has been changed, the thickness of the core layer in the lateral cladding regions is adjusted to be $5.50\ \mu m$ to maintain single-mode operation in the lateral direction and low propagation loss.

Fig. 4 shows the fundamental-mode effective index of the proposed ARROW structure with a silicon overlay versus temperature. In comparison with Fig. 2, it can be seen that the variation of the effective index is significantly reduced. The temperature dependence of the wavelength shift of the ARROW-based AWG with and without a silicone overlay are displayed in Fig. 5. The overall wavelength shift of the proposed temperature-insensitive ARROW-based AWG within the temperature range of 0–50°C is below 0.08 nm, and the temperature dependence of the channel pass wavelengths is reduced to 0.002 nm/°C, i.e., 0.002 nm/K.

4. Conclusion

The temperature dependence of the performance of AWG based on ARROW structures is analyzed. For the positive temperature dependence of the structure, a silicone overlay with a negative temperature coefficient is used on top of the channel of the 3-D ARROW structure to reduce the temperature dependence. Based on the structure, a feasible design of temperature-insensitive ARROW-based AWG devices is reported. The pass wavelength shift can be significantly reduced from 0.0126 nm/K to 0.002 nm/K.

REFERENCES

[1] Katsunari Okamoto, Fundamentals of Optical Waveguides, Academic Press, San Diego (2000).

[2] M. A. Duguay, Y. Kokubun, and T. L. Koch, "Antiresonant reflecting optical waveguides in SiO_2-Si multilayer structures," Appl. Phys. Lett., 49, pp. 13–15 (1986).

[3] Y. Kokubun, S. Yoneda, and S. Matsuura, "Temperature-independent optical filter at 1.55 μm wavelength using a silica-based athermal waveguide," Electron Lett., 34, pp. 367–368, 1998.

[4] Crystran Ltd., http://www.crystran.co.uk/.

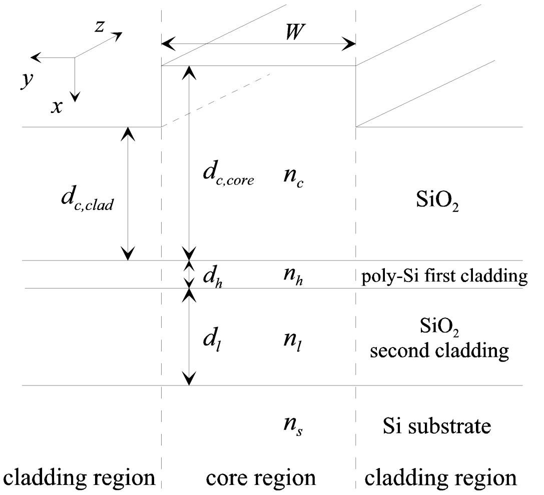

Figure 1: The schematic view of 3-D ARROW structure for AWG devices.

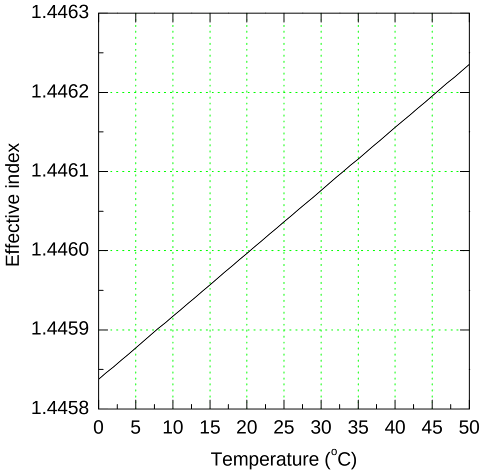

Figure 2: The effective index of the vertical 2-D ARROW structure in the core region versus temperature.

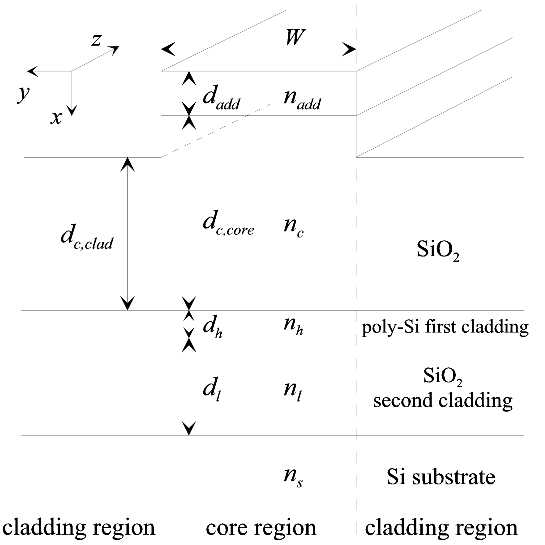

Figure 3: 3-D ARROW structure with a silicone overlay on top of the core layer in the core region.

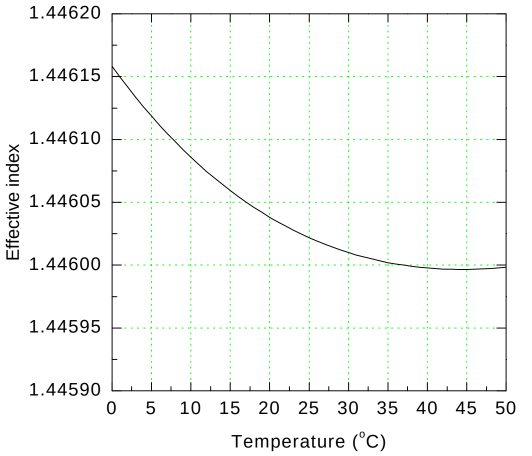

Figure 4: The temperature dependence of the effective index of the ARROW with a silicone overlay.

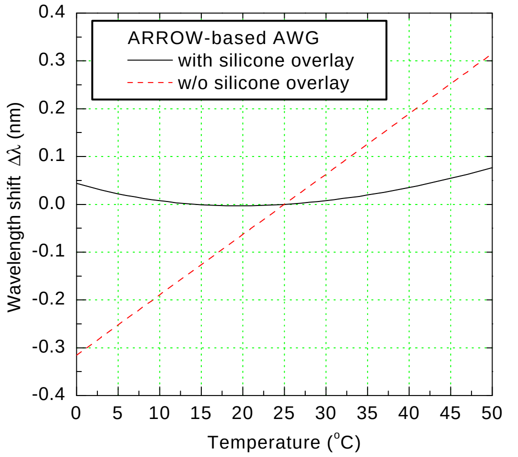

Figure 5: The wavelength shift versus temperature of ARROW-based AWG devices.