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Athermal AWGs in SOI by overlaying a Polymer Cladding on Narrowed Arrayed Waveguides

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Abstract: Athermal AWGs in SOI are experimentally demonstrated for the first time to our knowledge. By using narrowed arrayed waveguides and overlaying of polymer, we obtain a wavelength temperature dependence of 7.1pm/˚C and good optical properties.
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1. Introduction

Arrayed Waveguide Gratings (AWGs) are of great use in all-optical networks as (de-)multiplexers and wavelength routers and as part of more complex photonic switches, sources or receivers. Although AWGs have conventionally been fabricated in low-index-contrast glass technology like silica, the desire for high-density photonic integration has led to an increasing interest in ultrasmall AWGs based on the silicon photonic wire waveguides with high index contrast [1]. In combination with waferscale CMOS technology, the SOI (Silicon-on-insulator) photonic technology has the potential for mass production.

However, the large thermo-optic (TO) coefficient of silicon ($dn/dT=1.8\times10^{-4}/^{\circ}C$) makes these SOI-based AWGs strongly temperature dependent, such that an external heater or cooler has to be employed to stabilize the chip temperature. These elements would not only take extra space but also consume higher power, counteracting the benefits brought by SOI technology. While athermal glass-based AWGs have been demonstrated since several years [2,3], there has so far not yet been an experimental demonstration of athermal SOI AWGs. Other passive photonic components in SOI, such as ring resonators or Mach-Zehnder interferometers, have been made athermal through a number of methods [4-6], but temperature-independent AWGs have so far only been shown to be possible using simulations[7,8].

In this paper, we experimentally demonstrate 1×8 AWGs in SOI wire technology with a channel spacing of 400GHz. By insertion of the narrowed waveguides into arrayed waveguides and then overlaying a polymer layer on top, the wavelength temperature dependence of the AWGs is successfully reduced to 7.1pm/˚C, which is more than 10 times less than that of normal SOI AWGs. The AWGs also exhibit better performance after such modification and treatment. For the best channel, the cross talk is less than -15dB and the insertion loss is around 2.1dB.

2. Concept, design and fabrication

It is well known that athermal SOI components could be made by compensating the large positive TO coefficient of silicon by using a cladding (like some polymers) with a negative TO coefficient. For the case of silicon wire waveguides, an additional problem is that for the usual waveguide dimensions most of the light is confined to the silicon and only a fraction can penetrate into the cladding with opposite TO coefficient. To arrive at athermal components, it is therefore typically necessary to reduce the dimensions of the silicon wire to allow more light to penetrate into the polymer. On the other hand, reducing the dimensions of the silicon wire waveguides has a negative effect on the performance of the AWGs. For example, the phase noise in the waveguide arms would increase when they are narrowed, which would result in higher crosstalk between channels. The insertion loss would also increase. However, from the experiment, we found that the combination of proper layout design and polymer overlay treatment can greatly eliminate the disadvantage brought by using narrowed arrayed waveguides.

Our design is based on the normal waveguide dimensions ($450nm\times220nm$) for the access waveguides to the star couplers and the bend waveguides in the AWGs. The narrowed waveguides are inserted for the straight waveguide arms only. The schematic picture is shown in Figure 1. The standard SOI wafer with a silicon layer of 220nm and an oxide layer of 2μm is used for this work. The SOI waveguides are fabricated by deep UV lithography (193nm) and inductive coupled plasma reactive ion etch (ICP-RIE) etching in a standard CMOS fabrication processes. By gradually increasing the exposure dose on the SOI wafer from the left to the right hand side, several values of the width of the narrowed waveguides ranging from 330nm to 390nm could be obtained. After cleaning, Polymer PSQ-LH with a large TO coefficient of -2.4×10^{-4} as well as low loss at 1550nm and high thermal stability below 200˚C[9,10], is chosen as the cladding material and spin-coated on top of the fabricated SOI chips.

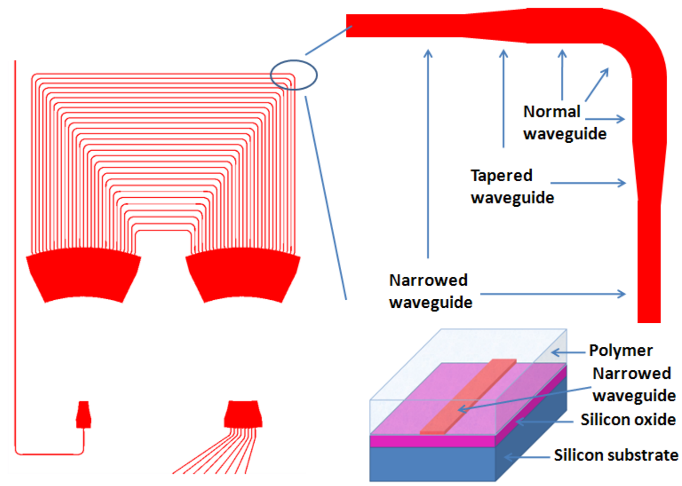
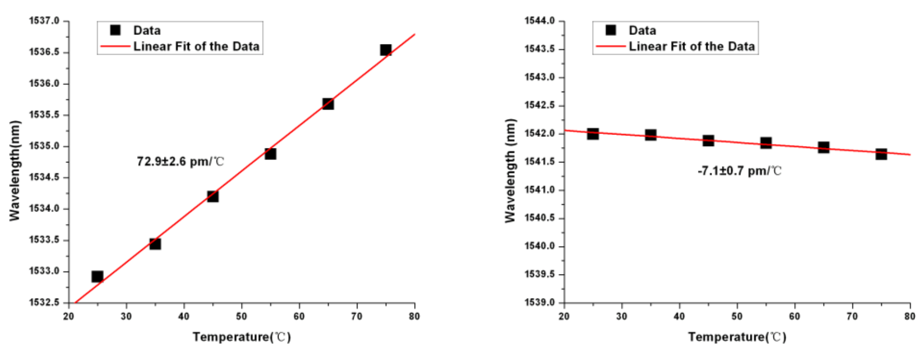


Fig.1: The schematic picture of the proposed AWGs with narrowed arrayed waveguides

3. Experimental results

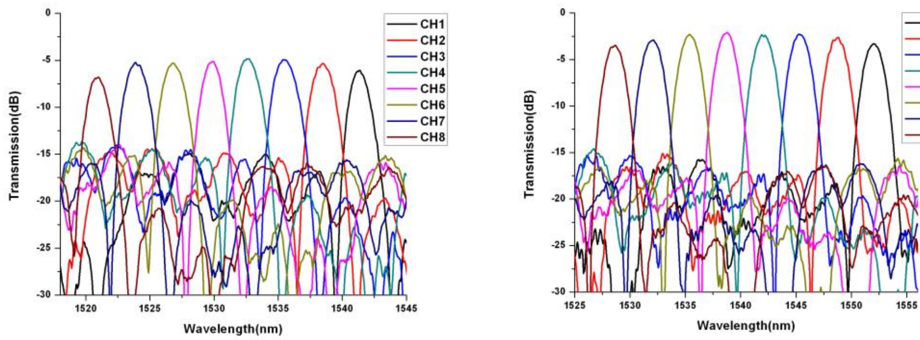
For measurements, a super luminescent light emitting diode is used as the light source. An optical spectrum analyzer (Agilent 86140B) is used to record the measurement data. In order to measure the AWGs spectra under different temperatures, the samples were mounted on a heating plate whose temperature could be controlled accurately. The lowest temperature dependence was obtained for a waveguide width of 345nm. Figure 2 shows the temperature dependence of the filter peak wavelength of the central channel (channel 4) for this waveguide width, before and after the polymer overlay. The temperature dependence of the filter peak wavelength was successfully reduced from above 72.9pm/˚C to -7.1pm/˚C, i.e. ten times lower than that of normal SOI AWGs.



(a) (b)

Fig.4: Temperature dependence of the peak wavelength of channel 4 before (a) and after polymer overlay (b)

We also notice that the AWGs characteristics are actually improved after the polymer overlay. Figure 5 shows the filter spectra for all 8 AWGs outputs at 25˚C before and after the polymer overlay. For the best channel (channel 5), the insertion loss is reduced from 5.2dB to 2.1dB. The crosstalk is reduced from -11dB to less than -15dB. The most important reason for this is the smaller index contrast between core and cladding after the polymer has been deposited. By lowering the contrast, not only the phase errors between the arrayed waveguides, but also the scattering loss of the narrowed arrayed waveguides caused by sidewall roughness are greatly reduced. The junction loss between the arrayed waveguides and two star couplers might also be lower.



(a) (b)

Fig.3: Transmission spectra for the 8 output ports of the AWGs before (a) and after polymer overlay (b). Waveguide width of the narrowed arrayed waveguides are 345nm

4. Conclusion

By insertion of the narrowed waveguides into the arrayed waveguides and overlay of a polymer layer on top, we demonstrated an athermal SOI-based 1×8 AWGs with 400GHz channel spacing. The wavelength temperature dependence of the AWGs is successfully reduced to 7.1pm/˚C, ten times lower than that of normal SOI AWGs. This kind of AWGs also exhibit better performance after such modification and treatment. The cross talk is less than -15dB and the insertion loss is around 2.1dB for the best channel.

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