Silicon-on-insulator microring resonator for ultra dense WDM applications

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Abstract *We demonstrate design, fabrication and measurement of silicon-on-insulator microring resonators suitable for ultra dense WDM applications with a channel spacing of 0.1nm. Considerations about applying it to practical use are also discussed.*

I. Introduction

Current IP-packet routers such as those developed by CISCO, Alcatel-Lucent, Juniper and other major telecom equipment vendors are operating at 40GBit/s channel rates and can have an aggregate bit rate of up to 640GBit/s. Further scaling towards larger data rates is inhibited by the non-linear scaling of the power consumption and by the interconnection complexity. To overcome this problem increasingly all-optical processing techniques are being investigated. One such technique is attaching an optical "label" to the IP-packet. This label typically contains the routing information and consists of a few very densely spaced wavelength channels (only 0.1nm apart) placed within the actual data channel. In order to get the routing information at the receiving end, a demultiplexer with a channel spacing of 0.1nm is needed to separate these wavelength channels.

Although this kind of demultiplexer has been realized based on conventional low-index-contrast SiO_2 waveguides [1], it has never been done before in the silicon nanophotonic platform: in most devices reported so far, the wavelength channels were separated by more than 1nm [2, 3]. To reach this tenfold improvement, one of the main challenges is the serious phase noise induced by the fabrication process. Due to the high index contrast of the SOI (silicon-on-insulator) nanowire waveguide, the modal effective index is very sensitive to the random variation of the waveguide dimension [4], which is inevitable for the current fabrication process. Therefore, by employing an arrayed waveguide grating [1, 5], which is widely used for WDM (wavelength division multiplexing) applications, it seems very difficult to obtain such a small channel spacing with sufficiently low crosstalk when using SOI nanowire waveguides. Instead, we can use microring resonators (MRR) [6] in a cascaded configuration [3] to realize such an ultra dense WDM (UDWDM) demultiplexer. In this paper, we demonstrate design, fabrication and measurement of the SOI MRR suitable for UDWDM applications with a channel spacing of 0.1nm. Issues related to applying it to practical use are also discussed.

II. Design

In this work, we adopt an SOI nanowire waveguide with a cross-section of $450\times220nm^2$ and a DVS-BCB (divinyldisiloxane benzocyclobutene) layer as the upper cladding. The first step is to determine the radius or the perimeter of the MRR to reach the desired FSR (free spectral range) specification [7]. The FSR is determined by the spacing between two adjacent data channels, which is typically 5~6nm. Therefore, we design the MRR with a radius of 17μm, which offers an FSR of 5.5nm.

Then the design of coupling strength between the bus waveguide and the MRR follows. Since the desired bandwidth of the resonant peak is very small in order to reduce the inter-channel crosstalk, i.e., much smaller than the 0.1nm-channel spacing, the coupling strength should be very weak. However, as the coupling strength decreases, the channel drop loss increases. Fig. 1 shows how drop loss and crosstalk vary as the field transmission coefficient (t) increases (i.e., the coupling decreases). Two values of the propagation loss (α) in the MRR, 3dB/cm and 10dB/cm are assumed, and the results are shown in Fig. 1 (a) and (b), respectively. In both cases, the drop loss increases and the crosstalk performance improves as t increases. For a given t, the performances are better in terms of both drop loss and crosstalk when the propagation loss is lower. Therefore, it is very important to realize a low-loss MRR, which is determined by the fabrication process.

III. Results and Discussions

The MRRs are fabricated using a 193nm deep ultraviolet (DUV) lithography process [8]. Following the fabrication of the SOI waveguides, a BCB layer is spin-coated on top of the samples and cured as the upper cladding. For the measurement, the

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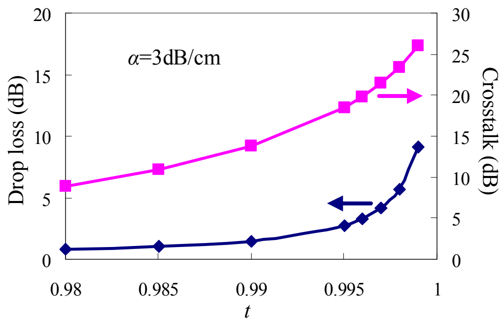
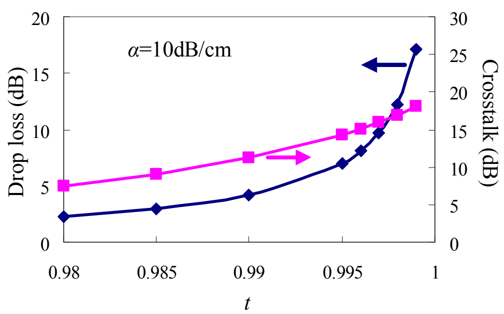
TE-polarized light is coupled into and out of the SOI waveguides with the help of grating couplers [9].



(a)

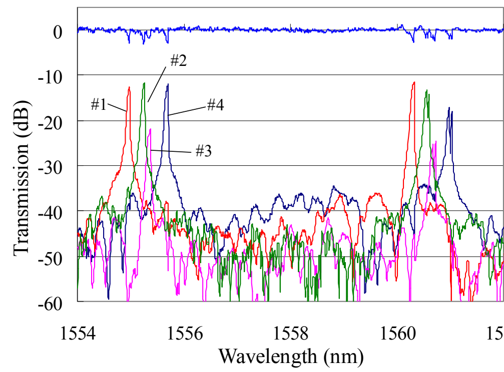


(b)

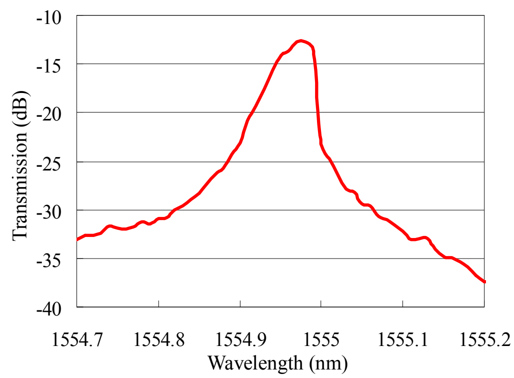
Fig. 1. The drop loss and crosstalk as a function of the field transmission coefficient (*t*).

We measured the spectral responses of four cascaded MRRs with nominal identical structure parameters. The results are shown in Fig. 2 (a). The spectral responses of the drop ports of the four MRRs are marked with numbers #1~#4, respectively. The FSR is about 5.34nm, which agrees well with the designed value (5.5nm). Fig. 2 (b) shows an enlarged view of the spectral response of drop port #1. The drop loss is about 12.7dB and the 3dB-bandwidth is 0.04nm ($Q\sim4\times10^4$). This corresponds to α=14dB/cm and t=0.9975. The extracted loss is much larger than the propagation loss of the straight waveguide (~3dB/cm) and this large discrepancy is being investigated. The estimated crosstalk is ~15dB when applying it for the demultiplexer with a channel spacing of 0.1nm.

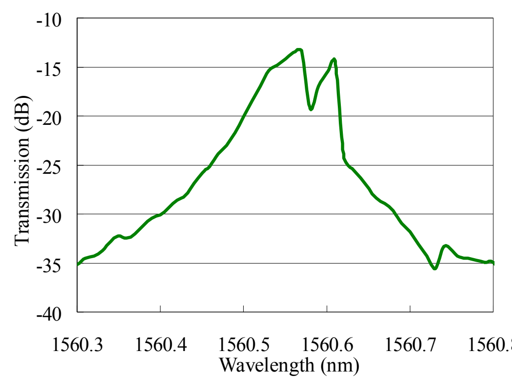
One also sees from Fig. 2 (a) that, although the four MRRs are nominally identical, they give different resonant wavelengths. The difference between the resonant wavelengths becomes as high as 0.7nm, which is seven times the channel spacing. This is caused by the random process error during fabrication and is very difficult to overcome at present. Therefore, in practice it is necessary to incorporate post-fabrication trimming or tuning elements. For example, the individual resonant wavelength of each MRR can be thermally tuned with micro-heaters [10].



(a)



(b)



(c)

Fig. 2. (a) The measured spectral responses of four cascaded MRRs. (b) The enlarged view of the spectral response of drop port #1. (c) The enlarged view of the spectral response of drop port #2.

Another phenomenon is the splitting of the resonant peak, as shown in Fig. 2 (c), the enlarged view of the spectral response of drop port #2. The splitting of the resonant peak not only increases the drop loss, but also broadens the peak which degrades the crosstalk performance. This is due to the coupling into the counterpropagating mode, which breaks the degeneracy of forward and backward modes [11]. The coupling is caused by the surface-roughness-induced reflection. According to Ref. [11], even a small reflection may lead to a serious contradirectional coupling when the coupling strength between the bus waveguide and the MRR is very weak, which is just our current case, unfortunately. Therefore, for the very weak-coupled MRR which is desired for UDWDM applications, reducing the sidewall roughness of the waveguide is of vital importance, not only for reducing the propagation loss, but also for lowering the reflection.

IV. Conclusion

We have demonstrated the design, fabrication and measurement of the MRR based on the SOI nanowire waveguide, which is suitable for UDWDM applications with a channel spacing of 0.1nm. The trade-off between the drop loss and the crosstalk exists when choosing the coupling strength between the bus waveguide and the MRR. The fabricated MRR exhibits a 3dB-bandwidth of 0.04nm ($Q \sim 4 \times 10^4$). The sidewall roughness has been found to be crucial to the device performance. In order to apply it in practical use, some post-fabrication trimming or tuning elements are also necessary.

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