Coupling loss reduction of vertically coupled microring resonator filter by spot size matched busline waveguides

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Abstract– **The input/output coupling loss of vertically coupled microring resonator filter was improved by introducing busline waveguides with large spot size, i.e. the ARROW-type waveguide and the rectangular busline waveguide with spot size transformer. Clear dropping responses were demonstrated for the ARROW based microring resonator filters and the coupling loss was successfully reduced by 22dB.**

1 Introduction

The input/output coupling loss of busline waveguide in the vertically coupled microring resonator filter was improved by adopting two types of waveguides, i.e. the ARROW-B waveguide and the rectangular waveguide with horizontal spot size transformer (SST). The insertion loss of the throughput response was reduced by ~20dB for both types of microring resonator filters, and clear dropping responses were observed for ARROW based microring resonator filters.

Vertically coupled microring resonator (VC-MRR) filter is an attractive Add/Drop wavelength filter due to its functionality, compactness, and the possibility of dense integration resulting from the cross-grid configuration [1],[2]. However, the input/output coupling loss from the busline waveguide to the single mode fiber was as large as 30dB, which is mainly caused by the spot size mismatch between the busline waveguide and the single mode fiber [1].

In the vertically coupled microring resonator filter, the top surface of the busline must be flattened to enable the stacking of microring resonator on the crossing point of busline waveguides [1]. The thickness of busline waveguide was limited to be less than 0.7μm due to the lift-off process [3], which was required for the planarization of top surface. Therefore, the spot size of the busline waveguide is as small as 0.95μm$\times$ 0.55μm, and this is too small to couple the light efficiently to single mode fibers.

In this study, we adopted an ARROW [4] and rectangular waveguide with horizontal spot size transformer as the busline waveguides to improve the input/output coupling loss.

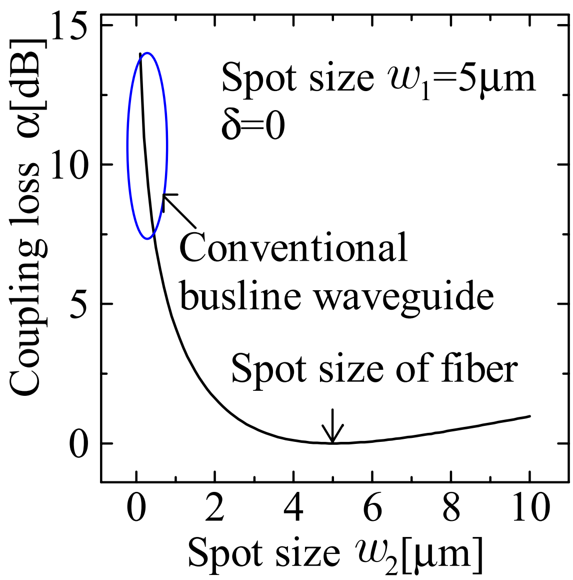

Fig.1: Spot size mismatch loss

2 Analysis of coupling loss

To reduce the coupling loss between the busline waveguide and the single mode fiber, the busline waveguide must be designed to match its spot size to that of the single mode fiber.

The coupling loss between busline waveguide and single mode fiber is shown in Fig.1, assuming that the spot size in the vertical direction is matched to that of the fiber and the spot size in the horizontal direction is varied. That is, Fig.1 shows the spot size mismatch loss in one dimensional case.

The spot size of single mode fiber is 5-6μm as shown in Fig.2(a), while that of the conventional busline waveguide is 0.95μm$\times$0.55μm as shown in Fig.2(b). Therefore, the spot size mismatch loss between the single mode fiber and the conventional busline waveguide is as large as 15dB per end facet. Therefore, a busline waveguide with large spot size was required to improve the input/output coupling loss.

3 Design of ARROW

ARROW-type waveguides [4] can be designed to act as a quasi-single mode waveguide with large spot size, when the thicknesses of interference cladding layers are optimazed. Thus we designed a vertically coupled microring resonator with ARROW busline as shown in Fig.3. The interference cladding layers of ARROW-B [5] consists of two layers which are low index first cladding layer and the second cladding layer with the same index as that of the core. In addition, by adopting the stripe lateral confinement (SLC) configuration [6], a thick channeled waveguide can be fabricated with flat top surface [3].

To make the spot size of busline waveguide matched to that of single mode fiber, we need to design the width and the thickness of busline core to be the same size as the single mode fiber. In the ARROW-type waveguides, the relation between the core thickness and the spot size is simply given by $w = d_{ce}/2.844$, where d_{ce} is the equivalent core thickness [7]. Therefore, the optimum core thickness is 14.2μm when the spot size of single mode fiber is 5.0μm. The lateral confinement by the SLC structure is based on the positive index difference in the same manner as the single mode fiber, the core width should be designed to about 10μm.

In the practical fabrication, however, the width of SLC was designed to be 2.0μm, because we used the same photo-mask as the conventional busline waveguide. Consequently we designed the thickness of core to be 5.0μm according to the core width. Fig.2(c) shows the field profile of ARROW busline, calculated by a finite difference mode solver [8]. The spot size was calculated to be 2.65μm$\times$2.33μm. Although the coupling loss is not reduced to zero by this design, we can expect the reduction of coupling loss to some amount owing to the expansion of spot size. This core size can be easily enlarged to about 10μm$\times$14.2 μm, and so the spot size mismatch between the ARROW busline waveguide and the single mode fiber can be reduced to nearly zero.

In this structure, the coupling loss to the single mode fiber was calculated to be 2.3dB per end facet.

4 Design of SST

To improve the coupling loss of the vertically coupled microring resonator filter, we inserted a spot size transformer [9] into the busline waveguide. This configration consists of conventional busline waveguides in the filter region and tapered busline waveguides at input/output ends, as shown in Fig.4.

To reduce the radiation loss at the tapered region, we adopted a horn-waveguide [10], of which width as a function of propagation distance z is given by

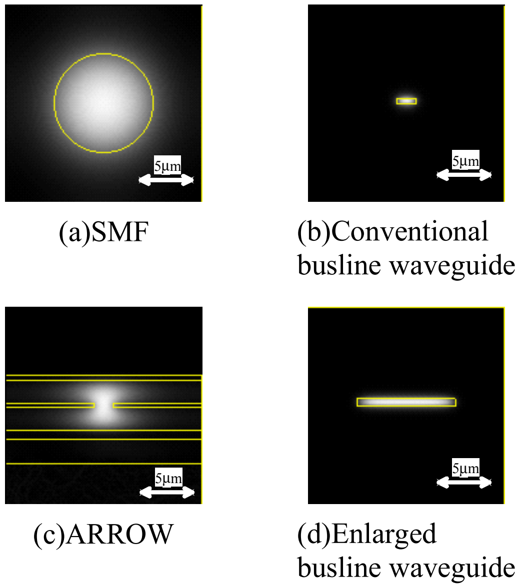

Fig.2: Electric field profiles of waveguides

$$W(z) = \sqrt{2\alpha\lambda_g z + W_0^2}, \tag{1}$$

where λ_g is the cavity wavelength, and W_0^2 is the width of tapered waveguide at the starting point.

We designed the horn-waveguide so that W_0 is 2.0 μm, the enlarged width $W(L)$ is 10.0μm, the length of tapered region L is $\sim$1.0mm. The field profile at the output end is shown in Fig.2(d). In this structure, the radiation loss was evaluated to be 0.06dB using the 2D-FDTD simulation as shown in Fig.5. Thus adopting this structure, we can expect to reduce the coupling loss at input/output ends to be less than 6.2dB per end facet.

The remaining loss is due to the spot size mismatch in the vertical direction, and this may be reduced by introducing the vertical tapered structure [9].

5 MRR with ARROW busline

First, we fabricated the vertically coupled microring resonator filter with ARROW busline as shown in Fig.3. Since the ARROW waveguide is channeled by using the SLC (Stripe Lateral Confinement) structure [6], in which the light is confined by inserting a thin low-index layer with stripe-opened channel, the top surface can be easily planarized [3]. In addition, ARROW is a quasi-single mode waveguide with large spot size.

It can be seen from Fig.2 (a)-(c) that the spot size of ARROW is close to that of single mode fiber. Thus ARROW is suitable for the busline of vertically coupled microring resonator. However, the dropping re-

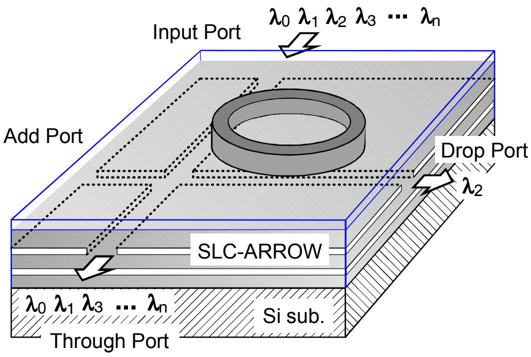

Fig.3: Structure of vertically coupled microring resonator with ARROW busline

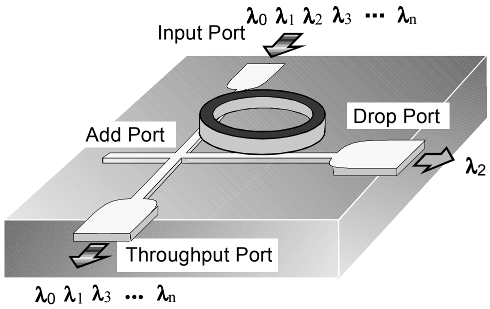

Fig.4: Structure of vertically coupled microring resonator with spot size transformer

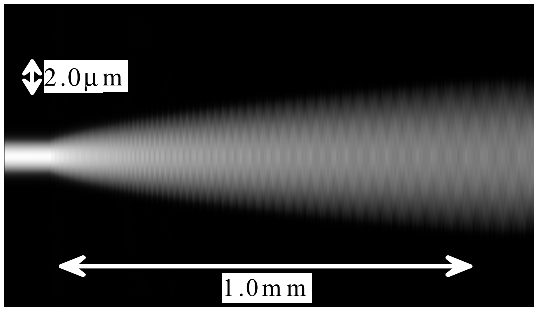

Fig.5: FDTD simulation of horn waveguide SST

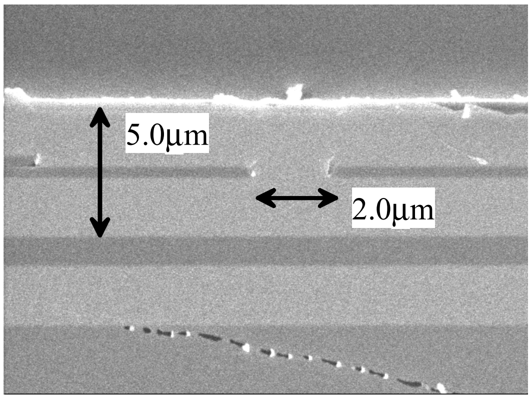

Fig.6: SEM cross sectional view of ARROW

sponse has not been observed due to the difficulty of coupling between the ARROW busline waveguide and the microring waveguide.

To improved the coupling between the busline and the ring waveguides, the equivalent index of busline (n_{eq}=1.58) was made closer to the equivalent index of microring (n_{eq}=1.68). In addtion, the top surface of the busline was planarized by the lift-off process [3] as shown in Fig.6. The ring radius was 15μm. Owing to the improved coupling between the ARROW and the microring waveguide, the dropping response was observed for the first time as shown in Fig.7. In addition, the insertion loss of the throughput response was reduced to 8dB, which is smaller by about 22dB than that of the conventional busline. Further improvement of insertion loss will be possible by enlarging the core size of ARROW busline.

6 MRR with SST

Next, we fabricated the vertically coupled microring resonator filter with the spot size transformer (SST) as shown in Fig.4. The SST used in this study is the parabplic horn type as described in section 4, which can achieve low loss single mode propagation. It can be seen from Fig.2(d) that the spot size at the end of busline waveguide can be matched to that of single mode fibers in the horizontal direction. The width of SST at the output end is 10μm so that the spot size is matched to that of single mode fiber. On the other hand, the width of busline waveguide in the device region is 2μm, which is the same as the conventional busline waveguide. The spot size of busline waveguide in the device region is about 0.95×0.55μm. Thus, the coupling between the busline and the microring waveguide is the same as the conventional device.

However, the thickness of core is 0.7μm, which is the limit resulting from the lift-off process to planarize the top surface of busline waveguide. We matched the spot size of busline waveguide to that of single mode fiber only in the horizontal direction. Therefore, the input/output coupling loss can be reduced by about 15dB. Further reduction of coupling loss will be possible by introducing the vertical taper in the SST.

The materials and the fabrication process of this structure are the same as those used for the ARROW based microring resonator filter. The insertion loss of the throughput response was reduces to 22dB, which

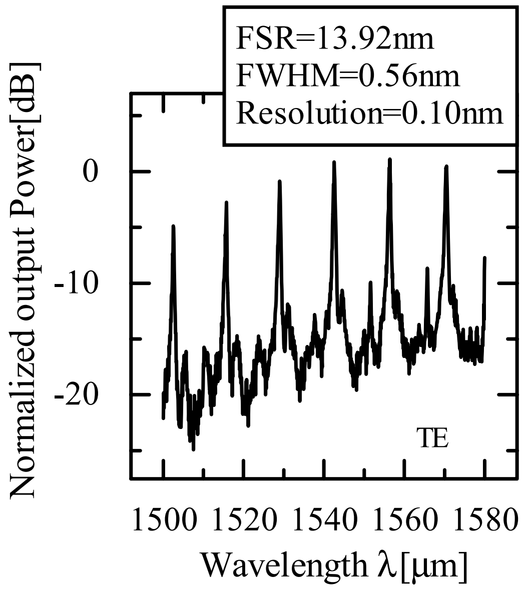

Fig.7: Dropping responce of MMR with ARROW

is about 10dB of improvement from the conventional busline waveguide.

7 Conclusion

By adopting the ARROW-B waveguide and the rectangular waveguide with SST, we reduced the input/ output coupling loss. The experimental results of input/output coupling loss were summarized in Table 1.

Although it is impossible to measure the coupling loss separately, the coupling loss was evaluated by the insertion loss at the throughput port. Since the insertion loss of thoughput response was reduced to 8dB, we can conclude that the coupling loss was success fully reduced by adopting an ARROW waveguide as the busline waveguide.

Table 1: Losses of filters

	Calculated i/o coupling loss	Insertion loss
conventional busline	30dB	30∼40dB
ARROW busline	4.6dB	8dB
busline with SST	12.4dB	22dB

Acknowledgement

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