Design of SiN_x Optical Sensor Using Polygonal Resonator Structure

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***Abstract*—In this paper, SiN_x polygonal resonator is carefully simulated for an optical sensor. The polygonal resonator has recently attracted much attention for application in bio and chemical sensors because it does not have a bending loss, which can be fabricated with high integration rate, and it has an advantage of using Multi Mode Interference (MMI) coupler. In polygonal resonator sensor design, high Q-factor and low loss Total Internal Reflection (TIR) mirror are important factors. Therefore, a 125 degrees TIR mirror that has a 97% reflectance considering the Goos-Hånchen shift and critical angle is designed. For rib type waveguide, we designed it to have 3 µm width, 0.5 µm height, and 0.25 µm etching depth. Regarding the simulation results of Finite Domain Time difference (FDTD) method, the Q-factor of SiN_x polygonal resonator was 5736 and Free Spectral Range (FSR) was 16.3 nm. When we changed the refractive index, the shift of the peak was 26.5 nm/Refractive Index Unit (RIU).**

Keywords- photonics; optical resonator; optical sensors.

I. INTRODUCTION

In recent years, optical resonators have been researched for their use as sensors and filter devices. When using these optical resonators as a biosensors, attaching antibodies on the surface are used for monitoring the change of refractive index after an antibody-antigen reaction. These sensors are called refractometric sensors [1]–[2]. They detect the variation of refractive index by measuring the output power at a fixed wavelength or shift of resonance wavelength. In order to obtain high sensitivity, a resonator should have a high Q-factor. The most common type of resonator is a ring resonator [3]. However, during the fabrication progress, it has the disadvantage of mass-production because a single mode condition should be applied. In the ring resonator structure, the waveguide width is too narrow to fabricate the resonator using photolithography because the common waveguide core material is Si, which has about 400 nm width for a single mode waveguide. When the waveguide of the ring resonator is at multimode, the output of the resonator has a lot of peaks and thereby, it is not suitable to be used as an optical sensor. For establish the single mode condition, a common method is to design the rib type waveguide or to use a low refractive index core material. However, bending loss is another disadvantage of the ring resonator. It has a high bending loss which limits the minimization of the resonator. This disadvantage reduces the integration rate. To overcome these drawbacks, we designed a polygonal resonator that does not have bending loss. Also, a polygonal resonator can use MMI coupler. Therefore, a polygonal resonator can be an alternative solution. In this paper, we simulated the polygonal resonators based on SiN_x material which has a refractive index of 1.9827 at 1.55 µm wavelength.

II. THEORETICAL ANALYSIS OF RESONATOR

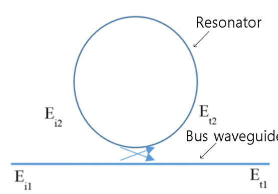

Figure 1. A Resonator structure

As shown in Fig.1, a resonator structure is composed of a bus waveguide and a resonator [4]. It has been used as sensor and filter device. E_{i1} is the input electric field, E_{t2} is the coupling electric field from waveguide to resonator, E_{i2} is the coupling electric field from resonator to waveguide and E_{t1} is the output electric field. The equation in this resonator can be expressed as:

$$\begin{pmatrix} E_{t1} \\ E_{t2} \end{pmatrix} = \begin{pmatrix} t & \kappa \\ -\kappa^* & t^* \end{pmatrix} \begin{pmatrix} E_{i1} \\ E_{i2} \end{pmatrix} \tag{1}$$

$$E_{i2} = \alpha \cdot e^{j\theta} E_{t2} \tag{2}$$

Here, t is the transmission coefficient, κ is the coupling coefficient and α is the attenuation coefficient. Using (1) and (2), the output of the resonator can be expressed as:

$$P_{t1} = |E_{t1}|^2 = \frac{\alpha^2 + |t|^2 - 2\alpha|t|\cos(\theta+\varphi_t)}{1+\alpha^2|t|^2 - 2\alpha|t|\cos(\theta+\varphi_t)} \quad (3)$$

III. WAVEGUIDE DESIGN AND TIR MIRROR

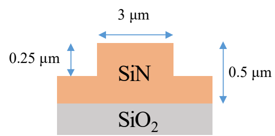

Figure 2. Waveguide structure

The design of a waveguide is important because it determines the propagation loss. Firstly, we designed the waveguide to have a SiN_x core and SiO_2 cladding material. SiN_x material has a refractive index of 1.9827 at 1.55 μm wavelength [5] and SiO_2 material has a refractive index of 1.44 at 1.55 μm wavelength [6]. As shown in Fig.2, the waveguide width, height and etching depth are 3 μm, 0.5 μm and 0.25 μm, respectively. This structure makes it possible to fabricate the resonator using a contact aligner that costs lower and has a higher productivity than using e-beam lithography. We also designed a TIR mirror which is a significant factor for the polygonal resonator. The critical angle and Goos-Hanchen shift should be considered carefully in designing a TIR mirror [7]. The critical angle of the SiN_x waveguide structure is 46.57 degrees and the estimated value of the Goos-Hånchen shift is calculated about 200 nm. The designed TIR mirror has an angle of 125 degrees and the reflectance is 97% as shown in Fig.3. According to the simulation, there are 5 Transverse Electric (TE) and Transverse Magnetic (TM) modes in the waveguide structure because of its wide width. However, the surface roughness of the SiN_x waveguide and the long path length of the resonator make higher order modes disappear. Therefore, the output of the polygonal resonator has a single mode electric field.

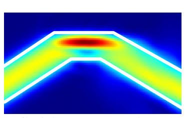

Figure 3. Electric field propagation in TIR mirror

IV. POLYGONAL RESONATOR

The polygonal resonator is an attractive structure because it has no bending loss and MMI coupler can be applied for use. These advantages make fabrication easier than the ring type resonator. However, sophisticated TIR mirror design should be required for low bending loss of the polygonal resonator. In the designed TIR mirror, each TIR mirror has 3% loss, so the total resonator loss is about 22%. Using equation (3), a 50:50 coupler is needed for high on-off ratio. Therefore, we designed 50:50 MMI coupler, which has 193 μm length. The total length of the polygonal resonator is 800 μm. The simulation results of the octagonal resonator is shown in Fig. 4. The results showed that the Q-factor of the polygonal resonator was 5736 and the FSR was 16.3 nm. When the refractive index was changed, the shift of the peak was 26.5 nm/RIU.

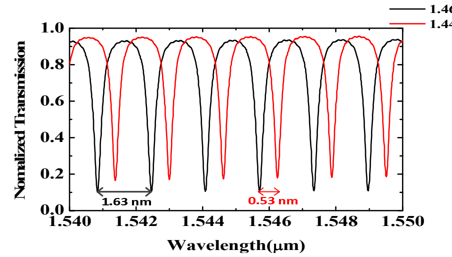

Figure 4. The output intensity of polygonal resonator

V. CONCLUSIONS

In this paper, we designed a polygonal resonator as an optical sensor. In contrast to ring resonators, having no bending loss and using MMI are the advantages of polygonal resonator. These advantages increase the integration rate and make fabrication easier. Also, wide width waveguide can be fabricated through photolithography just as a contact aligner. The polygonal resonator will be a good solution to overcome the disadvantages of a ring type resonator.

ACKNOWLEDGMENT

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REFERENCES

[1] N. A. Yebo, D. Taillaert, J. Roels, D. Lahem, M. Debliquy, D. Van Thorhout and R. Baets, “Silicon-on-insulator(SOI) ring resonator-based integrated optical hydrogen sensor,” IEEE photonics technology letters, 21(14), 2009

[2] Z. Vanessa, L. Peter, W. Martin and P. Daniel, “A highly sensitive refractometric sensor based on cascaded SiN microring resonators,” Sensors, 13, 14601-14610, 2013

[3] Vittorio M. N. Passoro, “Ammonia optical sensing by microring resonators,” Sensors, 7, 2741-2749, 2007

[4] John E. Heebner, Vincent Wong, A. Schweinsberg, R. W. Boyd and D. J. Jackson, “Optical transmission characteristics of fiber ring resonators,” IEEE journal of quantum electronics, 40(6), 2014

[5] Tryggve Bååk, “Silicon oxynitride; a material for GRIN optics,” Applied optics, 21(6), 1069-1072, 1982

[6] S. O. Kasap, Optoelectronics and photonics, Pearson, Canada, 33, 2013

[7] Tae-Kyeong Lee, *et al.*, “A high-Q biochemical sensor using a total internal reflection mirror-based triangular resonator with an asymmetric Mach-Zehnder interferometer,” Optics communications, 285(7), 1807-1813, 2012

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