Study of polymeric slot microring biosensors

Y. Liang,[1] M. Muneeb[1], S. Radosavljevic[1], M.S. Zhao,[2] and G. Morthier[1]

[1] Photonics Research Group, Department of Information Technology, imec and Center for Nano- and Biophotonics, Ghent University, Ghent B-9000

[2] School of Physics and Optoelectronic Engineering, Dalian University of Technology, Dalian, 116024, P.R. China

Slot waveguides can improve the sensitivity of biosensors by enhancing the interaction between the optical field and the biomolecules. Slot microrings have been demonstrated on high refractive index (RI) materials such as silicon and silicon nitride. In this paper, polymeric slot microrings are studied for applications in biosensors. Slot width and waveguide width have been optimized to get a high sensitivity and low bend loss. Compared with common polymeric microring biosensosr, slot waveguide microrings can achieve 110 nm/RIU which is more than double the sensitivity of normal polymeric microring biosensors.

Introduction

Integrated photonics biosensors have demonstrated their great potential for clinical, chemical and biological diagnostics in the past years. They have a lot of advantages such as having a high sensitivity, being label free and allowing real-time monitoring. Many structures have been demonstrated for biosensing, such as interferometers, ring resonators, photonic crystal and plasmonic structures. Most of them make use of the evanescent wave working principle. In order to enhance the interaction between the optical field and the biomolecules, a slot waveguide was proposed. Instead of confining the majority of the optical mode to the core which is formed by high index material, the slot waveguide confines the majority of the mode to the slot which is usually where biomolecules are present in biosensors. The more the mode overlaps with the slot, the higher the sensitivity that can be obtained. The first slot waveguide based structures were fabricated on silicon. However, it limited their application in biosensing as the water absorption loss is large at the wavelength of 1310 nm and 1550 nm which are transparent for silicon [1]. Polymer as optical material has attracted a lot of attention since a few years. It is transparent at both infrared (1300-1550 nm) and visible wavelengths. Transparency at visible wavelengths is preferred for optical biosensor devices, as the absorption loss of water at visible wavelengths is much lower than at infrared wavelengths. Moreover, several novel fabrication processes have been developed which allow easy and cost effective fabrication of polymer biosensors. Nanoimprint lithography (NIL) is one of them. High-resolution nanopatterns down to sub-25 nm resolution on a large scale can be achieved with low-cost equipment. This replication technology is either thermal or UV based. In our work, UV-based soft nanoimprint lithography (Soft UV-NIL) is adopted. Curing by high temperature and pressure are avoided. Moreover, the roll-to-roll technique makes it a productive process

Polymeric slot waveguides has been applied in a Young interferometer, which allowed to detect a refractive index difference of 6.4×10^{-6} RIU. In this article, polymeric slot microrings are studied. The slot waveguide structure is optimized to get a high sensitivity and low bend loss at a radius of 200 μm. A silicon master mold for soft mold fabrication is fabricated and then a polymer slot waveguide is also fabricated through Soft UV-NIL.

Simulation and fabrication

As is known very well, high sensitivity is desired for biosensing applications. A high Q factor is also needed, since it determines the detection accuracy. The Q factor is normally affected by the propagation loss of the microring, especially the bend loss. Slot waveguide parameters are optimized to get a high sensitivity and low bend loss.

1. Single slot mode condition

Prior to other simulations, the single mode condition should be confirmed for the slot waveguide. Figure 1 depicts the slot waveguide cross-section. All the simulations are performed at the wavelength of 890 nm.

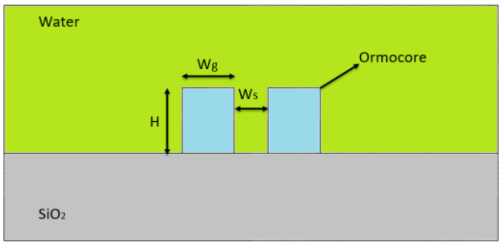

Figure 1: Cross-section of the slot waveguide

As the core material, a hybrid polymer Ormocore with a high refractive index n_{core}=1.543 is selected [2]. Silicon wafers are used as substrates with 3 μm thermal oxide on the top which acts as the under cladding, $n_{cladding}$=1.453. The upper cladding was assumed to be water (n_{water}=1.33) which is usually the solution in biosensing. The slot waveguide mode is illustrated in Figure 2 (a). The optical field is obviously enhanced in the slot.

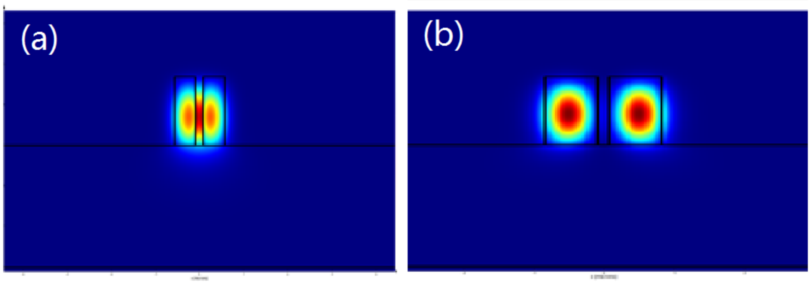

Figure 2: (a) slot waveguide mode, (b) second mode for slot waveguide

In our previous work on microrings[2], H was chosen to be 1 μm, which is also adopted in our present simulation. When the slot width (W_s) or the trench width (W_g) is too large, the second mode which is shown in Figure 2 (b) will be guided. As almost all the field of this mode is confined to the core, no enhanced interaction between mode and ambient is obtained. So in order to get the single slot mode condition, W_g and W_s should be considered simultaneously. The cut-off and single mode condition for different Ws and W_s are illustrated in the Table 1.

Table 1: The cut off condition and single mode condition for slot waveguide

W_s(μm)	Cut off for W_g(μm)	Single mode for W_g(μm)
0,1	0,45	0,75
0,15	0,5	0,73
0,2	0,55	0,70
0,25	0,55	0,68

From the table, we find that as W_s increases, the maximum value of W_g should decrease to maintain the single mode operation. However, the minimum value of W_g needs to increase to prevent mode cut-off.

2. Sensitivity and bend loss

The sensitivity (S) is an important parameter for biosensing. It can be expressed as:

$$S = \frac{\partial \lambda_m}{\partial n_{water}} = \frac{\partial \lambda_m}{\partial n_{neff}} \frac{\partial n_{neff}}{\partial n_{water}} = \frac{\lambda}{n_g} \frac{\partial n_{neff}}{\partial n_{water}}$$

Where λ_m is the resonance wavelength, n_{water}, n_{neff} and n_g are water refractive index, effective refractive index and group index of the waveguide respectively. Both W_g and W_s are the important parameters which influence the sensitivity. Figure 3 (a) shows the relationship between S and W_g and W_s.

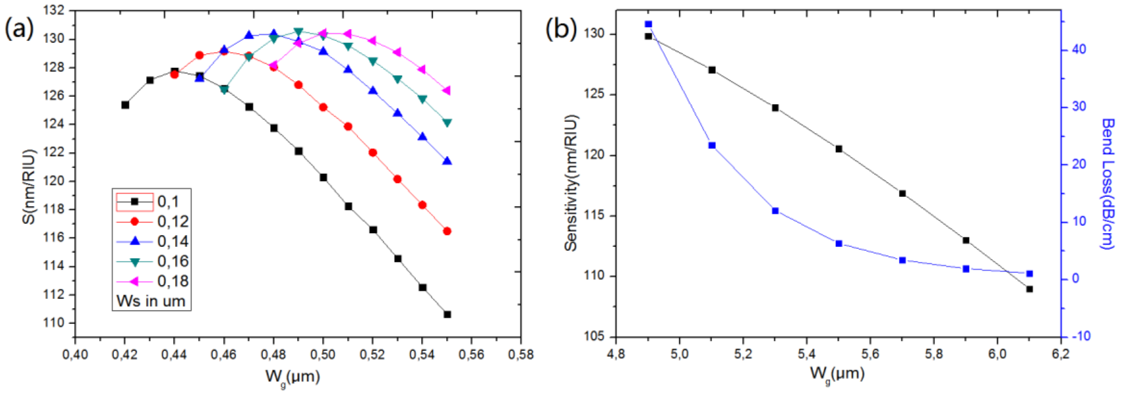

Figure 3: (a) the sensitivity with different width of trenches and slot, (b) relationship between sensitivity, bend loss and trench width

It can be seen that for a given W_s, S increases and then decreases with increasing W_g and a maximum value exists. The maximum value for each W_s increases with increasing W_g and it reaches the maximum, 130 nm/RIU when W_s=1.6 μm. Figure 3 (b) depicts the sensitivity and bend loss as a function of the trench width. Both sensitivity and bend loss decrease as W_g increases. Sensitivity decreases linearly while bend loss sharply drops down at the beginning and it tends to be stable at W_g =5.5 μm. So we choose 5.5 μm as the optimized W_g and the sensitivity is about 110 nm/RIU.

Fabrication

For polymeric slot microring fabrication, Soft UV-NIL is adopted. Before the Soft UV-NIL, a master mold should be prepared first. The process is illustrated in Figure 4.

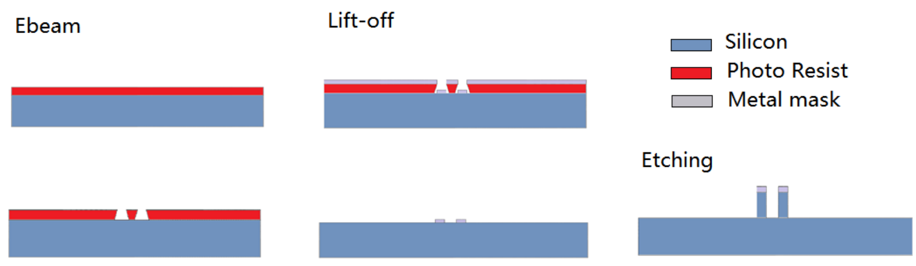

Figure 4: fabrication of master mold

The master mold was fabricated on a silicon substrate. First, an e-beam resist (ARP 6200.13) was spin-coated on the silicon wafer at 3000 rpm for 60 seconds. After baking at 150 °C for 2 minutes, it was exposed to e-beam. Then the development was applied for

4 minutes. A metal mask (10 nm Ti and 80nm Cr) was deposited on the wafer and the lift-off process followed. After etching, slot waveguide microrings are patterned on the silicon substrate which forms the master mold. The Soft UV-NIL has been illustrated in our previous work [2].

Characterization

For the nanoimprint lithography technique, the master mold fabrication is the most important part of the process. All the roughness and defects from the master mold will be replicated to the Ormocore chip. The cross-section and side wall SEM pictures are shown in Figure 5. The sidewalls are a little angled and the roughness is good enough. The height of the waveguide is about 800 nm and the width of the slot is about 200 nm which is a 50 nm larger than designed. This mismatch maybe because of the side etching during the etching process.

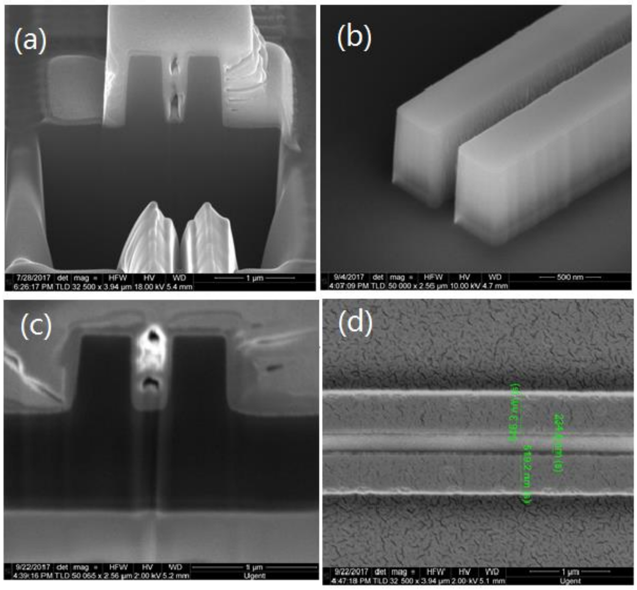

Figure 5: (a) and (b) are cross-section and side wall SEM pictures of the silicon master mold, (c) and (d) are cross-section and top view SEM pictures of Ormocore slot waveguide

After Soft UV NIL, the Ormocore slot waveguide is fabricated. The cross section and top SEM pictures are shown in Figure 5. the slot width is a little larger than it in the master mold and the height is almost the same. The process should be further improved before fabrication of slot waveguide microring biosensor.

Conclusion

In summary, parameters have been optimized in order to get slot waveguide microrings with high sensitivity and low bend loss. The sensitivity can achieve 110 nm/RIU. A silicon master mold was prepared and an Ormocore slot waveguide was also fabricated using Soft UV-NIL. However, these studies are still under investigation in order to obtain improved results.

References

[1] F. Dell'Olio and V. M. Passaro, "Optical sensing by optimized silicon slot waveguides," *Optics Express*, vol. 15, pp. 4977-4993, 2007.