Highly sensitive ring resonator based refractive index sensor for label free biosensing applications

Sanchit Kundal
Department of Electrical Engineering
Indian Institute of Technology, Jodhpur
Jodhpur, India
sanchit.1@iitj.ac.in

Arpit Khandelwal
Department of Electrical Engineering
Indian Institute of Technology, Jodhpur
Jodhpur, India
arpitkhandelwal@iitj.ac.in

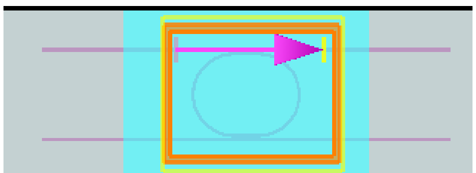

Fig. 1. Ring resonator engaged with target samples.

***Abstract*—Ring resonator based label free refractive index biosensor is proposed for detecting glucose and hemoglobin concentrations. To improve device sensitivity and Q factor, various parameters of ring resonator are optimized. The designed ring resonator sensor can sense hemoglobin and glucose concentrations with a high sensitivity of 424 nm/RIU and Q factor of 802.**

I. Introduction

The label-free based ring resonator sensor can detect various biological analytes with very sensitivity and Q factor. Refractive index of known biological samples are engaged with ring resonator and due to evanescent feild of ring resonator, we are able to see change in effective refractive index, whch will cause shift in the resonant wavelength [1]. Various shaped metal layers can be added to achieve SPR phenomenon to achieve high sensitivity [2].

II. RING RESONATOR DESIGN

The device connsists of ring waveguide, straight waveguide, source of wavelength around 1.53 μm and 2D monitor used for detection which is simulated on FDTD lumerical software. Due to high sensitivity campared to silicon, the proposed resonator is simulated with gallium arsenide (GaAs) with a coupling length of 800 nm , ring waveguide and straight waveguide gap of 800 nm, ring radius is 2500 nm and width of 200 nm.

The proposed device is engaged with known biological samples as shown by grey colour in Fig. 1. Various hemoglobin and glucose concentrations can be sensed by changing the known index of refraction of analyte and analysing resonant wavelength shift in the output transmission spectrum.

TABLE I
REFRACTIVE INDEX OF VARIOUS HEMOGLOBIN COCENTRATIONS [3]

Analyte	Concentration(g/dl)	Refractive index
1	4.775	1.34266
2	5.730	1.34306
3	6.685	1.34382
4	7.640	1.34442
5	8.595	1.34600
6	9.550	1.34824

TABLE II
REFRACTIVE INDEX OF VARIOUS GLUCOSE COCENTRATIONS [4]

Solution	Concentration(mg/dL)	Refractive index
1	0	1.30
2	50	1.32
3	100	1.34
4	150	1.36

III. RESULTS AND DISCUSSION

A. Label free based ring resonator refractive index sensor

Different samples of hemoglobin having different concentration as well as different blood sample with glucose concentration with known refractive index is immersed in ring resonator. Table 1 and 2 shows samples of refractive index of glucose and hemoglobin concentrations. As the proposed sensor is engaged with target analyte solutions, we observe change in the resonant wavelength in spectrum as shown in Fig. 2 and Fig. 3. The ring resonator sensor produces high sensitivity ($\delta\lambda/\delta n$) of 570 nm/RIU and Q factor ($n_{eff} * L * F/\lambda$) of 380.

B. Sensitivity and Q factor improvement of Ring resonator sensor

Q factor and sensitivity of the sensor is further improved by optimizing various sensor design parameters such as radius of

978-1-6654-7899-1/22/$31.00 ©2022 IEEE

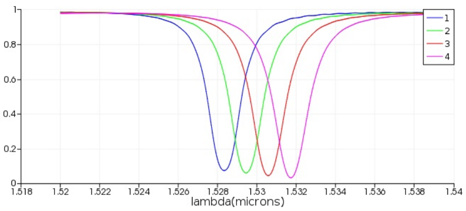

Fig. 2. Resonance spectrum for different glucose concentrations.

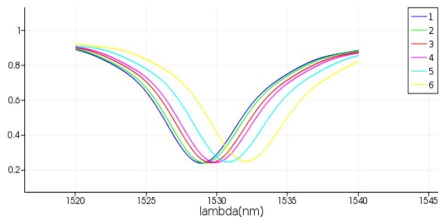

Fig. 3. Resonance spectrum for different hemoglobin concentrations.

ring and gap between ring waveguide and straight waveguide. The sensitivity and Q factor will vary for separate dimensions of design parameters and we are able to observe the dependency of all these parameters on the sensitivity and Q factor of the proposed sensor

To search optimized radius of ring resonator, various dimensions of ring radius are simulated. The ring radius is varied from 2500 nm to 3500 nm . It is found from Fig. 4 that the radius 2500 nm shows the highest sensitivity of 605 nm/RIU and maximum Q factor of 380.

Gap between ring and straight waveguide in the simulation is varied from 50 nm to 150 nm. The gap of 50 nm shows maximum sensitivity of 567 nm/RIU and maximum Q factor of 383 as shown in Fig. 5.

IV. CONCLUSION

A ring resonator based refractive index sensor is designed which has the capacity to sense various hemoglobin and glucose concentrations without any labels atatched to the sensor surface. The sensor can achieve high sensitivity and Q factor. The ring radius and gap between ring waveguide and straight waveguide is varied and their effect on resonator sensitivity and quality factor is studied. The proposed sensor possess a sharp Q factor of 1525 and high sensitivity of 1071 nm/RIU.

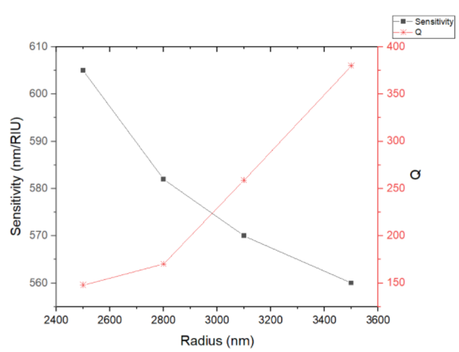

Fig. 4. Sensitivity and quality factor variation with ring radius.

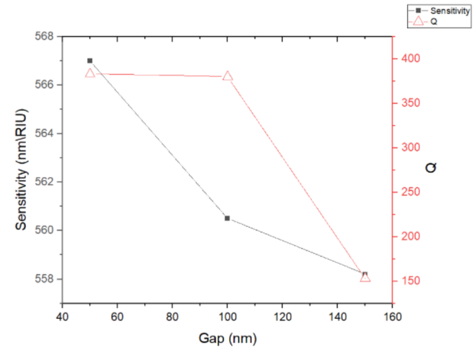

Fig. 5. Sensitivity and quality factor variation with gap.

REFERENCES

[1] L. Ali, M. U. Mohammed, M. Khan, A. H. B. Yousuf, and M. H. Chowdhury, "High-quality optical ring resonator-based biosensor for cancer detection," IEEE Sensors Journal, vol. 20, no. 4, pp. 1867–1875, 2020.

[2] M. Zhang, G. Wu, and D. Chen, "Silicon hybrid plasmonic microring resonator for sensing applications," Appl. Opt., vol. 54, pp. 7131–7134, Aug 2015.
Advances of the last decade," Biosensors and Bioelectronics, vol. 76, pp. 103–112, 2016

[3] A. K. Ajad, M. J. Islam, M. R. Kaysir, and J. Atai, "Highly sensitive bio sensor based on wgm ring resonator for hemoglobin detection in blood samples," Optik, vol. 226, p. 166009,

[4] S. Ameta, A. Sharma, and P. K. Inaniya, "Designing a multichannel nanocavity coupled photonic crystal biosensor for detection of glucose concentration in blood," in 2017 8th international conference on computing, communication and networking technologies (ICCCNT), (IEEE,2017), pp. 1–4