Gas Molecules Recognition via the Response Time of Silicon Nanophotonic Ring Resonator

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Abstract: A silicon photonic sensor for the recognition of different gas molecules is presented in this paper, by measuring the response time of ring resonator. The response time constant of various gas molecules is distinctive and ideal for gas sensing with high specificity, overcoming the limitations of conventional non-specific sensing platforms.

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1. Introduction

Silicon ring resonator has been widely used in sensing, such as biomolecules [1], temperature [2], pressure [3], gas [4] and many others. In gas detection, one of the approaches is by coating an absorption layer onto the ring structure surface. When the gas concentration is changed, the thickness and refractive index of the absorption layer will change accordingly. Consequently, the resonance peak of the ring resonator is shifted and the shift can be correlated with the concentration of gas. However, the critical problem of such sensing platform is the lack of specificity to different gases. In this paper, we propose a simple method to categorize gas molecules by the different response time constants, which is a breakthrough innovation to detect and differentiate gas molecules.

2. Results and Discussion

Figure 1(a) shows the silicon ring resonator sensing platform, whereby light is coupled to the silicon ring via a straight waveguide. The cross-section of the waveguide and the ring is 450 × 220 nm (width × thickness). The coupling gap between the straight waveguide and the ring is 200 nm. Grating coupler is designed to couple light into and out of the straight waveguide. The ring structure is exposed to the surrounding environment and acts as the main sensing unit. The ring structure is coated with a thin layer of polymer as gas absorption layer. Gas is injected to the ring surface via a microfluidic channel bonded on top of the chip. The whole device is built by standard CMOS fabrication process. Figure 1(b) shows the scanning electron microscope (SEM) image of the fabricated ring structure. Figure 1(c) shows the mode distribution when an absorption layer is coated on the surface of the ring. The strong distribution in the absorption layer indicates the large effect to the optical properties when the thickness and refractive index of this layer change.

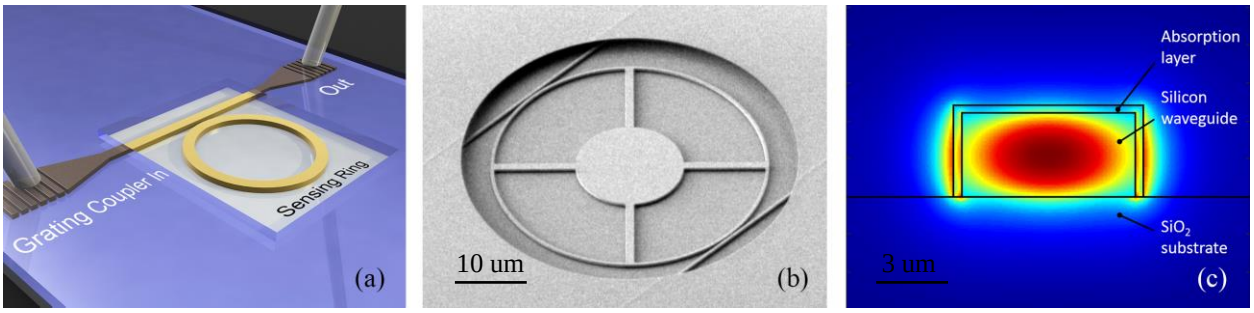

Fig. 1 (a) Schematic of the ring resonator sensing platform. Light is coupled to the device with a pair of grating coupler. (b) SEM image of the fabricated ring structure. (c) Simulation result shows the light confinement in the waveguide.

During the experiments, the resonance peak of the ring resonator is being monitored. Figure 2(a) shows the testing result when the peak position is plotted as a function of time. Here, 20-nm polydimethylsiloxane (PDMS) is used as the absorption layer and acetone is the target gas. Initially, the chip is tested in pure nitrogen gas as a blank control. At about 12,580 sec, 6, 000 ppm acetone vapor is injected to the chip surface. The response curve is enlarged in

Figure 2(b) and a time constant of 24.04 sec is observed. Subsequently, at about 13,000 sec, pure nitrogen is injected again. The response curve is enlarged in Figure 2(c) and a time constant of 40.65 sec is observed.

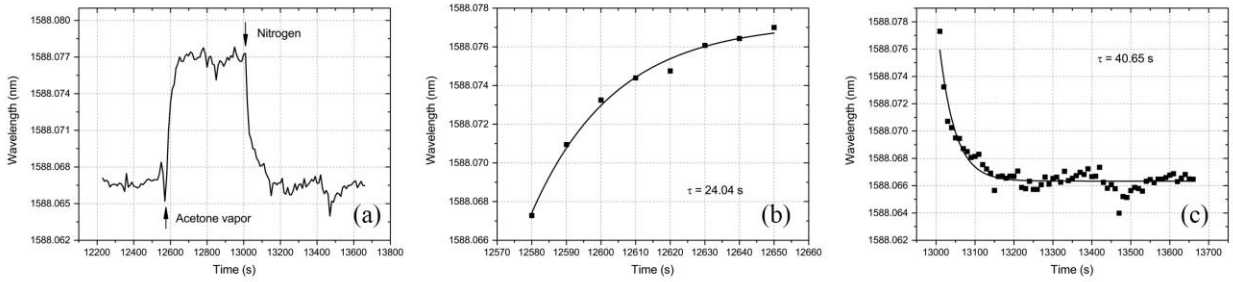

Fig. 2 (a) Transmission spectrum of ring resonator when pure nitrogen gas is replaced by acetone vapor. The response curve when (b) acetone vapor is injected to the chip surface, and (c) is replaced by pure nitrogen gas again.

On the other hand, 50-nm thickness of polyethyleneimine (PEI) is used as the absorption layer to detect CO_2. As shown in Figure 3(a), similarly, CO_2 and nitrogen is inject to the chip surface in turn. When CO_2 is used at about 830 sec, a time constant of 40.61 sec is observed as shown in Figure 3(b). Subsequently, when nitrogen is injected again at about 1,300 sec, the corresponding time constant of 500.6 sec is observed as shown in Figure 3(c).

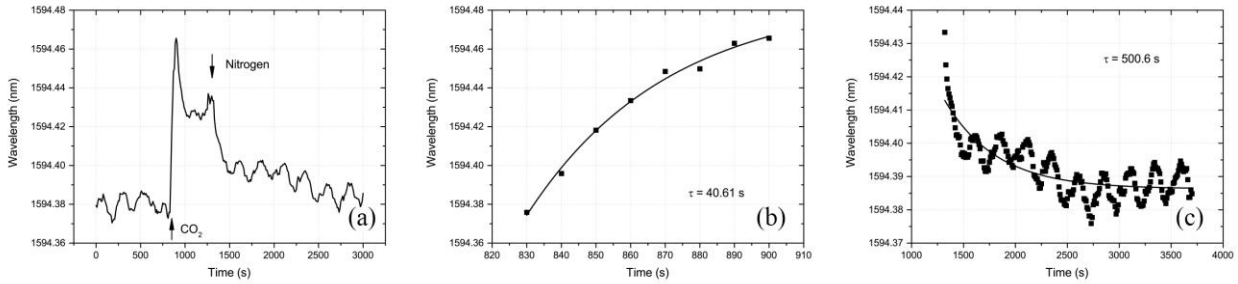

Fig. 3 (a) Transmission spectrum when N_2 and CO_2 is inject onto chip surface. The response curve when (b) CO_2 is injected to the chip surface, and (c) is replaced by pure nitrogen gas again.

The time constant is significantly different for the two different gas molecules, which offers a reasonable approach to distinguish different gases based on the same set of devices. Furthermore, a calibration database can be built for different gases whereby a unique time constant fingerprints for each gas can be measured. Therefore, the database of resonance time for different gas molecules will be developed using this method, which is an important approach for gas detection and sensing in future.

3. Summary

A sensor for the detection of different gas molecules is presented by measuring the response time of silicon nanophotonic ring resonator. The response time constant of various gas molecules is distinctive and ideal for gas sensing with high specificity, overcoming the limitations of conventional non-specific sensing platforms.

4. References

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