A Lab-on-a-chip Sensing Platform Enabling Concurrent Detection Using Subwavelength Grating Micro-ring Resonator

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Abstract: We developed a lab-on-a-chip optical biosensor that realized the concurrent detection of two analytes with high sensitivity. The silicon photonic chip is integrated with a microfluidics chip, which offers a promising solution to point-of-care detection.

1. Introduction

Since the 21st century, the world has been continuously subject to the threat of respiratory infectious diseases, some of which can be highly detrimental to human health and societal interactions. In the context of continued spread of coronavirus disease 2019 (COVID-19), the demand for rapid, accurate, and frequent detection is increasing. [1] Besides, because the common respiratory infectious diseases have similar clinical manifestations but diverse potential hazards, the identification of pathogen is significant to patients and communities. [2] Therefore, the importance of developing efficient sensors with high sensitivity cannot be ignored.

In past decades, the advances in silicon photonics and photonic integrated circuits (PICs) have offered new opportunities for disease diagnosis, and promoting the development of lab-on-a-chip (LOC) biosensor for point-of-care (POC) testing. [3, 4] Here, we proposed an optical biosensor based on subwavelength grating micro-ring resonator (SWGMR), and demonstrated the concurrent detection of COVID-19/influenza A H1N1 with high specificity and sensitivity.

2. Design and Working Mechanism

2.1. Design of silicon biosensing chip

The SWGMRs are fabricated on silicon-on-insulator (SOI) wafers and constructed by periodic pillars with a period much smaller than the operating wavelength. Compared with conventional strip waveguides, the subwavelength grating (SWG) structure shows good potential for biosensing owing to larger sensing region of the periodic structure, which significantly improves light-matter interaction and sensitivity. [5] The PIC layout of the chip and SEM image of SWGMR are shown in Fig. 1 (a) &(b). For the concurrent detection of two analytes, six independent channels were divided into two sensing units (the other two channels in the middle are reference channels). The probe for the analytes of interest, such as antibody and cDNA, could be immobilized on SWGMRs through microfluidic channels. When the sample is introduced, the specific combination of analyte to probe results in the variation of the effective reflective index n_{eff} of SWG waveguide, which could be manifested in the shift of resonance peak. The quality factor Q and bulk sensitivity S_{bulk} of the fabricated SWGMR is $\sim$1600 and 437 nm/RIU, respectively.

2.2. Design of microfluidic chip and packaging

In considering the design of a LOC biosensing platform to facilitate clinical detection, we developed a microfluidic chip that enables independent surface functionalization and dual-channel concurrent detection as shown in Fig. 1 (c). For this purpose, we proposed a specially designed Y-shape structure that supports two operation modes. Specifically, reagents are introduced from the lateral ports and exit the chip from the middle port after flowing through the SWGMRs in the process for functionalization. In this mode, the Y-shaped structure could avoid the cross-contamination caused by the regurgitation toward another branch. While for the testing, the middle port works as the inlet. The sample is bifurcated by the Y-shape splitter and flows to two sensing units. Additionally, a 3D-printing chip holder was designed and fabricated for the packaging of sensing chip, fiber array and microfluidic channel.

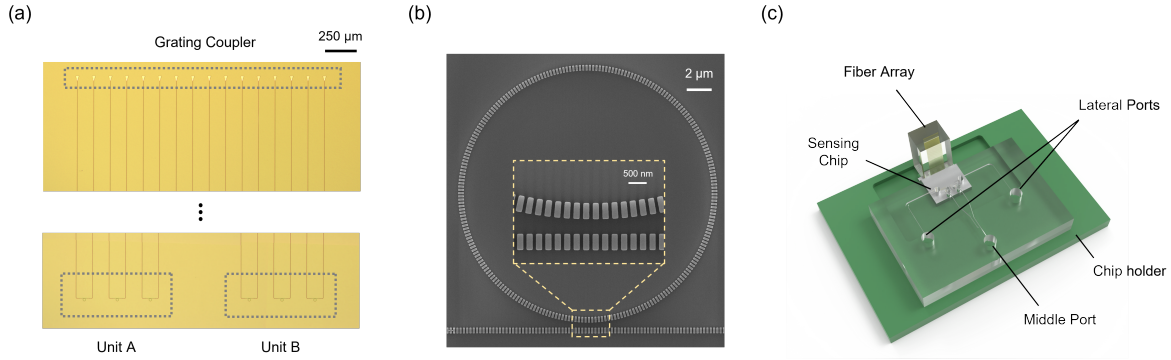

Fig. 1: Schematic of the SWGMR-based biosensor. (a) Layout of the silicon sensing chip. (b) SEM images of the SWGMR fabricated by E-beam lithography. (c) Illustrated model of the sensing platform.

3. Results and Discussions

For demonstration the sensing performance of device, SARS-CoV-2 spike antibody and influenza A nucleoprotein antibody was introduced from lateral ports for functionalization. Then the samples were pumped into the microfluidic channel via the middle port. The responses to the samples containing SARS-CoV-2 spike protein or influenza nucleoprotein are shown in Fig. 2. According to the peak shifts, the optical assay shows a clear response difference between positive (∼150 pm) and negative (∼15 pm), which indicates a good specificity with a low limit of detection (LOD).

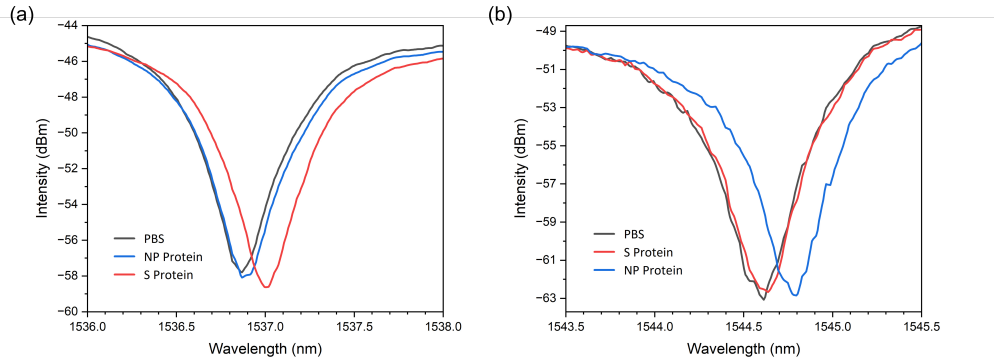

Fig. 2: Detection and differentiation of two antigens (a) Response of the device functionalized by SARS-CoV-2 spike antibody. (b) Response of the device functionalized by influenza A nucleoprotein antibody.

4. Conclusions

This work presented an SWGMR-based biosensing platform enabling the concurrent detection of two analytes. Besides, a microfluidic chip and 3D-printed holder for packaging were developed to improve reliability and facilitate operation. Furthermore, the POC biosensor realized the concurrent detection and differentiation of COVID-19 and influenza. The cross-validation indicated the high specificity and sensitivity of the optical assay. Therefore, the SWGMR-based biosensor offers a promising solution for identifying pathogens with similar symptoms.

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