Improving Detection Sensitivity for Nanoscale Targets Through Combined Photonic and Plasmonic Techniques

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Abstract

Introduction: Photonic technique such as the whispering gallery mode (WGM) is widely applied in the field of detection of small particles such as bacteria and viruses. WGM offers high detection sensitivity due to that the binding of a tiny particle to a waveguide setup (e.g., a cavity or a ring) will change the travelling distance of light in the waveguide leading to a shift in the resonance frequency of the setup. It has advantage over other detection techniques because the detection can be label free. However, the detection sensitivity may not be high enough when the size of detection targets is in nanoscale. The goal of this study is to improve the detection sensitivity for nanoscale targets by combining the WGM technique with a plasmonic technique such as Surface Plasmon Resonance (SPR) and Surface Enhanced Raman Scattering (SERS).

Use of COMSOL Multiphysics®: A 2D model consisting of a straight optical waveguide and a ring structure of two different refractive indexes was developed using COMSOL Multiphysics® as shown in Fig.1. A thin layer of gold is coated on the outer surface of the ring where the ring meets the vertical waveguide for photonic coupling and SPR excitation. Another gold layer with nanostructured surface is placed above the ring (the center part, close to the active sensing region where a circular target particle binds) for activating SERS hot spots in the active region.

Results: Fig.2a shows the obtained resonance pattern of basic whispering gallery mode along with excited SPR and SERS in the junction and active sensing regions. Fig.2b shows the result of a frequency sweep study which was performed to find the resonant frequency for the coupled photonic and plasmonic device. Fig.3 shows that the energy distribution between the ring and the surrounding medium changes with frequency. The distribution curve exhibits a sharp slope generated from plasmonic behavior. Based on this frequency sweep study, the output of vertical waveguide is calibrated with various sizes of target particles. By choosing the frequency with the lowest distribution ratio, we demonstrated that the sensitivity can be greatly improved. Moreover, the rough surface of gold layer for enhancing the SERS hot spots improves the detection sensitivity as well.

Conclusions: For the first time, WGM, SPR and SERS are successfully combined in a single device by using COMSOL for modeling. Our results show that the three techniques work in synergy, thus contributing to the improvement of detection sensitivity significantly. The obtained

results show good a linear relationship between particle size and waveguide output, and this is true even when the particle is only several nanometers in size. This work provides great new insight into how distribution of energy between the photonic ring structure and the surrounding medium can affect the resonance pattern. By selecting a proper frequency we can significantly improve and optimize the detection sensitivity.

Figures used in the abstract

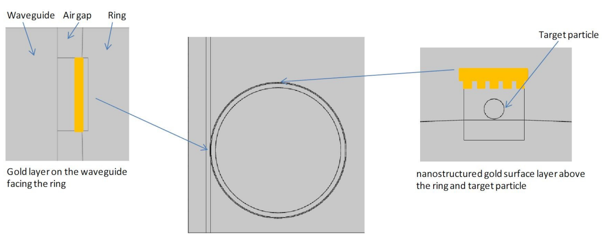

Figure 1: COMSOL model of a detection device built upon the combined photonic and plasmonic techniques.

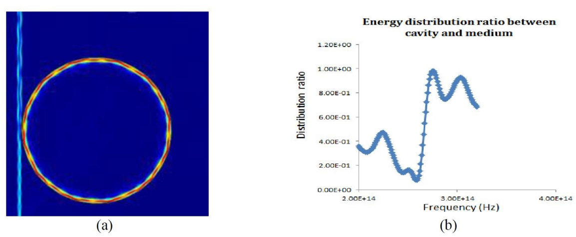

Figure 2: (a) The resonance pattern of basic whispering gallery mode. SPR and SERS are excited on the left and top region of the ring structure. (b) Energy distribution between cavity and medium changes with frequency. The sharp slope shows plasmonic behavior.

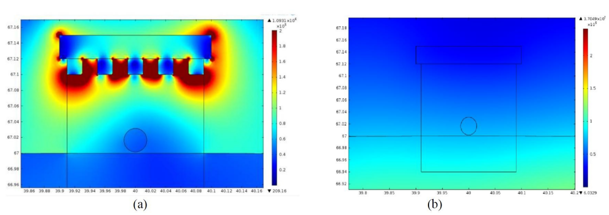

Figure 3: (a) A nanostructured surface generates strong local electromagnetic field (hot spots) through SRRS activation. (b) A flat surface generates a much uniform electromagnetic field.