Monolayer WS_2 Enhanced High Sensitivity Plasmonic Biosensor based on Phase Modulation

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Abstract: A monolayer WS_2 enhanced surface plasmon resonance biosensor is proposed. We theoretically and experimentally demonstrate that the sensitivity could reach to 3.5×10^4 deg/RIU, which was 300% higher than that of the conventional configuration.

OCIS codes: 240.0310 (Thin films), 240.6680 (Surface plasmon), 280.1415 (Biological sensing and sensors)

1. Introduction

The surface plasmon resonance (SPR) based biosensor is well-known for its unique advantages of real-time monitoring and label-free detection. However, the limited sensitivity of the conventional configurations does not support small biomolecules detection [1]. In this work, we employ two-dimensional (2D) tungsten disulfide (WS_2) as the sensitivity-enhanced thin film of the SPR based biosensor, as shown in Fig. 1a. Both the simulation and experimental results show that the proposed WS_2 enhanced SPR model could improve the sensitivity by more than 300%. Recently, the emerging 2D WS_2, which belongs to the transition metal dichalcogenides (TMDCs) family, has been widely used in solar cells and transistors due to its remarkable photoelectric properties [2, 3]. The direct bandgap of the 2D WS_2 allows much higher photoelectric conversion efficiency compared to its bulk scale [4, 5]. Here, the sensitivity enhancement of the proposed SPR model can be mainly contributed to two reasons: (i) The high optical absorption of the 2D WS_2 accelerates the rate of energy transfer from light to the electrons, thus enhancing the resonance effect. (ii) The hexagonal crystal structure of WS_2 offers a higher sensing area for absorption of the biomolecular sample.

2. Methodology and experiment

It is known that only the p-polarized incident light can excite SPR, and thus the s-polarized light can be used as the reference to eliminate the environment noise. The p-polarized reflected light possesses a jump-like phase shift upon excitation of SPR. Here, the differential phase, φ_d, between the s-polarized and p-polarized light is the key sensing parameter. The phase-sensitivity is defined as the ratio of the change in differential phase, $\Delta\varphi_d$, to the change in the refractive index (RI) of biomolecular sample, Δn_a. According to the Maxwell's equations and Fresnel's Formula, we theoretically study the influence of the number of WS_2 layers to the phase shift of the model. The monolayer WS_2 is able to induce the sharpest phase shift, thereby the largest change of φ_d, as shown in Fig. 1b-c.

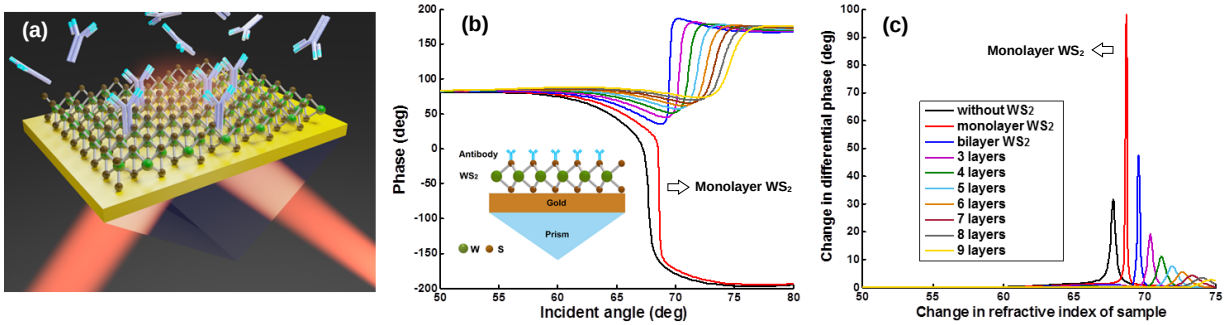

Fig. 1. (a) The schematic diagram of the WS_2 enhanced SPR model, it consisted of SF11 prism, gold thin film and the monolayer WS_2. The biomolecules can directly interact with the WS_2 surface. (b) The simulation results of the phase shift with various number of WS_2 layers. The sharpest phase shift was obtained with monolayer WS_2. (c) The simulation results of the change in differential phase under a fixed RI change of 0.05 in the sample. The largest phase change was observed in monolayer WS_2.

For the experiment, a 4 mW 632.8 nm He-Ne laser was used. In the p-polarized light path, an SPR configuration based on the Krestchmann geometry was employed, where the WS_2/Au thin film was attached to the base of prism. A flow chamber made of acrylonitrile butadiene styrene (ABS) was directly covered on the film. The sample solutions were injected into the chamber by a syringe pump to interact with the sensing surface. The phase modulation was realized by a galvo-mirror in the s-polarized path. The intensity of the final interfered light was detected by a photodetector. The WS_2 layer was first grown on the SiO_2/Si substrate by chemical vapor deposition (CVD) and then transferred onto the Au thin film. The PL spectrum and Raman spectra on Au substrate were measured as shown in Fig. 2.

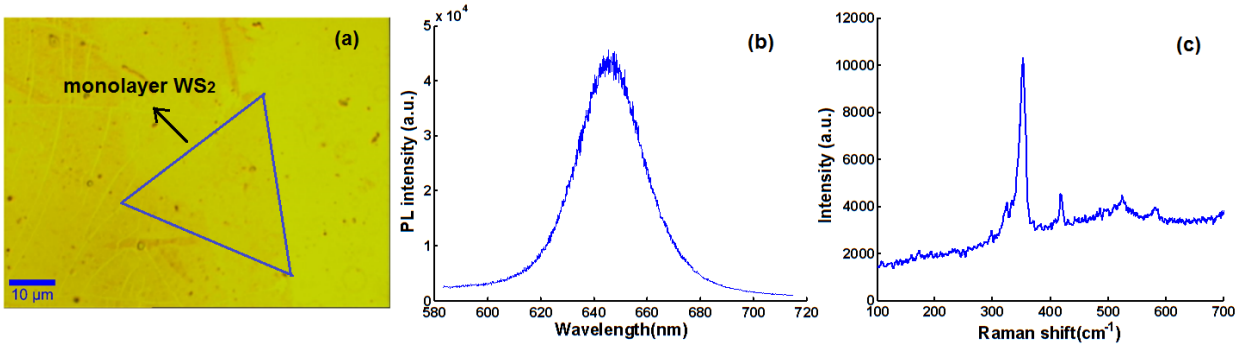

Fig 2. (a) The optical image of monolayer WS_2 on Au thin film (50 nm) substrate. (b) The PL spectrum of WS_2/Au thin film excited by 532 nm laser. The strongest PL peak is located at 645 nm. (c) The Raman spectra of the WS_2 monolayer at room temperature.

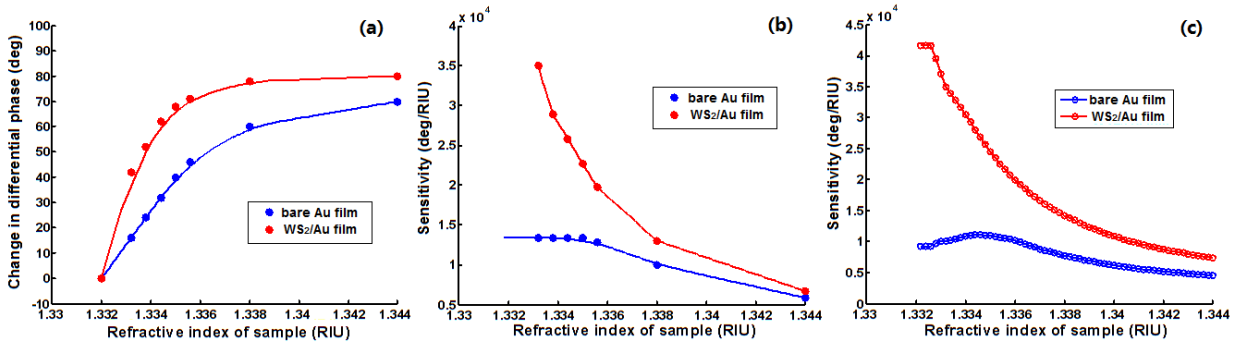

Fig. 3 (a) The changes in the differential phase φ_d between the DI water and glycerin solution (1%, 1.5%, 2%, 2.5%, 3%, 5%, 10%). (b) The relevant phase sensitivity of the measurement. (c) The simulation of the phase sensitivity for the sample with RI change from 1.332 to 1.344.

3. Results and conclusion

The phase sensitivity of the various glycerin solutions (from 1% to 10%) was measured experimentally (Fig. 3a-b) and the obtained results are well-matched with the theoretical study (Fig. 3c). With the optimization of the number of 2D WS_2 layers, the sensitivity of the WS_2 enhanced model can reach to as high as 3.5×10^4 deg/RIU for detecting minute RI change (0.0006 RIU). This sensitivity is more than 300% higher than that of the conventional model with bare Au substrate. The high optical absorption of the 2D WS_2 enhances the resonance effect, thus induces larger changes of the differential phase, thereby higher phase-sensitivity.

4. References

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