Graphene Enhanced Surface Plasmon Resonance Fiber-Optic Biosensor

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Abstract: We experimentally demonstrate a side-polished optical fiber based graphene-on-gold biosensor. Single layer of graphene is deposited to improve the sensitivity in single-stranded DNA detection. Our proposed biosensor provides a detection limit lower than 1 pM.
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1. Introduction

Graphene brings huge potential to sensing applications. Graphene-modified surface plasmon resonance (SPR) platform is proven to be more sensitive than the conventional configuration. The graphene layer strengthens the surface plasmon polariton (SPP) so that the hybrid structure is more responsive to adjacent medium variation. Besides, graphene shows strong absorption to biomolecules with aromatic rings through π-π interaction [1]. Compared with conventional surface functionalization in biosensors, single-layer graphene deposition is a simpler approach for molecule binding. On the other side, optical fiber based sensors are well recognized by their miniaturization, flexibility and in-situ monitoring capability. Taking advantages of both graphene-modified SPR and optical fiber, we propose a graphene-on-gold architecture in combination with side-polished optical fiber to realize a highly sensitive single-stranded DNA (ssDNA) sensor.

2. Experiments and Discussion

Fig. 1(a) illustrates the configuration of our proposed biosensor. A thin gold film is coated on a side-polished surface of optical fiber to excite SPP. Single layer of graphene is deposited on gold film for enhancing SPP and binding ssDNA molecules. To verify the superiority of graphene-on-gold configuration, we compare it with conventional side-polished fiber based SPR sensor through numerical analysis. As shown in Fig. 1(b), the presence of graphene layer enhances the transmission loss, which provides stronger SPP, and also shifts the resonance to a longer wavelength. As the refractive index of ambient medium increases, the graphene-modified SPR sensor undergoes larger resonant wavelength shift and peak transmission loss enhancement, therefore leading to a better sensitivity than conventional SPR configuration (Fig. 1(c)).

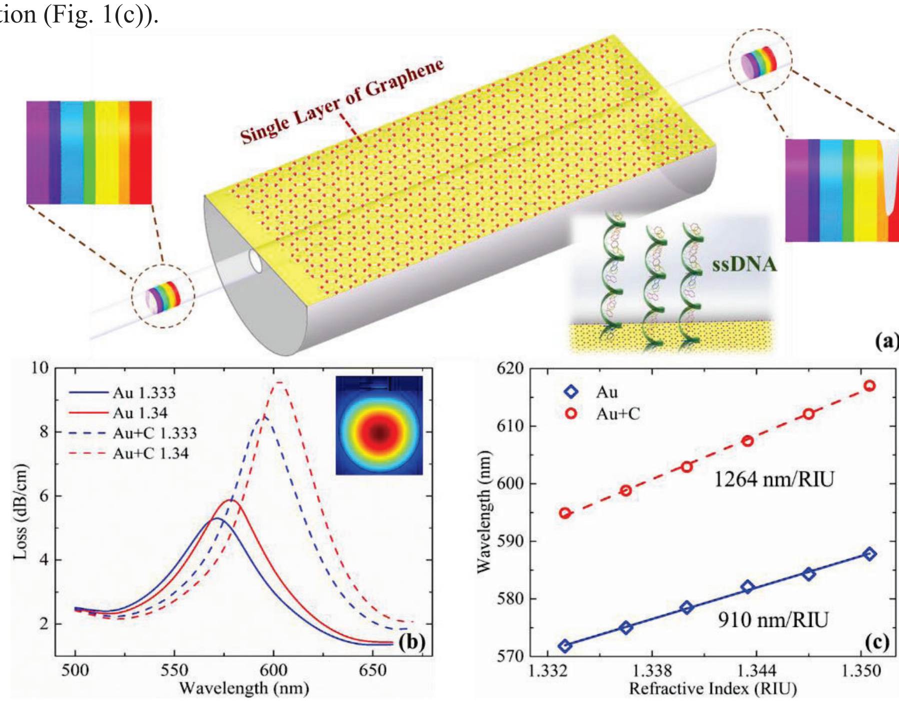

Fig. 1. (a) Configuration of the proposed graphene-on-gold ssDNA sensor; (b) Comparison of transmission properties and (c) sensitivities between conventional side-polished fiber based SPR sensor and the proposed graphene-on-gold fiber sensor.

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We polish a standard single-mode fiber to expose fiber core of ~2 mm long. Then we evaporate a 30 nm gold film on the plat polished surface. Before transferring graphene, we characterize the SPR behavior of this conventional configuration. Fig. 2(a) shows the variation of transmission spectra along with the increasing surrounding refractive index. As the refractive index gradually increases from ~1.33 (DI water) to ~1.35 (NaCl solution), there are obvious enhancement as well as redshift of the resonant dip on transmission spectrum. This phenomenon agrees well with the simulation results. The sensitivity is ~414 nm/RIU using the wavelength interrogation method (Fig. 2(b)).

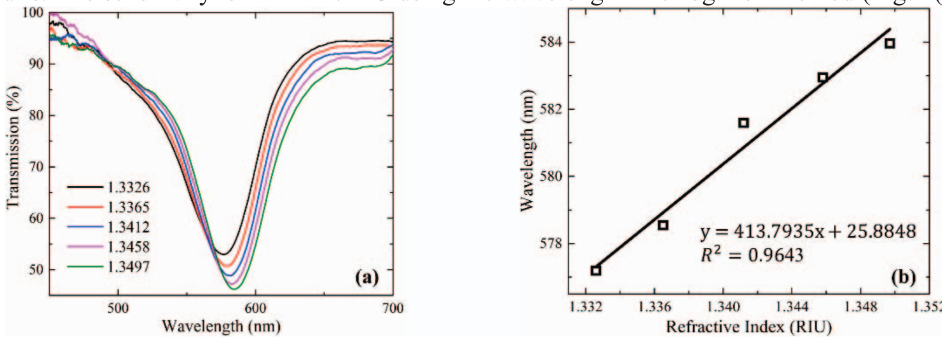

Fig. 2. (a) Transmission spectra of conventional side-polished fiber based SPR sensor; (b) Sensitivity of the conventional configuration.

Single layer of graphene is then transferred onto the gold film using the "PMMA mediated" approach [2]. The black curve in Fig. 3(a) is the transmission spectrum of graphene-on-gold sensor when immerging in DI water. Compared to that in Fig. 2(a), the spectrum of graphene-modified sensor has a deeper resonant dip. Also, the graphene layer leads to the redshift of resonant wavelength from 577.19 nm to 579.33 nm, which is in good agreement with the simulation results. After the characterization, we further test the capability of our sensor for ssDNA detection. Various concentrations of 7.3 kDa 24-mer ssDNA (5'-C TT CTG TCT TGA TGT TTG TCA AAC-3') range from 1 pM to 10 uM are applied to the biosensor. As shown in Fig. 3(a), there occurs a distinguishable deepening of resonant dip when ssDNA concentration is as small as 1 pM, which is ultralow compared to state-of-art fiber-optic DNA sensors [3,4]. The deepening continues as the concentration further increases, which is due to the increasing number of ssDNA molecules binding to the graphene layer. Besides, there is also a slight redshift of resonant wavelength, which means that the increase of refractive index of ssDNA solution is very small. Fig. 3(b) plots the linear decrease of transmission minimum and the gradually saturated wavelength shift against log pM concentration. The transmission minimum shows linear response to log scale ssDNA concentration over a wide detection range from 1 pM to 10 uM.

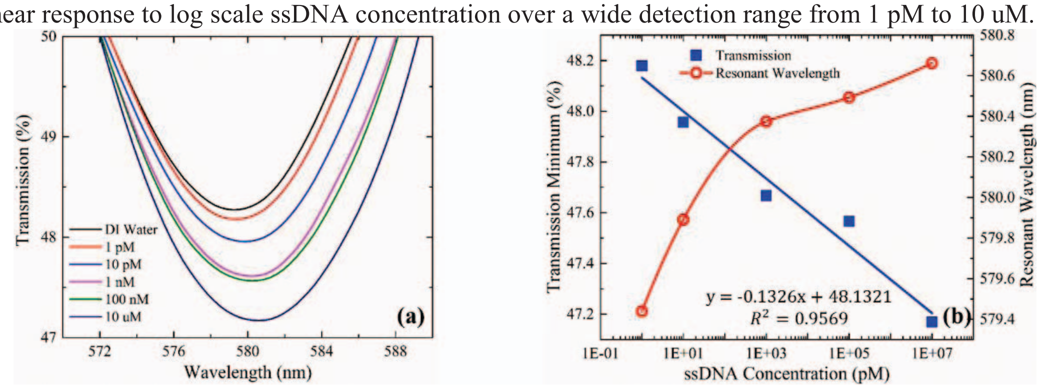

Fig. 3. (a) Magnified transmission spectra of graphene-on-gold biosensor when measuring various concentrations of ssDNA; (b) Transmission minimum and resonant wavelength against ssDNA concentrations (log pM).

3. Conclusion

We propose a fiber-optic biosensor based on graphene-on-gold architecture to realize ultralow detection limit as well as high sensitivity. The proposed highly integrated architecture shows great potential in small biomolecules detection.

4. References

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