# High Sensitivity SPR Sensor Based on Microfiber Coated with Gold Nanowires

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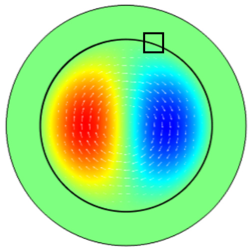
***Abstract*—In this paper, we proposed surface plasmonic resonance (SPR) sensor based on microfiber coated with gold nanowires. Using finite element method, this SPR-based fiber-optic sensor is investigated. Dependence of sensitivity of the sensor on the microfiber radius is simulated for analyte refractive index of 1.33-1.34. The simulation shows that there is an optimized microfiber radius of 8.5μm, yielding to the highest sensitivity of 4400nm/RIU among the radius of 7.5μm-10μm.**

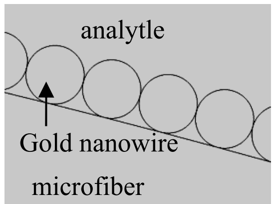
## I. Introduction

Recently, nanostructure sensors based on surface plasmon resonance (SPR) have attracted extensively attention due to the local enhance of field with the electron density oscillations. Surface plasmon resonance [1] as an important high sensitive mechanism has been widely used in various kinds of sensors. These SPR sensors has various structure, such as Au-film-coated D-shaped fiber, Au-film overlay prism, metal-film coated on the V-groove surface in a optical fiber and two coupled different core size fibers[2]. In this paper, we propose a novel SPR sensor based on a microfiber coated with gold nanowires. These gold nanowires are periodically placed around the microfiber side by side. Dependence of sensitivity of the sensor on the microfiber diameter is simulated for analyte refractive index of 1.33-1.34.

## II. Theoretical Analysis

Gold [2] as a more chemically stable metal is widely used in SPR sensors in different shape such as thin film and particles. In propose model, Fig.1 is a cross-section of a microfiber, which radius is 9.5μm, periodical surrounded by 900 gold nanowires which diameter is 70nm. As the metallic layer of sensor, Au can readily be tuned to the near-infrared spectral region where light penetration is deeper. With the excitation of evanescent field, gold nanowires surface plasma captured energy from the light. The complete excitation occurs when the wave vector of surface plasmons and evanescent matched. As the resonance is sensitive to the surrounding refractive index, the property of sensitivity obtained. Since the refractive index (RI) of biomaterial is around 1.33-1.34, in this paper, we focus on optimization of the sensitivity for the RI range of 1.33-1.34.






(a) (b)

Fig. 1. (a) is the cross section of microfiber with gold nanowires and (b) is the room in (a).

## III. Model and Simulated Results

In propose model, nanowires are set around the cross section of microfiber one by one making the number is an integer, so there is a tiny space between nanowires less than 1nm. The radius of microfiber and gold nanowires are 9.5μm and 35nm respectively. For the microfiber, the wavelength dependence of refractive index of silica is expressed by Sellmeier relation given in Ref [3]. The dielectric function of a gold nanowire is well described by the simple Drude model. From this model, the permittivity of gold can be written as:

$$\varepsilon_m(\lambda) = 1 - \frac{\lambda^2\lambda_c}{\lambda_p^2(\lambda_c + j\,\lambda)} \tag{1}$$

Where, and are the plasma and collision wavelengths of the gold respectively.

The model is built using finite element method (Comsol 4.4). Fig.2 shows the dependence of complex effective refractive index on the wavelength. The black solid line represents the imaginary, the blue dash line represents the real part. Note that a dip at the wavelength of 633nm appear in the curve of the imaginary part because the plamonic resonance is excited. Left inset in Fig. 2 shows the mode field inside microfiber, while right inset shows the excited plasmonic field around the gold nanowires. Consequently, we can calculate the transmittance spectrum of the sensor based on imaginary part using following equation:

$$\mathrm{T}(\lambda) = \exp\left(\frac{4\pi}{\lambda_0} imag(n_{eff})L\right) \tag{2}$$

Where T represents the transmittance and the length of transmittance L=5mm, effective refractive index $n_{eff}$ is complex. Real and imaginary part of $n_{eff}$ with wavelength is shown in Fig. 2.

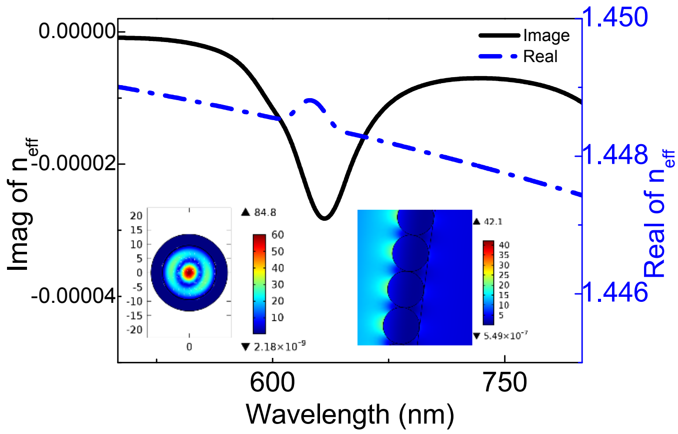



Fig. 2. The imaginary part and real part of the effetive refractive indices 9.5µm in 1.33

To estimate the influence of microfiber radius (MR) on the sensitivity, we change MR from 7.5µm to 10µm in 0.5µm step to find the optimal radius of microfiber. Transmittance spectra for different microfiber radius are given below.

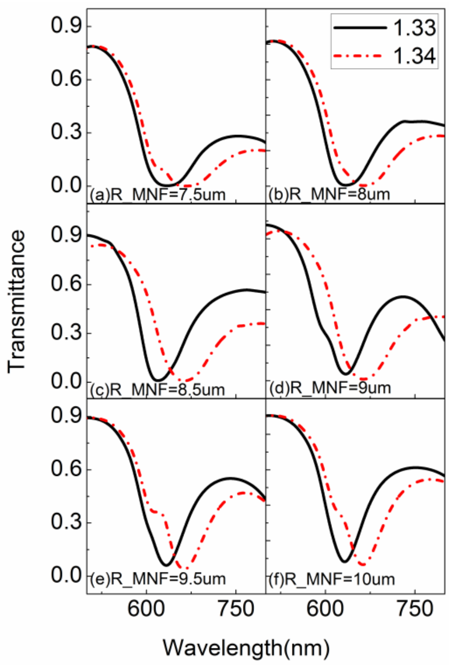



Fig. 3. Resonance wavelength of SPR sensor coated with gold nano-particles when radius of microfiber changes (a)7.5µm; (b) 8µm; (c)8.5µm; (d) 9µm; (e)9.5µm;(f)10µm.

Fig.3 represents the resonance wavelength in the condition for different size of microfiber with the number of gold nanowires changes to meet the requirement of closing to the optic fiber. The black solid line and red dash line represents the refractive index of 1.33 and 1.34 respectively. The dip red shifted from 635nm to 665nm, 633nm to 664nm, 619nm to 663nm, 634nm to 665nm, 633nm to 663nm and 629nm to 663nm corresponding to radius 8µm, 8.5µm, 9µm and 9.5µm in the refractive index range of 1.33-1.34. Fig.4 shows the sensitivity measured from the SPR spectra given in Fig.2 and Fig.3, which are respectively 3000 nm/RIU, 3100nm/RIU for 8.0µm, 4400nm/RIU, 3090nm/RIU, 3000nm/RIU and 3100nm/RIU for MR=7.5µm,8.0µm,8.5µm,9.0µm,9.5µm, 10µm.

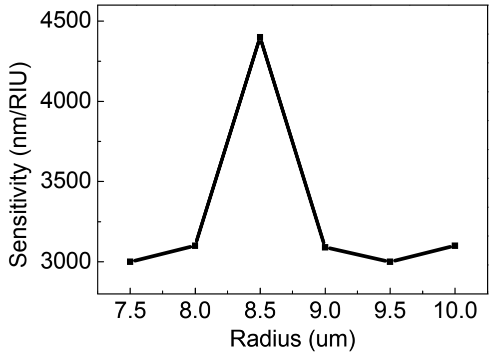



Fig. 4. Dependence of sensitivity on the microfiber radius

## IV. Conclusions

In summary, the SPR sensor based on microfiber coated with gold nanowires is investigated using finite element method. The simulation results suggest that 8.5µm radius of microfiber is optimal to achieve the highest sensitivity of 4400nm/RIU when the surrounding refractive index ranges from 1.33 to 1.34.

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## *References*

[1] Sheng Liu, etc. Hybrid plasmonic waveguide made of a microfiber attached to a metal film. Optics Express, 29 Jun 2015 Vol.23, No.13.

[2] Huanjun Chen, etc. Shape- and Size-Dependent Refractive Index Sensitivity of Gold Nanoparticles. Langmuir, 2008, 24, 5233-5237.

[3] A. K. Sharma and B.D.Gupta, On the sensitivity and signal to noise ratio of a step index fiber optic surface plasmon resonance sensor with bimetallic layers, Optics Communications 245, 159-169 (2005).

[4] Rana Tabassum, Banshi D. Gupta, SPR based fiber-optic sensor with enchanced electric field intensity and figure of merit using different single and bimetallic configurations. Optics Communications 367 (2016) 23-34.