

Plasmonic Sensor Based On Silver Nanoparticles For The Detection of Glucose

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Abstract

Sensors for detecting glucose concentrations are crucial to medical testing. Here, we introduce silver nanoparticles (Ag NPs) uniformly distributed in space to investigate the sensing properties for detecting glucose by using the finite-difference time-domain (FDTD) and experimental methods. The results show that the transmittance of dip for the proposed structural model gradually decreases as the number of Ag NPs increases, when the concentration of glucose is constant. And the transmission spectrum shows slight red shift with the increasing of the glucose concentration. Moreover, the simulation results are in agreement with the experimental results. Especially, the maximum sensitivity $S=1144.07407 \text{ nm}/RIU$ can be realized for glucose concentration variation from 0.3 to 0.4 mol/L. The research results reveal an excellent sensing property that has important application value in medical detection.

1. Introduction

Local surface plasmon resonance (LSPR) can focus light on the near of the nanoparticles, thereby forming an enhanced electric field on the surface of the nanoparticles [1]. Such unique optical property has been applied in many research fields, such as plasmon-assisted catalysis [2, 3], the detection of single molecules [4, 5], and luminescence enhancement [6], plasmonic sensors [7–9]. LSPR is a label-free analysis technique with the advantages of high sensitivity, fast, and reproducibility. Metal nanoparticles have attracted extensive attention from researchers due to their plasmonic properties, and they are often used in the construction of optical sensors. The researchers prepared Ag@Au for the colorimetric detection of glucose, because the small diameter gold nanoparticles have the activities of glucose oxidase and horseradish peroxidase. The system is simple to operate, low cost, and does not use any enzymes and organic developer in the detection [10–13]. Chen et al. reported a single-step non-enzymatic colorimetric method based on Cu_2O/Ag NPs for glucose detection. The glucose concentration measured by this probe is equivalent to the glucose concentration measured by a commercial glucose meter [14]. Adnan designed a simple and efficient method for colorimetric detection of enzyme-free glucose based on l-cysteine functionalized Ag NPs, which can be used in actual blood glucose detection [15]. In addition, Ag NPs can also be used as a plasma substrate for detection. Chen et al. [16] and Pan et al. [17] synthesized Au@Ag NPs for Surface-Enhanced Raman Scattering (SERS) plasma substrates, which can be used to quantitatively detect glucose. Tashkhourian et al. [18], Xu et al. [19], Jang et al. [20], Akafzade et al. [21], and Cai et al. [22] reported the glucose detection based on Ag NPs or Ag/Au NPs by observing the changes of the plasmon resonance peak. Researchers often use FDTD Solutions to build simulation structures to design plasmon sensors. Heidarzadeh designed a surface plasmon resonance (SPR) sensor based on ring-shaped Ag NPs for the detection of D-Glucose. The maximum sensitivity can reach up to $890.84 \text{ nm}/RIU$ [23]. Rakhshani et al. designed a plasmonic nanosensor with a silver nanorod array in a square resonant cavity coupled with a two-slot cavity to detect the concentration of glucose in water. The sensitivity can reach up to $892 \text{ nm}/RIU$ [24]. Simplifying the structure and improving the sensitivity of sensors is still a challenge for the development of glucose detection.

In this paper, we built a structure group of Ag NPs uniformly distributed in space and performed simulation calculations to investigate the transmission and sensing properties by using FDTD method. At the same time, we also did the corresponding experiments, and got consistent results with the simulations. Finally, the maximum sensitivity is $S=1144.07407 \text{ nm}/RIU$ can be realized in our paper.

2. Experiments And Simulations

Materials

Ag NPs (diameter 50 nm , 0.1 mg/mL) were purchased from Jiangsu Xianfeng Nano Material Technology Company Limited (Co., Ltd) as shown in Fig. 1(a). Glucose was purchased from Tianjin Komiou Chemical Reagent Co., Ltd as shown in Fig. 1(a). Distilled water was used in all experiments.

Experimental details

Firstly, four glucose solutions with the concentration of 0.1 mol/L were prepared. A series of Ag NPs solutions of different amounts of substance were added into the glucose solutions. After the solutions were stable, the ultraviolet and visible (UV-Vis) spectrophotometer was used to record the transmission spectra of the solutions in the room temperature.

Then four glucose solutions with different concentrations were prepared. Add the same amount of Ag NPs solutions to the solutions. After the solutions were stable, the transmission spectra in the range of 350 to 700 nm were measured using the UV-Vis spectrophotometer.

Structure and Simulations

As shown in Fig. 1(b), we build a structure group of silver nanoparticles uniformly distributed in space. The radius of Ag NPs is set to 25 nm . The incident wave is defined as plane wave that varies from 350 to 700 nm and its direction is parallel to the positive direction of z axis. We set the x-axis and y-axis directions as periodic boundary conditions, and z-axis as a perfectly matched absorption boundary.

The relationship between concentration of glucose with its refractive index is linear [25]. The approximate value of refractive index is 1.33102 when the concentration of glucose is 0.1 mol/L . It was set to the background refractive index of the simulation model. Then the transmission spectra were obtained by changing the number of Ag NPs. And the transmission spectra were obtained by changing the value of background refractive index as the number of Ag NPs was 70.

3. Results And Discussions

Figure 2(a) and 2(b) depict the experimental and simulated transmission spectra when the concentration of glucose is 0.1 mol/L , and we can observe that the experimental results are well in agreement with simulation results. When the concentration of glucose is constant, the transmittance at the dip gradually decreases as the number of Ag NPs increases. The resonance wavelength is about 424.681 nm . Due to

the increasing of the number of Ag NPs, the distance between Ag NPs becomes closer and closer, more and more photon energy absorbed, resulting in the decreasing transmittance.

When the amount of substance silver nanoparticles is 1.4×10^{-7} mol, the experimental transmission spectra of different concentration of glucose are shown in Fig. 3(a). We can discover that the resonance wavelength has a slight red shift as the concentration of glucose increases from 0.1 mol/L to 0.4 mol/L. Fig. 3(b) depicts the simulated transmission spectra of different background refractive index, when the number of Ag NPs is 70. We can also discover that the resonant wavelength has a slight red shift as the background refractive index increases, which can be used to detect glucose. The experimental results are consistent with the simulated results.

In addition, we plot the electric field distribution at the dip in Fig. 4, when $n=1.33102$, $N=70$, and $N=400$. We can discover that there is a localized field enhancement on the surface of Ag NPs at the resonant wavelength because of the existence of LSPR. It is more obvious when there are more particles in Fig. 4(b).

As is well known, SPR sensing is sensitive to change of the refractive index at the surrounding medium. Here, we define the sensitivity, $S = \Delta \lambda / \Delta n(nm/RIU)$. $\Delta \lambda$ is the lambda difference, which is resonant wavelength of the dip position of two adjacent refractive index. Δn is adjacent refractive index difference. We can obtain that the maximum sensitivity is $S=1144.07407 \text{ nm/RIU}$ which is higher than references listed [23, 24], when the refractive index varies from 1.33426 to 1.33588 from Table 1.

Table 1
the relationship between sensitivity
and wavelength differences

$\Delta \lambda$	Δn	S
1.56076	0.00162	963.43210
1.75585	0.00162	1083.85802
1.85340	0.00162	1144.07407

4. Conclusion

In summary, Ag NPs are widely applied in optical sensors due to their outstanding optical properties such as large specific surface area and plasmonic characteristics. We investigate the sensing properties for detecting glucose by using the FDTD and experimental methods. A structure group of uniformly distributed Ag NPs was introduced in this paper. We can observe that there is localized field enhancement on the surface of Ag NPs at the resonant wavelength. The simulated results are consistent with the experimental. The results show that the transmittance at the dip decreases as the number of Ag NPs increases, and that the resonance wavelength shows red shift as the concentration of glucose increases. The maximum sensitivity is $S=1144.07407 \text{ nm/RIU}$. The study may be pave the way for glucose detection.

Declarations

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Competing interests

The authors declare no competing interests.

Availability of data and material

The data generated by the simulations and experiments during the current study are not publicly available.

Code availability

The codes for the current study are not available.

Authors' contributions

This research was planned by Zihui He and Lingqiao Li. Numerical simulation was performed by Wei Cui, Hui He and Lingqiao Li. Lingqiao Li did the experiments. The authors Zihui He, Hui He and Lingqiao Li discussed the results. Lingqiao Li wrote the original manuscript.

Ethics approval

Not applicated.

Consent to participate

Not applicated.

Consent for Publication

Not applicated.

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Figures

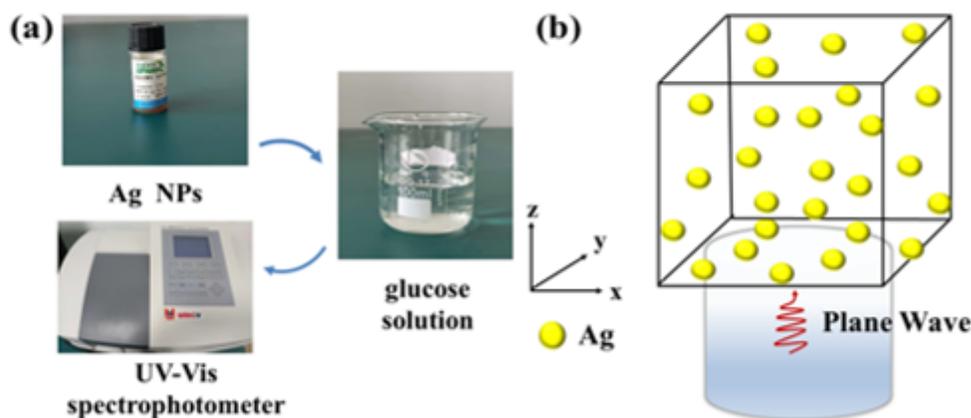


Figure 1

(a) The photo of materials and instrument (b) The model of simulation

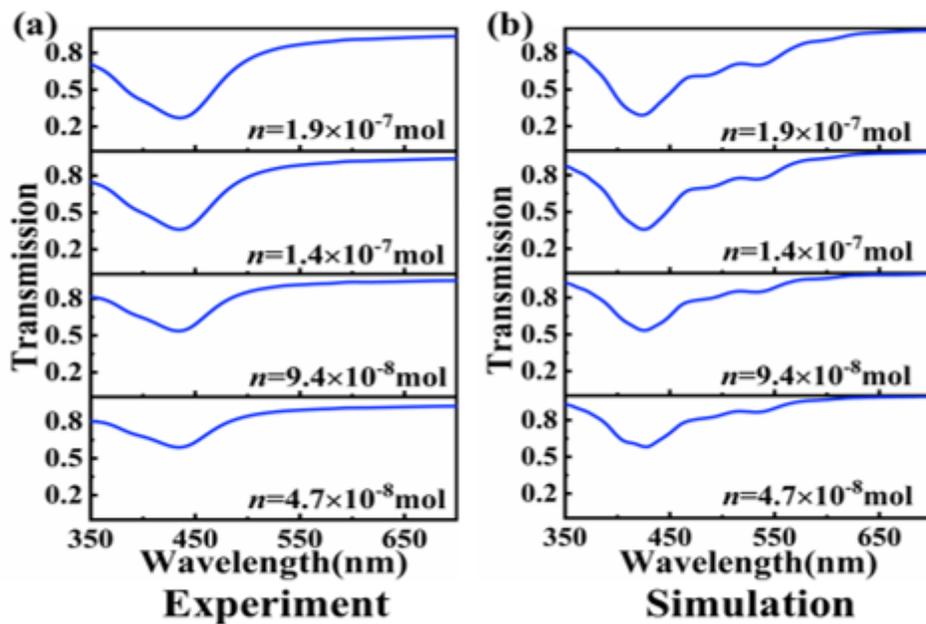


Figure 2

(a) Transmission spectra of different amounts of substance of Ag NPs, $c=0.1 \text{ mol/L}$ (b)

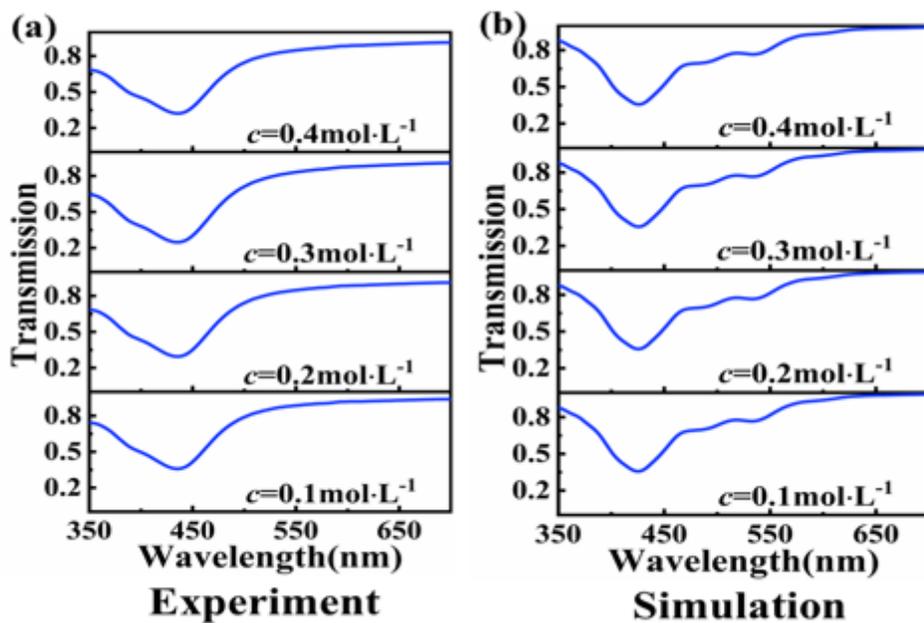


Figure 3

(a) Transmission spectra of different concentration of glucose (b) Simulated transmission spectra of different refractive index ($n=1.33102, 1.33264, 1.33426, 1.33588$)

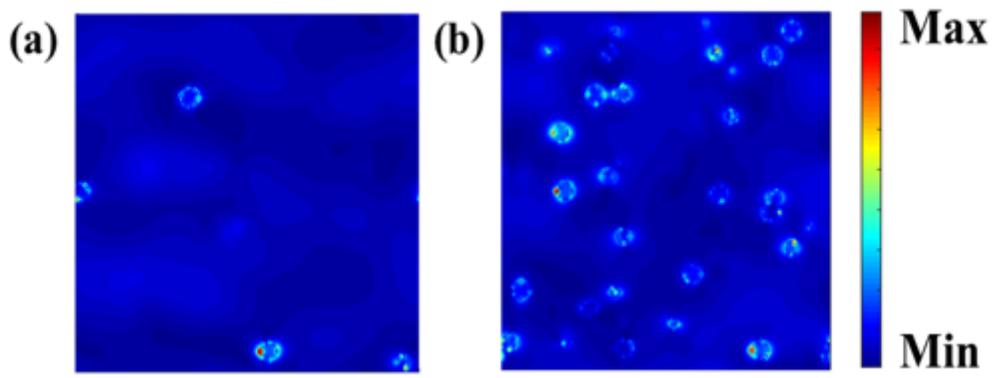


Figure 4

Simulated electric field distribution at 424.681 nm , $n=1.33102$, (a) $N=70$ (b) $N=400$