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Construction and Performance Study on a Novel Photothermal Sensor Device with Easy Operation and Low Cost

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Abstract

A novel, simple, and economic photothermal sensor device based on the photothermal effect was constructed from laser lamp, a common infrared temperature detector, and self-prepared porous glass sample cells. The photothermal sensor device was used to measure and analyze gold nanostars with an absorption peak of 880 nm. The influencing factors on device performance including irradiation angle, laser lamp height, irradiation time, and category of the gold nanoparticles were also systematically evaluated. The results showed that the temperature increased the most when the absorption peak of the gold nanostars is close to the wavelength of the laser lamp and the irradiation angle relative to the horizontal plane is 90°. The constructed photothermal sensor device was preliminarily confirmed to be stable, highly efficient, and easy to operate. Thus, it presents promising application prospects in analytical chemistry, medical detection, and environmental analysis.

Keywords: Photothermal effect; Sensor; Construction; Gold nanostars

Introduction

In recent decades, biosensing techniques have achieved significant improvements aligned with the rapid development of photoelectric technology. The development of biosensing techniques may include various approaches ranging from traditional enzyme-linked immunosorbent assay, ultraviolet analysis, infrared spectroscopic analysis, electrochemical analysis, mass spectrometry, or fluorometric analysis [1-4]. However, these methods require expensive and complex instruments and involve tedious detection protocols; thus, they are difficult to employ for real-time online measurement. Considering this limitation, developing a fast, simple, and inexpensive detection method for biological devices has become a research hotspot.

Photothermal conversion is a practical technology that has attracted considerable attention among researchers [5-7]. Most of them studied on the therapeutic imaging of various tumors and cancer. Photothermal sensing is widely used in fast, non-destructive online testing but seldom used in the construction of photothermal sensors. By conducting an immunological experiment, Bischof group established a photothermal sensor analysis method in which nanogold is used as the photothermal conversion reagent and an infrared camera is employed to record the temperature [8]. Wang group applied photothermal sensing technique to detect explosives [9]. Despite their obvious benefits, however, the methods proposed in both studies require the use of expensive instruments, thereby hampering their wider applications [10].

Herein, a new, simple, and inexpensive photothermal conversion device based on the photothermal effect was constructed with a laser lamp, a common infrared temperature detector, and self-prepared porous glass sample cells. The factors influencing the photothermal sensor device, including the laser wavelength, irradiation angle, laser lamp height, and irradiation time, as well as the category of gold nanoparticles, are specifically investigated. The results that the constructed photothermal sensor device was confirmed to be feasible, stable, highly efficient, and easy to operate.

Experimental

Reagents and chemicals

Hydrochloroauric acid trihydrate and tris base (TB) were purchased from Shanghai Sinopharm Chemical Reagent Co., Other chemicals were all of the reagent grades and used without further purification. Ultrapure deionized water was used throughout the experiments.

Apparatus

Laser lamp was purchased from XI' AN Herschel LD Laser Technology CO.LTD; Infrared temperature detector was purchased from Shenzhen jumaoyuan science & technology Co., Ltd. The UV-vis absorption spectra were recorded on Cary 5000 spectrophotometer (Agilent, the United Stated).

Synthesis of characterization of gold nanostars

Gold nanostars were prepared in a one-step process according to our early work [11]. In a typical synthesis, 0.36 g TB was dissolved in 5 mL of ultrapure water, and 100 μL of 48 mmol/L^{-1} $HAuCl_4$ solutions was added under magnetic stirring for 15 min, followed by adjusting the pH to 10-11 by dropwise addition of 1.0 mol/L^{-1} NaOH solution. Afterward, the reaction vessel was transferred to the water bath and maintained at 60° for 60 min. The solution color changed from light yellow to purple and finally blue-green. The products were purified for three times by centrifugation at 6000 rpm and the resultant precipitates were redissolved in ultrapure water for further use.

Construction of the photothermal sensor device

The photothermal sensor device (Figure 1) uses a common laser as the light source, a certain amount of gold nanostars was placed into the small holes of the glass plate, and the temperature of the gold nanostars solution was monitored with a temperature detector under different heights, angle of the laser lamp with 200 mW, irradiation times. And the temperature changes in the system were obtained, the photothermal sensor analysis method was established.

Results and Discussion

Effect of the irradiation angle of the laser lamp on photothermal conversion

To optimize the performance of the constructed photothermal conversion device, the gold nanostars were used as the photothermal conversion reagent, TEM and UV-Vis absorption spectra of gold nanostars were shown in figure 2, the gold nanostars have average size of 100 nm with more than five branches and the maximum absorbance peak of gold nanostars was observed at 878 nm. The effect of the irradiation angle of the laser light on photothermal conversion was studied. As shown in figure 3, the temperature of each of the gold nanostar samples continuously increases with time. The maximum temperature change (ΔT) is 3.2°C. The fastest increase in temperature is achieved when the irradiation area of the sample reaches the maximum, that is when the included angle between the laser light and the horizontal plane is 90°.

Effect of the height of the laser lamp on photothermal conversion

The effect of the height of the laser lamp was analyzed to study the performance of the constructed photothermal conversion device further. Figure 4 reveals that the height of the laser lamp slightly influences the temperature of the gold nanostars. This result may be ascribed to the laser light featuring considerable energy, which will not dissipate over a short distance.

Effect of irradiation time on photothermal conversion

The effect of irradiation time on the system temperature was investigated. If the irradiation time is too short, the gold nanostars in the system cannot absorb all of the available energy. As shown in figure 5, when the irradiation time is prolonged, the energy absorption of the gold nanostars in the system gradually reaches saturation. The highest temperature is detected within 10 min of irradiation.

Effect of the wavelength of the laser light on photothermal conversion

Different wavelengths (i.e., 532 nm, 880 nm, and 1200 nm) of the laser lamp can cause different impacts on photothermal conversion. The relevant mechanism may be related to the different overlapping degrees between the laser wavelength and the maximum absorption wavelength of the gold nanoparticles. Electron resonance is generated at high degrees of overlapping, further increasing photothermal conversion efficiency and temperature. The related results are shown in figure 6. The maximum temperature increase, (ΔT=3.4°C) is achieved when the maximum absorption peak of the gold nanostars is close to the laser light wavelength. When the maximum absorption peak of the gold nanostars significantly differs from the laser light wavelength, the temperature of the gold nanostars slightly and slowly increases by about 1.8°C.

Conclusions

On the basis of the photothermal effect, high-efficiency photothermal conversion device is constructed. The effects of irradiation angle, the wavelength, the height of the laser lamp and irradiation time are analyzed, Under optimized assay conditions, the real temperature of the assay had increased 3.4°C. The result revealed that the photothermal sensor device is preliminarily confirmed to be feasible, stable, and easy to operate. It presents promising application prospects in analytical chemistry, medical testing, and environmental analysis, among others.

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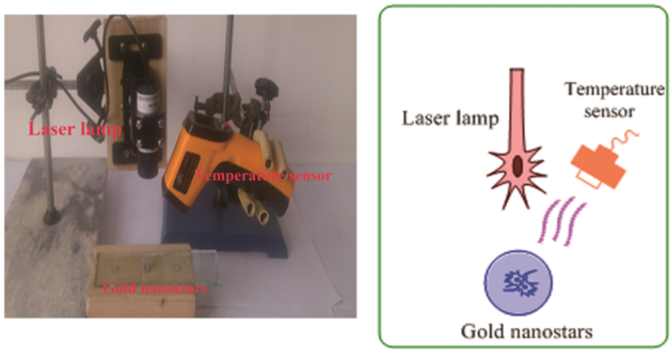

Figure 1: Detection mechanism of the proposed photothermal sensor device.

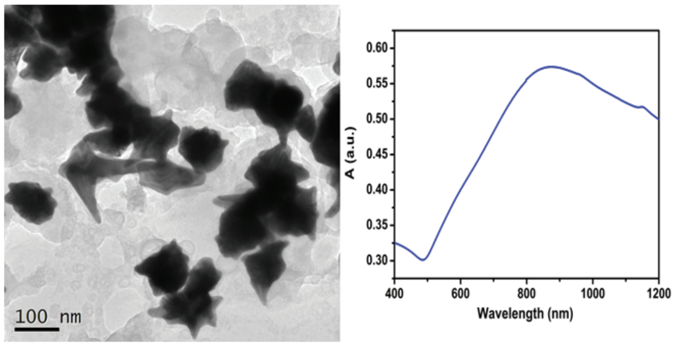

Figure 2: TEM and UV-vis absorption spectra of gold nanostars.

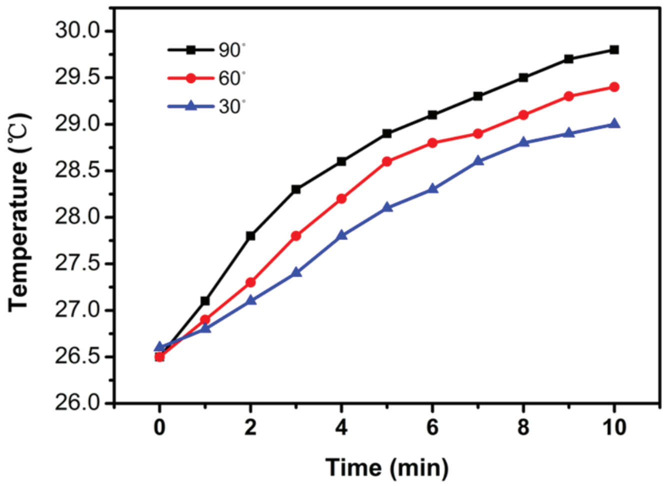

Figure 3: Effect of irradiation angle of the laser lamp on photothermal conversion (Absorption peak of gold nanostars: 878 nm; Wavelength of the laser lamp: 880 nm; Irradiation time: 10 min; the height of the laser lamp: 8 cm).

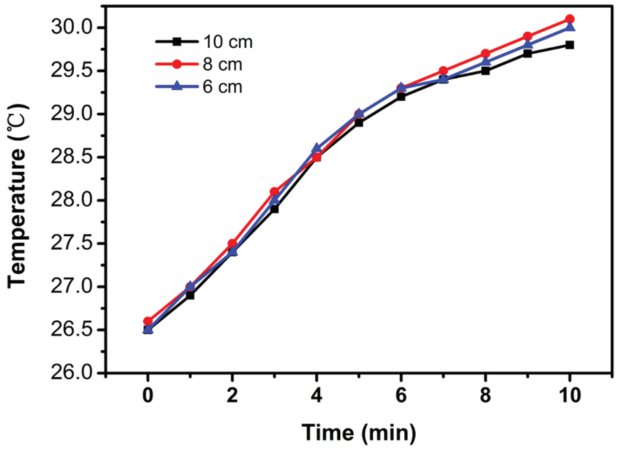

Figure 4: Effect of the height of the laser lamp on photothermal conversion (Absorption peak of gold nanostars: 878 nm; Wavelength of the laser lamp: 880 nm; Irradiation time: 10 min; irradiation angle of the laser lamp: 90°)

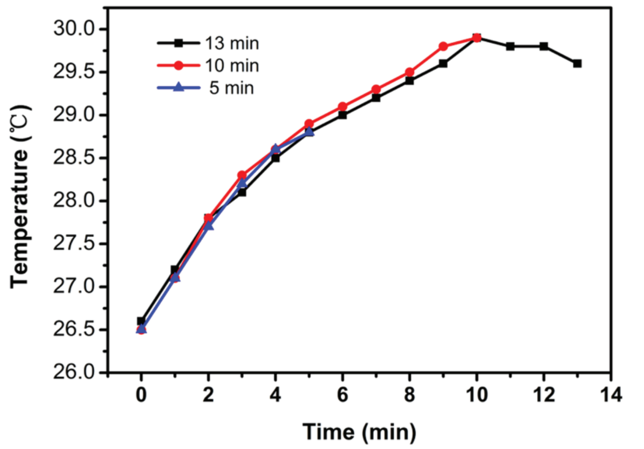

Figure 5: Effect of irradiation time of the laser lamp on photothermal conversion (Absorption peak of gold nanostars: 878 nm; Wavelength of the laser lamp: 880nm; irradiation angle of the laser lamp: 90°; the height of the laser lamp: 8cm)

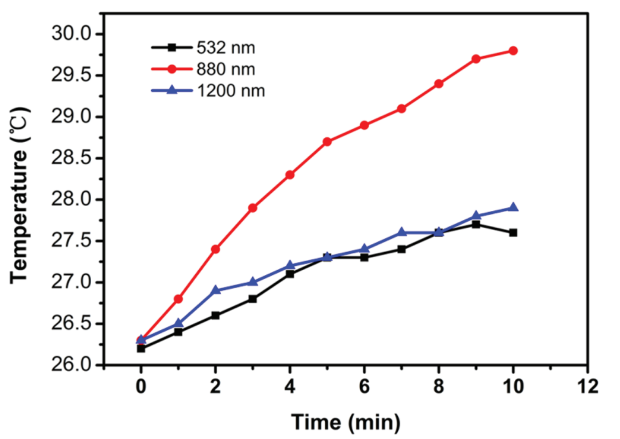

Figure 6: Effect of the wavelength of the laser light on photothermal conversion (Absorption peak of gold nanostars: 878 nm; Irradiation time: 10min; irradiation angle of the laser lamp: 90°; the height of the laser lamp: 8 cm)

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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