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Synthesis of Gold Nanorods for Multifaceted Applications †

Marina Sidorova * and Anton Popov *

Nanotechnas—Center of Nanotechnology and Materials Science, Institute of Chemistry, Faculty of Chemistry and Geosciences, Vilnius University, Naugarduko St. 24, LT-03225 Vilnius, Lithuania

* Correspondence: marinasidorova@chgf.stud.vu.lt (M.S.); anton.popov@chgf.vu.lt (A.P.)

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Abstract: Different length gold nanorods (AuNRs) were synthesized using different methods. The obtained AuNRs were characterized using scanning electron microscopy (SEM), dynamic light scattering (DLS) technique, and UV-Vis spectroscopy. These techniques allowed for a detailed study of the structural and optical properties of the AuNRs and provided valuable insights into the synthesis. The characterization results were crucial to guide the synthesis and to further understand the potential applications of AuNRs.

Keywords: nanoparticles; nanostructures; synthesis; gold nanorods

1. Introduction

The unique size- and shape-dependent optical and thermal properties of gold nanoparticles (AuNPs), as well as versatility of their functionalization and targeting, make them valuable tools in a variety of scientific and technological fields for a wide range of applications, including diagnostics, drug delivery, imaging, sensors development, and synthesis of organic compounds [1–3].

Among AuNPs, gold nanorods (AuNRs) are in high demand due to the tunability and sensitivity of their longitudinal surface plasmon resonance [4,5]. The anisotropic AuNRs structure displays two surface plasmon bands, corresponding to surface electron oscillation on transverse and longitudinal sides [6]. Typically, a two-step synthesis process using surfactants and seed particles, where gold seeds are prepared and then added to the growth solution, is used. Researchers continue to explore new applications for these nanomaterials, making them an active area of research and development [7].

The main aim of this study was to synthesize AuNRs of different lengths using the seed-mediated method. The obtained AuNRs were characterized using different techniques. The width and length of AuNRs were defined using SEM, the hydrodynamic size was defined with the DLS technique, and absorbance spectra were recorded. The evaluation of morphology and properties of AuNRs provided a deeper understanding of the synthesis and possible applications of nanoparticles.

2. Results and Discussion

2.1. SEM Analysis

AuNRs were synthesized via the seed-mediated method. To perform the imaging procedure, both samples of shorter and longer nanorods were diluted 10 times. The SEM images are presented in Figure 1.

Figure 1 shows the appearance of the AuNRs. The dimensions of the shorter nanorods were 35.7 ± 3.8 nm in length and 12.2 ± 1.0 nm in width. The longer nanorods had a length of 94.4 ± 12.1 nm and a width of 15.4 ± 2.4 nm. These observations indicate that the length of AuNRs is different by a factor of three, while the width of both types of AuNRs is relatively the same.

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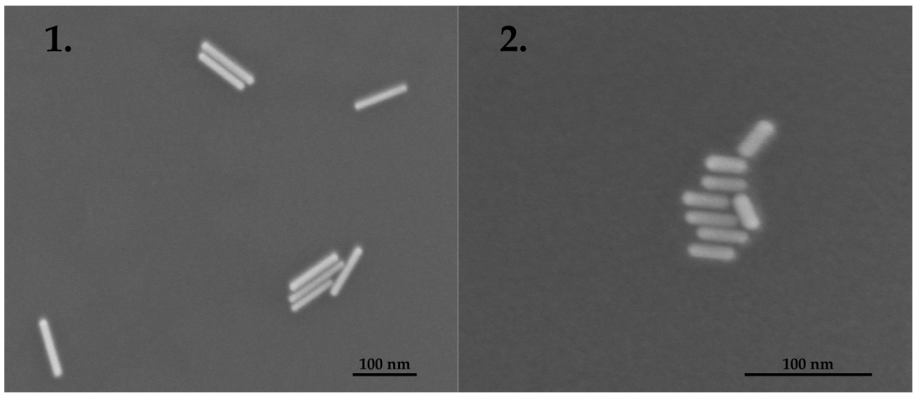

Figure 1. SEM images of (**1**) longer and (**2**) shorter AuNRs.

2.2. UV-Vis Analysis

Before recording the absorption spectra of AuNRs, samples were diluted 10 times. Figure 2 shows the UV-Vis absorption spectra of short and long AuNRs.

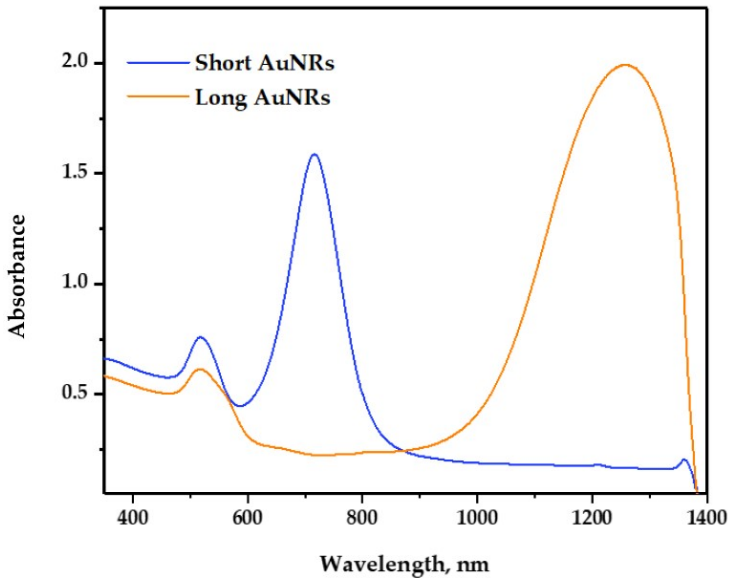

Figure 2. Absorbance spectra of short and long AuNRs.

For both types of AuNRs, two peaks are visible. The absorption maximums occur at wavelengths of 524 and 718 nm for short and 529 and 1270 nm for long AuNRs. Gold nanorods have two surface plasmon resonance modes: transverse and longitudinal. The transverse surface plasmon resonance, due to an electronic oscillation across the width of the rod, is basically of the same type as the plasmon resonance of simple gold nanospheres. It peaks at approximately 520 nm and is comparatively weak. However, the longitudinal mode yields a much larger extinction coefficient and is due to the oscillation of electrons in the longitudinal direction of the rod. It occurs at longer wavelengths than the transverse resonance [8].

2.3. DLS Analysis

DLS analysis was carried out to define the hydrodynamic size of AuNRs. DLS results are presented in Figure 3.

According to the results of the DLS analysis, the hydrodynamic sizes of AuNRs were 1.3 and 37.8 nm, 4.8 and 32.7 nm for short and long AuNRs, respectively. The measured values do not reflect the true hydrodynamic size of AuNRs. These peaks are believed to be

due to rotational diffusion in the AuNRs samples and are independent of either the length or the width. These peaks indicate that the AuNRs exhibit a rotational diffusion coefficient characteristic of the corresponding spherical nanoparticles [9].

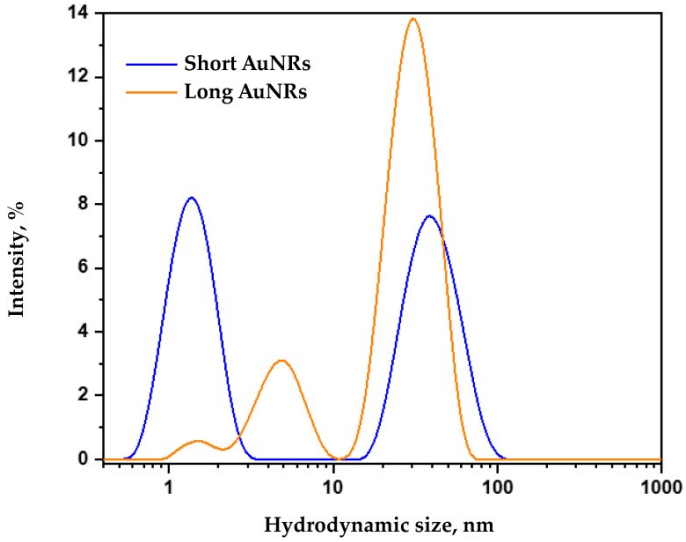

Figure 3. Short and long AuNRs size distribution by dynamic light scaterring (DLS).

3. Materials and Methods

3.1. Seed Solution Preparation of Shorter Gold Nanorods

The seed solution of shorter gold nanorods was prepared using the seed-mediated synthesis method. Briefly, 1 mL 0.2 M CTAB solution was mixed with 1 mL 5 mM $HAuCl_4$ and placed in a thermostat at 35 °C for 5 min. Cold 800 µL 0.01 M $NaBH_4$ solution was poured into a warm mixture, and the final solution was left at 35 °C for 1 h. The growth solution was produced by combining 5 mL of 0.2 M CTAB and 5 mL of 1 mM $HAuCl_4$ solutions. Then, 160 µL 5 mM $AgNO_3$ solution was added to the warm mixture. After slowly pouring 55 µL 0.1 M ascorbic acid into the mixing solution, the liquid became transparent. The final solution was left in a thermostat at 35 °C for 5 min. Finally, 12 µL of the seed solution was slowly added to the growth solution and incubated at 35 °C for 24 h. After incubation, the gold nanorods solution was centrifuged at 7000 rpm for 20 min. Then, it was washed with 10 mL 0.1 M CTAB solution twice. Afterwards, 5 mL 0.1 M CTAB was added to the final product.

3.2. Synthesis of Longer Gold Nanorods

The longer gold nanorods were synthetized by mixing 2.4 mL 0.01 M $HAuCl_4$, 960 µL 0.02 M $AgNO_3$, and 270 µL 1 M HCl together. Then, 720 µL 0.33 M hydroquinone was slowly dropped into the solution and the mixture was left in a thermostat at 35 °C for 5 min. After incubation, 3 mL 0.5 mM $NaBH_4$ solution was added. The longer gold nanorods solution was centrifuged at 6000 rpm for 20 min and washed 3 times with a 0.1 M CTAB.

3.3. Materials Characterization

Morphology of the gold nanorods was defined using data obtained via scanning electron microscopy (SU-70; Hitachi, Tokyo, Japan). The absorbance spectra of AuNRs were ascertained using a UV-Vis spectrometer (UV-1900i, Shimadzu, Kyoto, Japan). Measurements were performed in the wavelength range from 350 to 1400 nm. The hydrodynamic sizes were measured with the Zetasizer Nano ZS (Malvern, Herrenberg, Germany).

4. Conclusions

Shorter and longer nanorods were synthesized via seed-mediated methods. The lengths were 35.7 ± 3.8 nm and 94.4 ± 12.1 for shorter and longer nanorods, respectively.

The width of shorter nanorods was 12.2 ± 1.0 nm and 15.4 ± 2.4 nm of longer nanorods. The following results suggest that produced AuNRs are suitable for further application and investigation.

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Conflicts of Interest: The authors declare no conflict of interest.

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