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Rapid, thermostable antimicrobial peptide-mediated synthesis gold nanoparticles as highly efficient charge trapping medium for sol-gel-derived thin film

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ABSTRACT

In this study, peptide-mediated synthesis of gold nanoparticles (Ni-GNPs) was conducted via a rapid biological protocol using the thermostable antimicrobial peptide nisin. Gold ions in the reaction mixture were mixed with nisin peptides and autoclaved to form colloidal Ni-GNPs. Characterization analysis revealed that the UV–vis spectra of the GNPs showed a peak at 530 nm. X-ray diffraction and X-ray photoelectron spectroscopy of the Ni-GNPs confirmed their crystalline nature. Scanning electron images of the Ni-GNPs showed that they were spherical in shape and were uniform in size. Transmission electron microscopy analysis revealed the presence of peptides on the surface of spherical GNPs. The attachment of GNPs to the particles was demonstrated using circular dichroism. Ni-GNPs showed the presence of intact antimicrobial peptides on the surface of nanoparticles. The obtained Ni-GNPs were embedded as a charge storage medium in an insulator and ZnO semiconductor interface based on sol-gel-derived solution of processed thin film transistors. The fabricated device clearly exhibited hysteresis characteristics, suggesting that charge trapping occurred via the GNPs.

1. Introduction

Nanoparticles have been demonstrated as indispensable materials which have applications in the fields such as medicine [1], catalysis [2,3], water purification [4], biosensor [5] and environmental remediation [6]. Therefore, rapid, cost-effective, and green chemistry approaches for synthesizing nanoparticles have gained significant interest in the scientific fraternity. Among the physical and chemical methods available for synthesizing and stabilizing nanoparticles, most involve the use of inflammable, toxic chemicals that are eco-toxic [7]. In contrast, biological routes are not only inexpensive, mild, but also eco-friendly and often involve the use of renewable resources. Thus, biological materials such as plant materials, bacteria, proteins, peptides, and nucleic acids have been used to produce metallic and non-metallic nanoparticles [8]. Among metal nanoparticles, gold nanoparticles (GNPs) have been extensively studied and used in many products because of their versatile applicability in diagnostics, plasmonic sensors, catalysis, medicine, and electronics [9]. GNPs have strong affinity towards sulfur atoms, which are used in diagnosis, sensors, and therapy. Thus, the synthesis and applications of gold-binding peptides have been extensively studied [10].

In the present study, a novel and facile one-pot synthesis of GNPs was described using thermostable peptides at high temperature. Nisin peptides were used as the reducing and stabilizing agent of Au^{3+} to form Ni-GNPs. Nisin, a class-Ia bacteriocin or lantibiotic, is a peptide composed of 34 amino acids (molecular mass of 3.5 kDa). The peptides can be obtained from strains of *Lactococcus lactis* subsp. *lactis* isolated from milk and vegetable-based products. The formed Ni-GNPs were characterized using various methods. Circular dichroism (CD) revealed the intact peptide on the formed nanoparticle surface. This is the first report of the rapid synthesis of Ni-GNPs using thermostable nisin peptides as reducing materials at high temperature without the loss of antimicrobial activity. Efforts have been made to fabricate non-volatile memory devices such as thin film transistors (TFTs) based on Ni-GNPs. Thus, the formed Ni-GNPs may be valuable not only in the health sector and food industry, but also in the field of biosensors.

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2. Material and methods

2.1. Microorganism and chemicals

Details of microorganisms and chemicals are provided in the supplementary file.

2.2. Nisin peptide mediated synthesis of Ni-GNPs

To synthesize Ni-GNPs in aqueous solution, 1 mg/mL of nisin peptide (2.5% (w/w), approximately 1,000,000 IU/g) was added to an aqueous solution of 0.5 mM $HAuCl_4 \cdot 4H_2O$ in phosphate buffer (pH 6.8) and incubated for 30 min at room temperature. Finally, the mixture of solutions was transferred into a 50 mL Teflon-lined autoclave, and then sealed and maintained at 121 °C for 30 min. Ni-GNP synthesis in the mixture was monitored by UV–Vis spectroscopy.

2.3. Characterization of Ni-GNPs

Details of the characterization of Ni-GNPs are provided in the Supplementary File.

2.4. Antimicrobial activity

Details of antimicrobial activity testing are provided in the Supplementary File.

2.5. Device fabrication and measurement

The precursor was obtained by dissolving zinc acetylacetonate hydrate (Sigma Aldrich, St. Louis, MO, USA) in 2-methoxyethanol to a final concentration of 0.1 M. The prepared dispersion of Ni-GNPs was spin-coated on the SiO_2 dielectric followed by thermal annealing at 300 °C for 30 min in an electric furnace to remove organic compounds and reorganized Ni-GNPs on the SiO_2 surface. The prepared ZnO precursor was spin-coated at 4000 rpm for 40 s. The films were dried on a hot plate at 200 °C for 10 min to remove possible solvents. The films were annealed for 1 h in a tube furnace at 400 °C for precursor decomposition and oxidation. Finally, Al electrodes were thermally grown onto the active layer with a shadow mask, where the channel width and length were maintained at 1000 and 100 μm, respectively. The resulting source and drain electrode thickness was approximately 100 nm. Current–voltage (I–V) measurements were performed using a semiconductor analyzer (Keithley 4200) with a probe station.

3. Results and discussion

3.1. Synthesis and characterization of Ni-GNPs

In the present study, a rapid hydrothermal method was employed to synthesize Ni-GNPs for possible applications in the biosensor field where Ni-GNPs are employed to improve ZnO-based-TFT performance. Yue Li et al. and Gajanan Ghodake et al. reported synthesis methods for AuNPs using peptides in $NaBH_4$ and NaOH, respectively, which required more than 1 h to complete [11,12]. Here, mild conditions were employed to reduce $HAuCl_4$. After heating $HAuCl_4$ in the presence of nisin peptides, a change in color from colorless to red was observed (Fig. 1a). UV–vis spectral analysis of the red-colored solution showed a single and characteristic

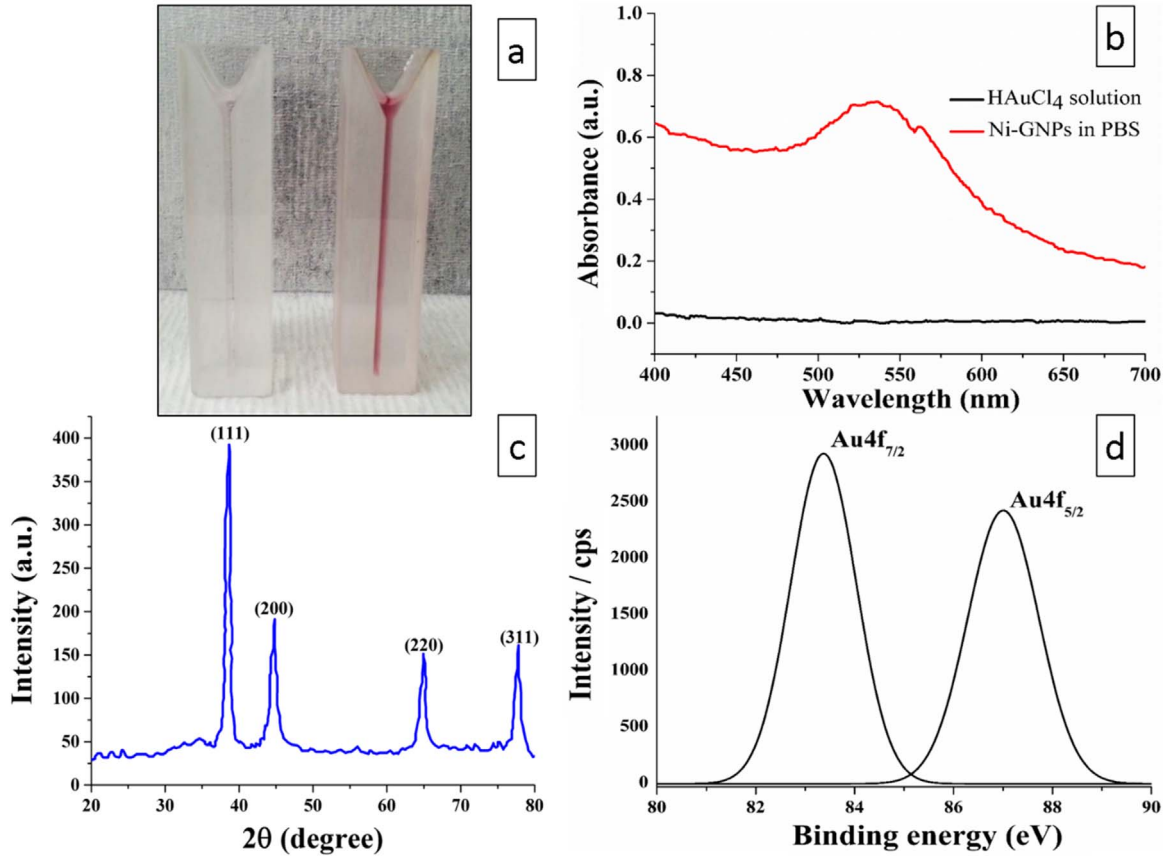

Fig. 1. (a) Change in color from white to red after 1 h of reaction, (b) the UV–vis spectra of aqueous solution of $HAuCl_4$ and as-prepared Ni-GNPs, (c) XRD pattern of the Ni-GNPs, (d) XPS spectrum of Au 4f. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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