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Gas sensor of Au/AgNPs/PSi/c-Si using pulsed laser ablation using a YAG:Nd laser

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ABSTRACT

Pulsed laser ablation in liquid was employed to synthesize silver nanopartical (Ag). Silver nanoparticles are synthesized by pulsed laser ablation of high purity zinc target in double distilled water with 36.924 J/cm^2 laser fluences at RT. UV–visible absorption and transmission electron microscope are used for the characterization of silver nanopartical (NPs). The optical properties, size, and the morphology of the synthesized silver nanopartical were influenced strongly by laser fluence and wavelength. The use of water gave spherical silver nanopartical NPs with average size 16 nm. The absorbance spectrum of the silver nanoparticles solution displays a quasisymmetric absorption band centered at 417 nm, which indicates that the nanoparticles in the growth solution are quasispherical approximately 8 nm in size. The silver nanoparticles, was faint yellow in color. It is expected, that the obtained results will find applications in the synthesis of new materials with modified properties, in the fabrication of catalysts with optimized selectivity and efficiency, in medicine for preparation of nanoparticle-based probes with great potential for targeting, imaging and treating different diseases etc. Chemical interaction between the (100–400 ppm) vapor methanol gas and Au/Ag NPs/p-PSi/c-Si device surface caused to some of variations in the output signal recorded as resistance decrease of device at room temperature.

1. Introduction

Last years considerable efforts have been directed to preparation and investigation of nanostructured materials. Broadly defined, nanostructured materials are solids composed of structural elements (mostly crystallites) which characteristic size falls in the range of 1–100 nm [1]. Noble metal nanoparticles NPs such as Ag have been a source of great interest due to their novel electrical, optical, physical, chemical and magnetic properties [2,3]. They were very attractive for biophysical, biochemical, and biotechnological applications due to their unusual physical properties, especially due to their sharp plasmon absorption peak at the visible region. Another important advantage Ag nanoparticles prepared by PLAL process were stable for a period of months. Additionally, silver nanoparticles are chemically stable and typically exhibit surface enhanced Raman scattering SERS in the visible wavelength range, where they may cause a tremendous increase in various optical cross-sections. The resonance frequencies strongly depend on particle shape and size as well as on the optical properties of the material within the near-field of the particle [4]. Silver has been used for thousands of years as a disinfcetant, and nowbody can neglect its value as a catalyst [5]. When a laser pulse reaches a sample surface, some of the energy is reflected by the surface. It is noted that the reflectivity depends on the material and laser wavelength [6]. The energy absorbed by the sample is transferred from optical photons to electrons and then to the lattice, which then diffuses the energy into the material [7]. Extremely high energy pulses may cause photochemical reactions which remove atoms and molecules from the surface. The heated surface can reach temperatures close to the critical temperature and cause rapid vaporization process. The vaporization resulting in plasma that consists of ionized vaporized atoms and electrons. It is possible that the plasma cloud absorbs some of the incident laser energy and thereby only allows a fraction of the laser energy to reach the surface (plasma shielding). The plasma expands and is heated by photon absorption. Later the vapor cools and aerosol particles begin to form. The rest of the energy diffuses into the material via heat transfer. Depending on the applied laser energy, the surface may be melted into a liquid with a moving solid–liquid interface. Liquid may be removed from the molten pool as droplets that result in a higher ablation rate. The absorption of laser light by metal nanoparticles gives rise to a succession of energy transformation processes. These involve the successive excitation and relaxation of the metal electrons, its interaction with the lattice, i.e. electron–phonon relaxation and

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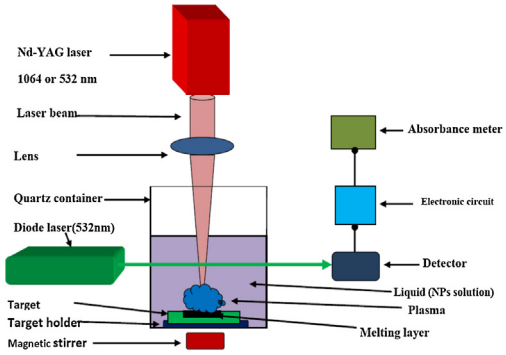

Fig. 1. The experimental setup for laser ablation of Ag metal.

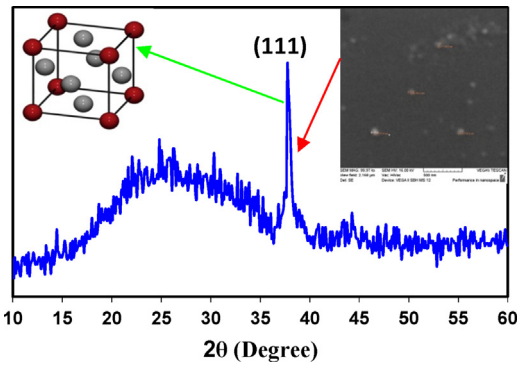

Fig. 2. XRD pattern of silver nanoparticles produced by 1064-nm laser ablation (E = 1000 mJ/pulse) of silver plate immersed in 1 ml of DDDW. The laser shots set of 35 pulses, respectively.

the phonon–phonon thermalization. Afterwards, several thermal processes like melting or evaporation can be activated. The heat diffusion from the metal particle to the support takes place on a time scale much shorter than the pulse width. This enables a simple thermodynamic treatment of the laser induced temperature rise [8,9].

2. Experimental

For electrochemical anodization, boron doped p-type silicon substrate of <1 0 0> orientation with resistivity (0.01–0.02) Ω cm was used. For anodization, constant DC current source is used with electrolyte solution containing 1:1:2 ratio of HF (48%):DI water:ethanol, respectively. The electrochemical cell used has two electrode configurations with a platinum electrode as cathode and silicon wafer as anode. As the starting material was of p-type silicon substrate hence, anodization was carried out at room temperature in the dark. p-type porous silicon samples were fabricated at anodization time 4 min and current density 40 mA/cm^2. In contrast, the cell is called ECE if the p-type c-Si samples were not illuminated. The samples were rinsed first with pentane, then with 98% methanol and finally with deionized water (18.5 MΩ cm). Next, the samples were dried at about 60 °C on a hot plate rather than drying in the N_2 nozzle in order to avoid cracking and peeling of the PSi layer.

Fig. 1 shows the experimental setup for laser ablation of solid metal target immersed in distilled water (DW), Nd-YAG laser 1064 nm wavelength was used. Q-switched Nd-YAG laser system type HUAFEI providing pulses of 1064 nm wavelength with maximum energy per pulse of 1000 mJ, pulse width of 10 ns, repetition rate of 10 Hz and effective beam diameter of 5 mm, was used for laser ablation. The laser is applied with a lens with 110 mm focal length used to achieve high laser fluence. Silver NPs were synthesized by pulsed laser ablation on a piece of silver metal plate (ounces: 99.999%) placed on the bottom of holder, vessel containing 1 ml of DW [10–12]. The spot size of the laser beam on the surface of the metal plate of 0.5 mm in radius (r). The laser fluence (F) was 36.924 J/cm^2 where:

$$F = \frac{\text{Pulse eneregy}}{A} \& A = 2\pi r^2 \quad (1)$$

The pulse energy was 580 mJ/cm^2. The pulse duration and the repetition rate of the laser pulse were 10 ns and 10 Hz, respectively. The number of laser shots applied for the metal target was 35 pulses. The silicon p-type substrate used after it has been cleaned by a chemical etching Process. The deposition Process for one drop of Ag nanoparticles was hold on porous silicon substrate by using thermal deposition process for the purpose drying samples then hold the samples measurements. Absorbance spectra (SPE spectra) of NPs solution were measured by UVVIS double beam spectrophotometers, CECIL C. 7200 (France) and SHIMADZU. All spectra were measured at room temperature in a quartz cell with 1 cm optical path. Additionally, spectrophotometer was used to estimate of metals nanoparticles [13]. Then the thermal evaporation system (Edwards) has been used to evaporate the high purity (99.9%) gold on silver NPs/p-PSi/c-Si device under low pressure (about 10^{-6} Torr).

3. Results and discussion

The structure and lattice parameters of Ag NWs are analyzed by a LabX XRD 6000 SHIMADZU XR Diffractometer with Cu Kα radiation (wavelength 1.54059 Å, voltage 30 kV, current 15 mA, scanning speed = 4°/min). The crystallinity of the produced material was characterized using X-ray diffraction (XRD). Four peaks could be recognized in Fig. 2, the film is polycrystalline according to the ASTM standards where (1 1 1) Ag could be recognized. The peak can be indexed to the face-centered cubic (fcc) phase of silver (JCPDS file No. 04-0783). No impurities can be identified from this pattern. The calculated lattice constant according to the (1 1 1) peak is 4.08 Å which is closely consistent with the standard value (4.086 Å).

The effect of laser irradiation on colloidal solution examined by measuring absorption spectra which is shown in Fig. 3. The spectra exhibited absorption bands with a maximum around 417 nm, which is typical for the excitation at the plasmon resonance in silver nanoparticles and weak absorption due to inter-band transitions in the region less than 300 nm. A comparison of absorbance of inter-band transitions at this region indicates that the formation efficiencies of colloids increase with an increase in the laser wavelength under our conditions. The bandwidth of the plasmon

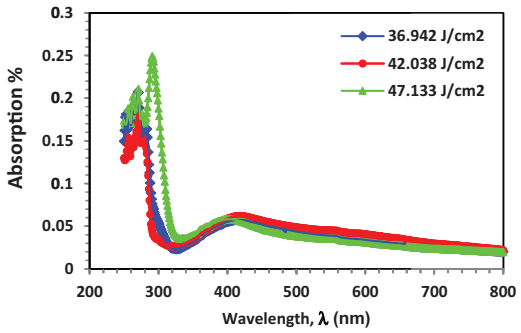

Fig. 3. Absorption as function of wavelength of silver nanoparticles produced by 1064-nm laser ablation (E = 1000 mJ/pulse) of silver plate immersed in 1 ml of DDDW.