Ideality factor of Al/nanosilver/PS/Si/Al sandwich structure

Hanan R. A. Ali

Physics Department, College of education for pure sciences, Tikrit University, Iraq

Email: dr.hanan.ridha@tu.edu.iq

Abstract: In this work, n-type (p-Si) porous Si nanostructures were fabricated by photochemical etching of n-type (p-Si) chips. The etching time of 20 min and the density of current of 20 mA / cm² were examined to discuss their impact on nanopore array formation. Crystal size was assessed by XRD. AFM confirmed the non-metric size of porous Si showing a rough Si surface increased with etching time and increased the depth and width (diameter) of the surface etching. Colloidal silver nanoparticles were also prepared by laser ablation in liquid (LAL) with Nd: YAG laser pulses and an Ag target submerged in ethanol using laser fluorescence (1.32 J / cm²). The effect of laser flux on the physical properties obtained from this study of Ag nanoparticles has been studied. The energy band gap prepared for the Ag nanoparticles was determined from the optical properties and found between (1.85 eV). Optical constants of deposit film were obtained using transmittance and absorbance spectra. Electrical properties of prepared Al/Ag/PS/p-Si/Al sandwich Solar cells are represented by I-V characteristics under dark conditions.

1. Introduction

Porous Si was discovered by Uhlir during electrophoresis polishing tests on Si wafer with an electrolyte including (Hydrofluoric acid) [1,2]. PS materials have high (PL) efficiency at ambient temperature in the visible area. PS is distributed in terms of pore diameter and can be few nanometers to a few microns relayed to configuration parameters. The inner surface of the PS to unit volume (V) is large in the range of 500 m² / cm³ [3]. Much effort was devoted to synthesis Psi in many applications like photodetector, solar cells, gas sensor [4-10]. In recent years many researches try to use silver NPs or nanosilver layers with porous silicon owing to its unique properties like low resistivity especially for antibacterial, high surface energy, which makes it readily aggregate and oxidized Raypah and Ahmed [11] try to passivate porous silicon utilizing nanosilver layer. Wan et al. [12] studied the reduction of silver NPs on mesoporous silicon for medical applications. Raypah et al. [13] synthesis Ag NPs for utilizing as passivated on porous silicon by studying the effects of etching time. Zhang et al. [14] fabricated a mesoporous organosilica decorated with silver NPs for antibacterial. This work is focused on preparing porous Si by electrochemical etching, to prepare colloidal Ag nanoparticles to deposited on glass and porous Si to study their structural and optical properties and the I-V of the device obtained.

2. Material and methods

Si samples from Al-Mansour Factory were scrubbed with alcohol to remove contaminations and oxide layer from their surface. The scrubbing solution consists of Hydrofluoric acid (10%) for 4 minutes to take of the oxide layer. Homogeneous PS layers of various thicknesses were created by photoelectrochemical (EC). Figure (1) displays the
PEC system, in this situation, the surface of the n-type Si wafer was illuminated by appropriate energetic photons. The n-type crystalline foil of Si with its resistance (2-20) cm, the thickness of 508 μm, and (100) is used. Electrochemical etching was carried out in (1: 1) Hydrofluoric acid (40%) - (99.99) ethanol mixed at room temperature T, using (Au) electrode as displayed in Fig (1). A density of current of 20 mA / cm² was applied for 20 minutes using to produce an etched area of the sample (0.785 cm²).

![Figure 1. The photographic image of the PEC system.](image)

Ag NPS was synthesis by laser ablation of a 1 cm² compacted Ag granule (supplied from Merck) in Ethanol [15](supplied by Poch) at T. The Ag target was located in the nethermost of the quartz bowl filled with 5 mL of the solution on the top of the target. The colloidal solutions are manufactured by irradiating Ag granules using a pulsed Nd: YAG laser operating at λ = 1064 nm (HUAFEI type), a 7 nm pulse width, and 10 Hz repetition. The laser fluorescence applied for ablation was constant at (1.32 J / cm²) and the ablation time 6 min. The laser beam was centered on the target surface using a lens with a focal length of 10 cm. The diameter of the laser beam was 2.3 mm. The deposited silver on porous silicon was done by casing a method using 5 drops from a pipette of 100 μL to get the desired devise.

XRD (Shimadzu - XRD6000, Shimadzu Company /Japan). The X-ray source was Cu-Kα radiation with 0.15406 nm wavelength to evaluate the structure of the obtained materials. AFM (AA3000 USA), was utilized to study surface topography. The) scanning electron microscope study has been carried out by (Jeol JSM-6335F Japan) to determine the morphology of the deposited films. Transmission electron microscopy (type CM10 pw6020, Philips-Germany), was utilized to determine the diameter of silver nanoparticles.

3. Results and discussion

The XRD spectra offer a clear contrast between the PS surfaces created at various etching times and the density of current (20 mA / cm²). From the figure below, sharp peaks and small peaks are seen in Figure (2), observing a nano-crystalline structure of the Si layer. The widening of the peak was the result of an increased pore thickness. XRD spectra display modified PS.
Sherrer's formula \( D = \frac{K\lambda}{\cos \theta} \) was used to obtain the crystal size (D) [16] and shown in Table 1. From the D values, one can predict that the cut layer exhibits a nano-crystalline structure. The exact strain \( \delta = \frac{\beta \cos (\Theta)}{4} \) and the dislocation intensity \( \Omega = \frac{1}{D^2} \) (12,13) were calculated, and their values are given in Table 2, showing that X-ray diffraction from the p-PS layer manufactured at the time of drilling (20 min) at a constant density of current (20 mA / cm²) which is stress-dependent decreases with increasing engraving time.

**Table 1** structural parameters of n-PS.

| Etching time (min) | \( 2\theta \) (deg) | FWHM (deg) | D (nm) | \( \sigma \times 10^{14} \) (lines.m⁻²) | \( \delta \times 10^{-4} \) (lines⁻².m⁻⁴) |
|-------------------|----------------------|------------|--------|--------------------------------------|--------------------------------------|
| 20                | 28.59                | 2.25       | 3.624  | 761.171                              | 95.597                               |
|                   | 26.78                | 0.98       | 8.289  | 145.541                              | 41.801                               |
|                   | 31.04                | 0.72       | 11.392 | 77.052                               | 30.415                               |

AFM images of PS patterned with 20 min motifs and a density of current of 20 mA / cm² give the formulation of normal PS structures on a Si chip. Mean pore diameter, mean roughness \( R_a \), and mean square root \( R_{rms} \) were estimated from AFM images. Fig 3 offer 2D AFM image of PS at a various etching time (20 min) and a density of current of 20 mA / cm². AFM analysis displays a homogeneous and smooth structure. It has columnar grains and a diameter size \( D_{size} \) of 34 nm. Table 2 illustrates the AFM parameters. the surface exhibits coarser grind and rough surface. These results are listed in Table 2 below.

**Table 2** AFM parameters of n-ps.

| PS At 20 mA/cm² | \( D_{size} \) (nm) | \( R_a \) (nm) | \( R_{rms} \) (nm) |
|----------------|----------------------|---------------|------------------|
| 20             | 34                   | 0.177         | 0.206            |
Figure 3. AFM image of the n-PS surface

The microstructure of PS samples prepared for different engraving times. They are examined with a light microscope. Figure No. (4) illustrates writing. Micrograph of composite porous Si with etching time (20) min. Samples prepared in 20 minutes reveal a high density of small samples. Directing the pores in the excavated area.

Figure 4. Optical micrograph of PS.

Figure 5 shows the XRD patterns of the synthesized Ag NPS film ablated in methanol and deposited on the glass, and XRD patterns of Ag have large peaks at angles of: 38.120, 44.260, 64.440 and 77.40 conformable to (111), (200) and (220) and (311) planes. These results were consistent with those obtained by the reviewer [17]. All diffraction peaks are indexed to an FCC structure provided with (ICDD card no.: 00-004-0783). D = 50 nm as obtained by the "Sherrer formula", the peak width of the dominant plane was evaluated and included in Table 3. A strong and narrow peak is observed along (111) orientation. The structural parameters of Ag NPs are listed in Table 3.
Figure 5. XRD pattern of Ag film

Table 3 Summary of (XRD) parameters of Ag NPs ablated in methanol and grown on a glass substrate.

| 2θ (deg) | FWHM (deg) | D (nm) | σ x10^{14} (lines.m^{-2}) | δ x10^{-4} (lines^{-2}.m^{-4}) |
|----------|------------|--------|--------------------------|-------------------------------|
| 38.11    | 0.175      | 47.78  | 4.3                      | 7.2                           |
| 44.30    | 0.21       | 40.65  | 6.0                      | 8.5                           |
| 64.46    | 0.17       | 55.03  | 3.3                      | 6.2                           |
| 77.40    | 0.19       | 53.42  | 3.55                     | 6.4                           |

3D images (AFM) were synthesized for Ag NPs. The mean diameter size of Ag membranes manufactured. AFM analysis is measured using the software declaration at approximately 45 nm relayed on the preparation situations. AFM image of Ag NPs is displayed in Fig. 4. The surface is very smooth. The average film surface roughness is 0.211 nm as shown in Table 4.

Table 4 AFM parameters of Ag NPs

| specimen  | Average particle size (nm) | roughness average (nm) | RMS (nm) |
|-----------|----------------------------|------------------------|----------|
| Ag Thin film | 45                        | 0.211                  | 0.482    |

TEM images of Ag nanoparticles are shown in Figure 6a. The microscopic images confirm the presence of the nanoparticles and demonstrate that the Ag nanoparticles prepared with a 1.32 J / cm² laser metal have various sizes, ranging from 10 to 50 nm. These nanoparticles have an almost spherical shape. Figure 6b shows SEM images of an Ag NPs SEM image assure that these NPs had many morphologies, and could
reveal that Ag morphology was irregular with an average size ranging from 11 to 40 nm.

Fig. 6 TEM and SEM images of Ag NPs (left to right)

Figure (7) offers the transmittance $T$ of Ag NPs ablated in methanol by laser and deposited on a glass substrate versus wavelength. It has three zones, the first zone was in the UV range, has an extreme value of transmittance about 78%, at 322 nm. The second zone was in the wavelengths range of (322-420) nm, indicating a decrease in transmittance to (52%) at a wavelength at (420) nm and third at wavelengths above (420-900) nm, show a slow increase in transmittance. The energy bandgap ($E_g$) of Ag is evaluated by draw $(\alpha h\nu)^2$ against $(h\nu)$. $(E_g)$ relayed on film structure, configuration, and allocation of atoms in crystal lattice [18-20]. $E_g$ was estimated to be (2.64 eV) for Ag thin film.

Figure 7. Transmittance versus wavelength of Ag thin film.

Figure (8) depicts I-V characteristics in forward and reverse bias dark current of Al/Ag/PS/ Si/Al Photodetector. The forward current is less than 0.4 V, which could be attributed to recombination current that happened at low voltages. This could be happening when every electron is excited to form the valence band to get the balance back. The second area at high voltage performs the diffusion region. In this area, the bias voltage-transfer electrons with sufficient energy to break through hurdles between
the two sides of the junction. The inset offers the variance of ln(I) with a bias voltage of Al/Ag/PS/ Si/Al heterojunctions. The ideality factor of heterojunction estimated is found (2.44) for Al/Ag/PS/ Si/Al heterojunction relying on etching density of the current, etching time, and laser fluence. When the structure has a series of resistance and interface states, the ideality factor turns into higher than unity, most Schottky diodes show variation from the ideal thermionic theory. Recombination currents are streaming inhomogeneous in structure and constantly at local sites.

4. Conclusions
The Ag / PSi Ag heterodynamic nanostructure was synthesized with PLAL. The colloidal suspension was deposited onto the PS, which was gained utilizing 20 mA / cm2 and 20 min electrochemical etching process. Ag precipitation on PS yielded a heterocyclic Al / Ag / PS / p - Si / Al suspended solar cell, demonstrating improved PS properties. An IV was used for the solar cell manufactured in the dark, and the analysis showed the good performance of the ideal factor.

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