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Rapid thermal oxidation for silicon nanocrystal based solar cell

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Abstract

In this work, silicon nanocrystal based heterostuctured solar cell with quantum efficiency (0.55) % has been constructed and characterized. A 100 nm thick Ag_2O nanocrystal thin film was grown on nanocrystallines Silicon (Ps) by rapid photo thermal oxidation of pulsed laser deposited Ag metal film, using a halogen lamp at 720K for 90s in static air. X-ray diffraction, Surface morphology and illuminated I-V characteristics were investigated and discussed.

Keywords: Silicon nanocrystal; Solar cell; Quantum efficiency.
PACS: 81.15.Fg; 85.30-z; 88.40.hm.

1. Introduction

The crystalline silicon is an important and dominant material over several years due to its well known properties and established infra structure for photovoltaic manufacturing [1]. Due to wide use of solar energy, there is the need of creation of new technologies and materials hence; porous silicon is expected to be promising one. Presently, an increasing interest has been shown in antireflection coating made from porous silicon by researcher [2-7]. For solar cell, porous silicon layer acts as graded layer with varying expanded band gap offers increased absorption in visible spectrum regions. [8-12].

The reduction in surface reflectance of multicrystalline silicon based solar cells still represents one of the most important ways of improving their performance. It is now well established that nanoporous silicon (PS) is a promising candidate to replace traditional texturization followed by the deposition of a SiO2:TiO2 double-layer as a passivation and antireflection coating (ARC) for these cells [13-16], In the other hand comparing with DSSC the (Dye sensitized solar cell) Ever since, O'Regan and Gra¨tzel introduced DSSCs in 1991, their efficiency has been improved continuously, and there is a trend of using DSSCs assembled with a sandwich structure, porous nanocrystalline metal oxides, counter electrodes, and electrolytes, in order to get high conversion efficiency.[17]

Mesoporous film-based dye-sensitized solar cells (DSSCs) have recently received considerable attention as practical solar energy conversion devices [18, 19]. DSSC is composed of a few micrometer-thick films consisting nanocrystallines oxide covered with monolayer of Rubipyridyl- based charge-transfer dye, a redox electrolyte and a platinum metal electrode. Such a high efficiency of DSSCs was achieved only when the nanoporous TiO_2 electrodes which facilitate high optical density of a dye monolayer are applied [20].

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As a result many manufacturing steps could be merge in silicon nanocrystal based solar cell. Beside that nanostructure semiconductors are easily accessible and in the last decade a great number of semiconductors materials have been manufactured as Nanoparticles. Semiconductors Nanocrystal are well suited for the development of novel opto-electronic devices, due to their flexibility and simple process ability combined with their optical properties.

Silver oxide (Ag_2O) is a p-type semiconductor with direct band gap around 1.4eV that is used in photography, optical memory, and as solar energy converters [21-23]. Many techniques have been used to grow Ag_2O films; furnace thermal and anodic oxidation of silver, thermal evaporation, reactive electron beam, reactive dc magnetron sputtering, and Pulsed laser deposition [24-26].

In this work, a combination between two materials above has been achieved through the fabrication of (Ag_2O_3 /Ps/Si) multi layer solar cell. Quantum efficiency filling factor and other parameter was measured and result was discussed.

2. Experimental procedure

A commercially available p-type silicon with (1-3)Ω.cm resistivity and square shaped has been used .(Cp_4) solution and ultrasonic cleaner to prepared the sample. Porous silicon as a substrate containing silicon nanocrystial was obtained using electro-chemical etching process describe in detailed on other work [27]. A Q-switched (1.06μm, 9nsec) Nd-Yag laser was employed to evaporate a (99.999) silver metal (Fluke CO.) on the surface of (Ps substrate) so, a nanostructure thin film of this material was obtained using pulsed laser deposition technique at (423K) as a substrate temperature and (10^{-3}) as a vacuum ambient.

A (P-type) Cuprous oxide (Ag_2O_3) nanostructure thin film was obtained using Rapid thermal oxidation (RTO) technique, with the aid of halogen lamp at oxidation temperature of (720 K) and (90 sec) as an oxidation time. The conductivity type of the film was investigated using seebeck effect measurements.

Thin Aluminum film on top and back of the device was used as ohmic contact. Surface morphology and x-ray diffraction was carried out using cu-kα x-ray source (1.5Å) and Atomic force microscope from (Angstrom advanced Inc.) respectively. Quantum efficiency, filling factor of the solar cell was tested by placing it under illumination of a 100 W tungsten filament lamp, placed 15 cm away. The J-V characteristics were measured using a DC power supply and Keithley electrometer. The Photoconductive property of semiconductors Can be used to determine the excess minority carriers lifetime. The experimental setup is schematically illustrated in the following figure (1).

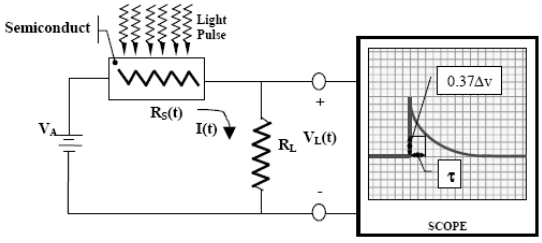

Fig. 1: Experimental setup for carrier life time measurement.

3. Result and discussion

The X-ray diffraction and surface morphology of the nanostructure Ag_2O_3/Ps could be recognize in Figure (2). The results insures the formation of silver oxide Ag_2O thin film which appear at two main peak at (111) and (101) as shown in figure (2)

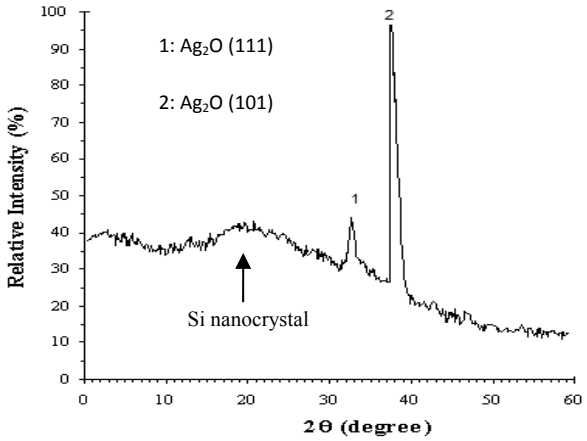

Fig. 2: Ag_2O_3/Ps a-x-ray diffraction pattern.

The surface morphology of as deposited Silver thin metal film on the porous silicon substrate before any heat treatment show in figure (3) the poured structure was destroyed ; this is related to the thin film growth mechanism.

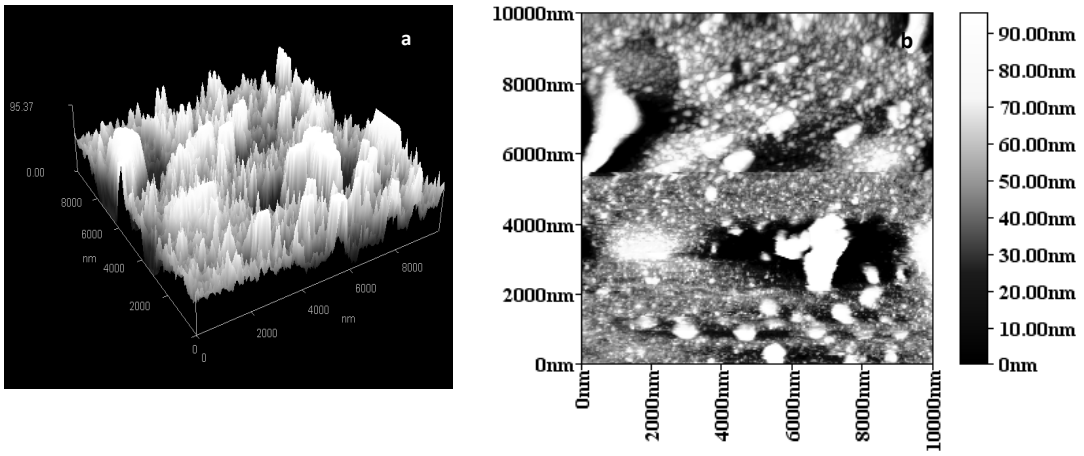

Fig. 3: Surface morphology of as deposited silver thin film (Ag) /Ps a- (3D), b- (2D).

By rapid thermal oxidation at 720K figure(4) a re-crystallization of the deposited atom above the nano-crystalline silicon substrate begin to take place and at the same time the surface morphology of the porous silicon itself changed due to the formation of nano silicon dioxide (SiO_2) and the reduction in porous silicon grain size and roughness.

The result shows a uniform net work like porous surface with a root mean squire value (23.5nm) that revealed low roughnesses of about (16.8nm) which insure homogeneity in pore size values. comparing with figure (3) where the RMS was (21.8nm) and the roughness about(16.1) the increase in its value on first case related to the re-distribution of oxide atoms on the porous surface and also associated with the increase in the average grain size (from 208.32 to 218.02nm). The obtained films display smooth, uniform grain size and void free, i.e., very limited NO. of droplets were observed.

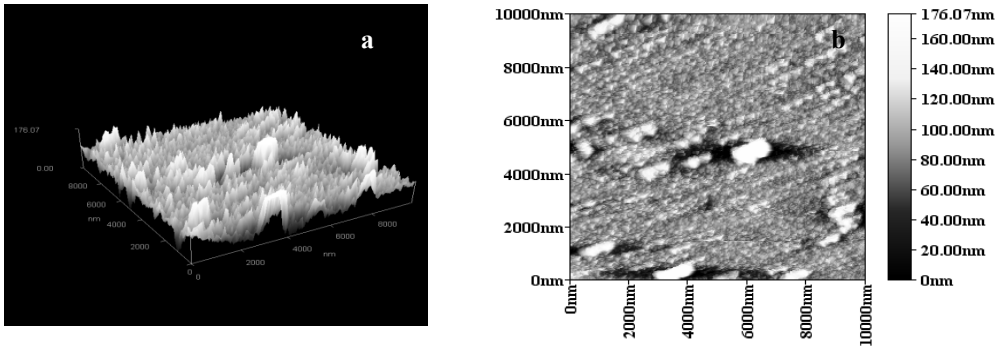

Fig: 4: Surface morphology of Ag_2O_3/Ps oxidized at 623K a- (3D), b- (2D).

This could be recognized in film morphology due to the substrate pre heating up to 423 K during pulsed laser deposition process. It is clear that the film consists of large islands distributed on the substrate. This can be interpreted by the increasing of surface mobility which is related to the increasing kinetic energy of the incident atoms. Physically, as the atom hits the substrate surface, it loses its velocity component normal to the substrate with an assumption that the incident energy is not too high: Therefore, the atom is adsorbed on the substrate surface.

Initially, the adsorbed atoms are not in thermal equilibrium with the substrate and especially at the substrate surface. In this process, these adsorbed atoms with each other's forming larger clusters. The next course in the film formation process is the coalescence, in which the small islands start coalescing with each other in an attempt to reduce the surface area. This tendency to form larger islands which is termed agglomeration is enhanced by increasing the surface mobility of the adsorbed atoms. Large particles appear related from the sublimation or particulate phenomena during pulsed laser deposition process.

The relationship between I_{sc} and V_{oc} as a function of load resistance could be recognize in Figure (5) a, b. The efficiency of the device has been measured in two cases the for Ag_2O/Ps/Si and Ps/Si for comparison. It value found to be (0.55 , 0.35) respectively, the improved in value of Quantum efficiency (QE) in the first case is related to the reflected of light rays from one side inside the key hall surface merely to strike another, resulting in an improved probability of absorption, and therefore reduced reflection comparing to the crystalline silicon surface [28].

Also due to the absorption phenomena in the surface oxide layer and at the first junction that formed between Ag_2O nanostructure thin film and Porous silicon, beside that, the interfacial porous silicon oxide ($Psio_2$) layer between porous silicon (Ps) itself and metal oxide Ag_2O play a significant role in enhanced the properties, science it has been found that the porous silicon could be oxidized at high temperatures forming an porous oxide layer. Heating of porous silicon to high temperature in a strongly oxidation ambient leads to vary rapid oxidation of the structure.

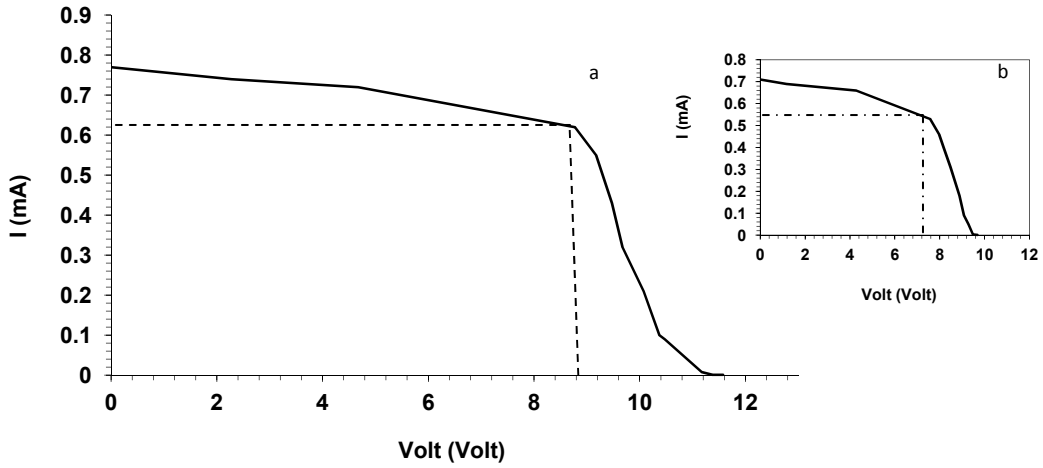

Fig. 5: Quantum efficiency for a- Ag_2O /Ps/Si, b- Ps/Si, heterojunction device.

Rapid Thermal Oxidation of porous silicon makes it suitable as dielectric layer for any electronic device. Most of its applications involve the formation of stable SiO_2 layers obtain by a simple technological process like thermal oxidation of porous Si at high temperature is conveniently carried out by the use of rapid thermal oxidation (RTO); involving transient heat of oxygen ambient so that careful control of the potential rapid surface reaction can be maintained.

Figure (6) give the open voltage decay pulse of the Ag_2O/Ps/Si and we could recognize the long carries life time of about (115 μsec) which give rise in the enhancement of other device photocurrent and quantum efficiency.

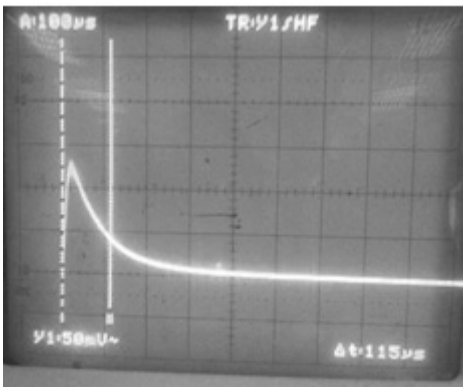

Fig. 6: Open voltage decay pulse.

4. Conclusion

According to the obtained photovoltaic properties a good enhancement in the device performance and solar QE could be obtained by rapid thermal oxidation of the surface metal layer which at the same time induced an interfacial silicon dioxide layer that greatly enhanced the photovoltaic properties. The encouraged optoelectronic properties of this heterojunction suggest that it candidate to be visible - enhanced photo detectors. The method of fabricating Ag_2O layer by rapid thermal oxidation is relatively simple, cheep, and it is hoped it can be improved either by doping or annealing.

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