Rapid thermal oxidation of copper nanostructure thin film for solar cell fabrication

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Abstract

In the present work is the deposition of copper oxide using the pulsed laser deposition technique using Reactive Pulsed Laser as a Deposition technique (RPLD), 1.064µm, 7 nsec Q-switch Nd-YAG laser with 400 mJ/cm^2 laser energy's has been used to ablated high purity cupper target and deposited on the porous silicon substrates recorded and study the effect of rapid thermal annealing on the structural characteristics, morphological, electrical characteristics and properties of the solar cell. Results of AFM likelihood of improved absorption, thereby reducing the reflection compared with crystalline silicon surface. The results showed the characteristics of the solar cell and a clear improvement in the efficiency of the solar cell in the case of copper deposition or not.

Key words

PLD, Cu_2O, Surface morphology, Solar cell properties.

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الأكسدة الحرارية السريعة للتراكيب النانوية لاغشية اوكسيد النحاس في تصنيع الخلايا الشمسية

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الخلاصة

في العمل الحالي تم ترسيب أكسيد النحاس باستخدام تقنية الترسيب بالليزر النبضي، حيث تم استخدام ليزر نديميوم ياك النبضي يعمل بضابط عامل نوعية بطول موجي 1.06 مايكرومتر و امد نبضة 7 نانو ثانية و بطاقة 400ملي جول/سم^2 لغرض اجراء عملية الاستئصال لسطح معدن النحاس عالي النقاوة والترسيب على سطح القواعد السليكون المسامي. حيث تم دراسة تأثير التلدين الحراري السريع على الخصائص التركيبية والسطحية والخصائص الكهربائية وخصائص الخلية الشمسية. اظهرت نتائج AFM احتمال تحسين الامتصاص، مما يقلل من الانعكاس مقارنة مع سطح السيليكون البلورية و أظهرت النتائج تحسن واضح بخصائص الخلايا الشمسية (الكفاءة) في حالة ترسيب اوكسيد النحاس من عدمه.

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 SiO_2:TiO_2 double-layer as a passivation and antireflection coating (ARC) for these cells [13-16]. Beside that nanostructure semiconductors are easily accessible and in the last decade a great number of semiconductors materials have been manufactured as nanoparticles. Semiconductors Nanocrystals are well suited for the development of novel opto-electronic devices, due to their flexibility and simple processability combined with their optical properties. One of these semiconductors materials is cuprous oxide, it is a p- type semiconductor material with a band gap of 2.17eV. This transition metal oxide has been investigated extensively due to the potential application in solar cells, gas sensor, electrode materials and others [17-21].

In this work, a combination between two materials above has been achieved through the fabrication of (Cu_2O /Ps/Si) multi-layer solar cell. Quantum efficiency filling factor and other parameter was measured and result was discussed.

Experimental

A commercially available p-type silicon with 1-3Ω.cm resistivity and square shaped has been used. (Cp4) solution and ultrasonic cleaner to prepared the sample. Porous silicon as a substrate containing silicon nanocrystial was obtained using electro-chemical etching process. The Si wafer was immersed by a mixture of electrolyte solution HF, 40% and ethanol, 99% concentrations. The formation of PS layer is using the AC process in the chemical solutions HF: ethanol (1:4) at current density 30mA/cm^2 of 20 min under external incandescent light. A Q-switched (1.06μm, 9nsec) Nd-Yag laser was employed to evaporate a 99.999 copper 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 (Cu_2O) nanostructure thin film was obtained using Rapid thermal oxidation (RTO) technique, with the aid of halogen lamp at oxidation temperature of 720K and 90 sec as an oxidation time. The conductivity type of the film was investigated using Seebeck effect measurements. A thin Aluminum film on top and back of the device was used as Ohmic contact. Quantum efficiency, filling factor of the solar cell were measured by placing it under illumination of a 100mW/cm^2 tungsten filament lamp, placed 15 cm away.

The fill factor (FF), is a measure of the junction quality and series resistance of a cell. It is defined as:

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \qquad (1)$$

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$\eta = \frac{P_{max}}{P_{inc}} \qquad (2)$$

where $P_{max} = V_{oc} I_{sc} FF$

where V_{oc} is the open-circuit voltage; where I_{sc} is the short-circuit current; and where FF is the fill factor where η is the efficiency[22].

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 Fig. 1.

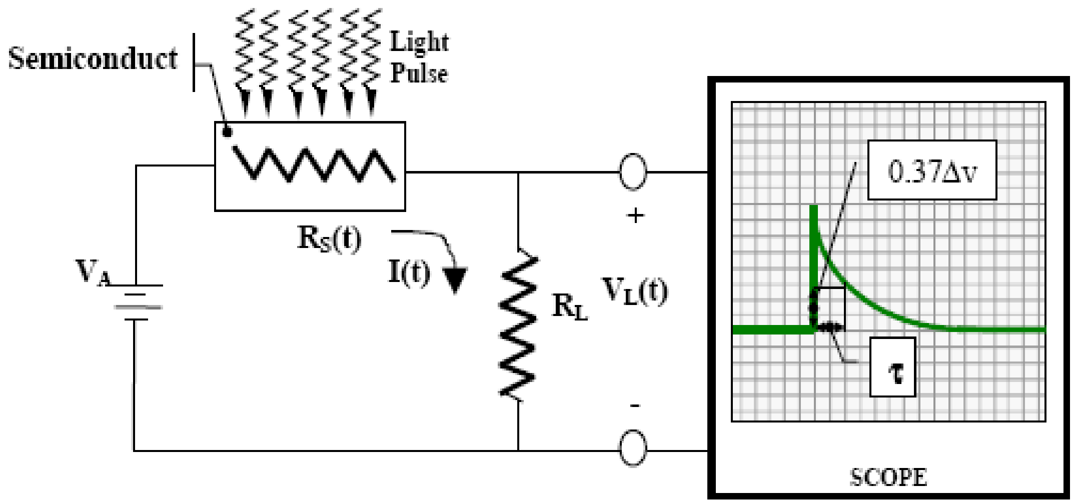

Fig. 1: Experimental setup for carrier life time measurement.

Results and discussion

Structural and morphological properties

The x-ray diffraction and surface morphology of the nanostructure Cu_2O /PSi could be recognize in Fig. 2 (a and b) respectively.

The x-ray diffraction pattern insures the formation of cuprous oxide thin film which appears at two main peaks at (111) and (002). The AFM Image revealed the formation of porous surface; a combination between porous silicon surface and Cu_2O nanostructure. In this case some light rays will be reflected 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.

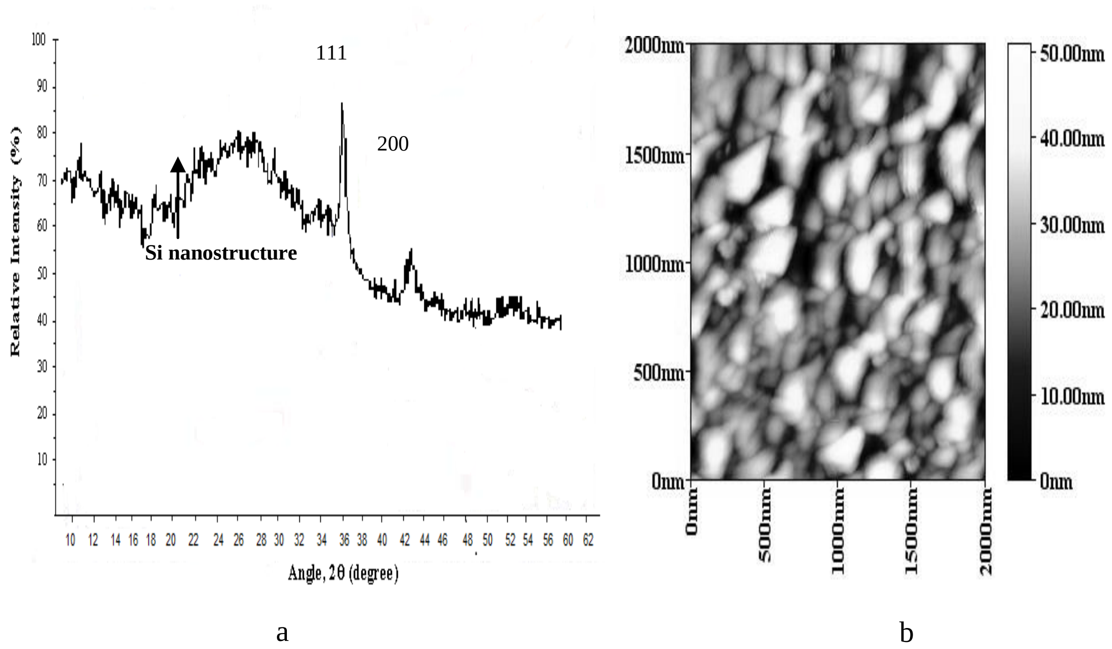

Fig.2: a-X-ray diffraction b-Surface morphology of Cu_2O/Ps.

The relationship between I_{sc} and V_{oc} as a function of load resistance could be recognize in Fig. 3 (a and b). The efficiency of the device has been measured in two cases the for Cu_2O/Ps/Si and Ps/Si for comparison. It value found to be 6.42 and 4.028 respectively, the improved in value of Quantum efficiency (QE) in the first case is due to the absorption phenomena in the surface oxide layer and at the first junction that formed between Cu_2O nanostructure thin film and Porous silicon, besides that, the interfacial porous silicon die oxide (P-SiO_2) layer between porous silicon (PS) itself and metal oxide Cu_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. 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.

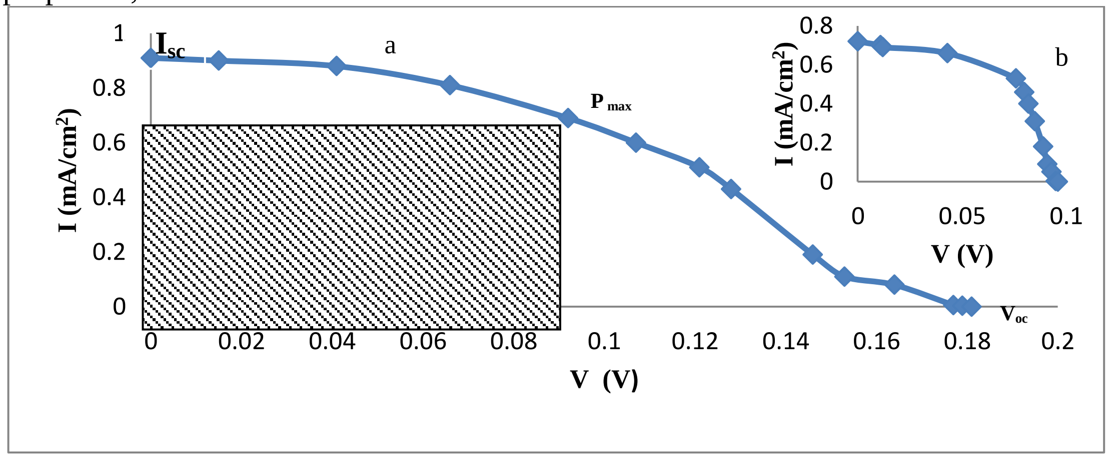

Fig. 3: Maximum output power for a-Cu_2O/Ps/Si, b- Ps/Si heterojunction solar cell.

The estimated value of the filling factor found to be 0.396 and 0.58 for two device respectively, the higher value in the second case related to higher short circuit current and open circuit voltage.

Optical properties

UV-VIS

Fig. 4 (a and b) shows the optical transmittance and absorption spectra for the deposit copper oxide thin films. The curve testify that the film surface is smooth with wavelength longer than 300 nm and that's give an indication why we used this device in solar cell applications. As seen from the figure, the copper oxide films are suitable for optical analysis from which the absorption coefficient and energy band gap may be determined.

Fig. 4-c explain linear relationship is obtained by plotting α^2 against hν, based on Eq. (3) below.

$$\alpha h\nu = A(h\nu - Eg)^n \qquad (3)$$

where α is absorption coefficient, *A* is constant (independent from ν) and *n* the exponent that depends upon the quantum selection rules for the particular material. The photon energy (hν) for y-axis can be calculated using Eq. (4).

$$E = h\nu = hc/\lambda \qquad (4)$$

where h is Plank's constant (6.626x10^{-34}), c is speed of light (3x10^{8}) and λ is the wavelength. A straight line shown in Fig.4-b is obtained when α^2 is plotted against photon energy (hν), which indicates that the absorption edge is due to a direct allowed transition (n = 1 for direct allowed transition). The intercept of the straight line on hν axis corresponds to the optical band gap (Eg). The Cu_2O films showed a higher energy gap of 2.62 eV, this value of energy band gap give same indication for solar cell application.

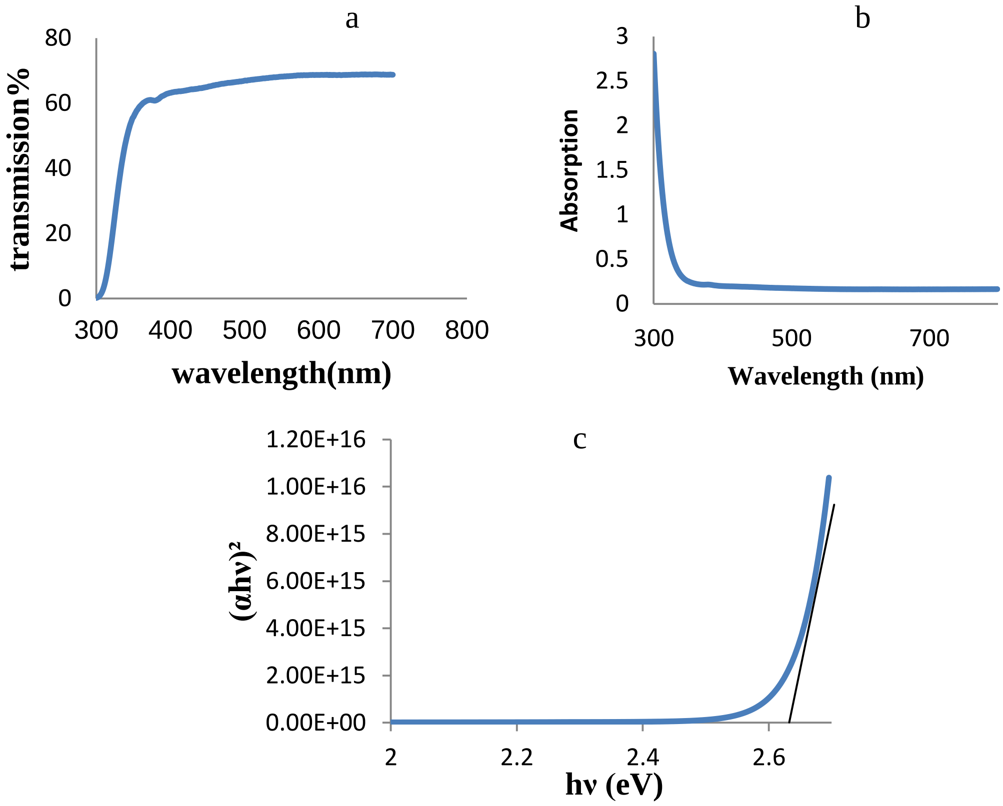

Fig 4: Plot of optical properties of deposit thin copper oxide a – Transmission, b- Absorption and c – Energy band gap.

Fig. 5 gives the open voltage decay pulse of the Cu_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.

The internal quantum efficiency may also be written in terms of the recombination lifetimes as τ is inversely proportional to r.

Define the radiative and nonradiative recombination lifetimes τ_r and τ_{nr}.

$$1/\tau = 1/\tau_r + 1/\tau_{nr} \quad (5)$$

The internal quantum efficiency is then given byr_r /r = (1/τ_r)/(1/τ).

$$\eta = \tau / \tau_r = \tau_{nr} / (\tau_r + \tau_{nr}) \quad (6)$$

Fig. 5: Open voltage decay pulse.

Conclusions

Cu_2O Nano structure thin film was successfully deposit using reactive pulsed laser deposition (PLD) method on porous silicon substrates. AFM showed resulting showed an improved probability of absorption, and therefore reduced reflection comparing to the crystalline silicon surface. Optical properties shoes good transmission for range higher than 300 nm and energy band gap 2.62 eV. The efficiency of the device showed different in two cases for Cu_2O/Ps/Si and Ps/Si as a 6.42 and 4.028 respectively and the value of the filling factor found to be 0.396 and 0.58 for two device respectively, the minority carrier life time for Cu_2O/Ps/Si give the open voltage decay pulse and long carries life time of about 115 µsec which give rise in the enhancement of other device photocurrent and quantum efficiency.

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