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Characterization of Porous Si Solar Cell

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ABSTRACT
Fabrication of the PS is generated by electrochemical etching process. The work is to differentiate the characterization of the PS solar cell compare to the bulk silicon. In order to determine the structural of the surface morphology of PS, the sample is characterized by SEM. The optical properties of PS are determined by photoluminescence (PL) and Raman scattering. The value of the efficiency and energy band gap measured to improve and identify the optical properties of the PS. The fabricated device was analyzed by I-V measurement.

Keywords: **PS solar cell, SEM**

1. Introduction

For past several decades, the researchers have had the advanced solar technologies and learnt how to create solar convertors. One renewable energy technology uses photovoltaic (PV) solar cells, which convert incoming solar radiation directly into electricity. The history of solar cell started in the late 19th century. In 1954 at Bell Labs, the three American researchers, Gerald Pearson, Calvin Fuller and Daryl Chapin have designed a silicon solar cell capable for energy conversion efficiency with direct sunlight but produced less than a watt of power (Faucet, 2002). Today's PV solar panels are widely used to supply the power of satellite and buildings. Typically solar cells use a solid state p-n junction created by a multi-step process that is used by the semiconductor industry to manufacture integrated circuits. There are many advantages of using solar cells such as silence, reliability, long lifetime, low maintenance and low pollution during operation. The solar cell absorbs energy from sunlight and retains that energy until too much light hits it, with Albert Einstein's explanation in 1905 of the photoelectric effect. Then, solar electricity at higher efficiencies would become feasible with the photovoltaic effect. Further work brought the solar cell efficiency up to 15 percent (Ulhir, 1956; Sze and Ng, 2003). In 1956, porous silicon (PS) was discovered by Uhlir when performing electrochemical etching of silicon to be used in solar cell.

There are two forms of solar conversion, which is thermal conversion and quantum conversion. In thermal converter, light is converted into heat at certain temperature. A solar cell is a device that converts solar energy into electricity by the photovoltaic (PV) effect. Solar cell act as energy sources for a wide variety of uses, which is including calculators and other small devices such as telecommunications, rooftop panels on individual houses, and for lighting. Solar cells are providing electricity to the power plants in the form of large arrays (Goetzberger et al. 1998). A solar cell uses light absorbing materials that generate what is called an electron hole (e-h) pair when the material is illuminated. The voltage produced by solar cell depends on the material used. Since a voltage is produced from the presence of photons, the term photovoltaic is used to describe the process in PV solar cell. The solar cell device comprises two major regions which are specially tailored to conduct negative and positive charges. Solar cell has used p-type and n-type semiconductor materials. Solar cells respond to different wavelengths of light (Greg, 2002). PS is classified according to the pore diameter. Porosity is defined as the fraction of vacancy within the PS layer. It can be determined easily by weight measurement. During formation of porous layer through anodization, the porosity of wafer can be increased through increasing current density, decreasing HF concentration and thickness of silicon layer. The porosity may range from 4% for macroporous layers to 95% for mesoporous layers (Canham, 1997).

PS produced by electrochemical etching using concentrated hydrofluoric acid. The final thickness of porous silicon depends on the total amount of charge exchanged during the electrochemical process. It can be selectively dissolved in dilute hydroxide solutions at room temperature because of its large specific surface (Asmiet et al., 2010a; Asmiet et al., 2010b). PS depends on the etching parameters. Physical properties of PS may be varied with etching parameter such as current density, hydrofluoric acid concentration, and substrate doping type (Asmiet et al., 2011).

2. Experimental setup

N-type Si wafer with (1 1 1) orientation, resistivity of 0.75 Ω cm size of 1×1 cm, and thickness of 28mm with doping concentration of $1.8\times10^{17}cm^{-3}$. The PS wafer was fabricated by electrochemical etching with radius 0.4 cm in order to match with the size of the opened-circular of the electrochemical cell. The wafer was placed in an electrolyte solution (HF: ethanol, 1:3) with current density of 60 m A/cm^2 and for a duration of about 30 min. Before etching process, Si substrate was cleaned to remove the oxide layer by the RCA method. Si wafer was immersed in HF acid to remove the native oxide.

The electrochemical cell was made of Teflon and has a circular aperture on its bottom, under which the silicon wafer is sealed. After etching processing all samples were rinsed with ethanol and dried in air. Surface morphology and structural properties of nanostructures were characterized by using scanning electron microscopy (SEM).Photoluminescence (PL) and Raman spectroscopy measurements were also performed at room temperature by using He-Cd laser (λ=325 nm) and Ar^+ laser(λ=514 nm), respectively.

The open-circuit voltage V_{oc}, short-circuit current I_{sc}, maximum voltage V_m and the maximum current I_m are the prominent parameters, which are illuminated I-V characteristics and to investigate the solar cell efficiency. The efficiency of the cell at the maximum power point can be calculated as following:

$$\eta = \frac{P_m}{P_{in}} = \frac{I_m V_m}{P_{in}}$$

The fill factor (FF) is

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}$$

Where, P_m = an output power, P_{in}= an incident power.

3. Result and Discussion

Fig.1 is the structure of the surface of PS that prepared by electrochemical etching. The results show that the regular porosity and pore size distribution in different locations. It means that the pore diameter and microstructure are depended on anodization conditions such as HF: ethanol concentration, etching time, temperature, and current density (Schnell and Schaefer, 2001). Much more homogeneous and uniform distributions of pores have been shown compared with other samples, which prepared with different electrolyte composition (Khalid et al, 2008) Fig.2 shows the cross section of PS prepared by electrochemical etching.

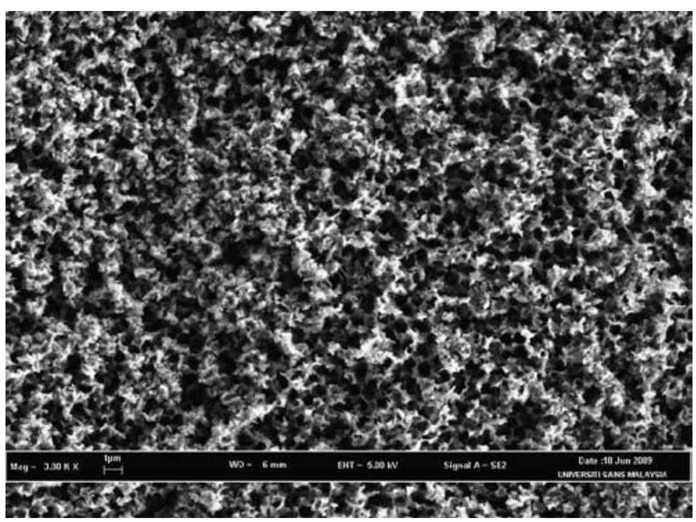

Fig.1. SEM images of porous silicon prepared by electrochemical etching.

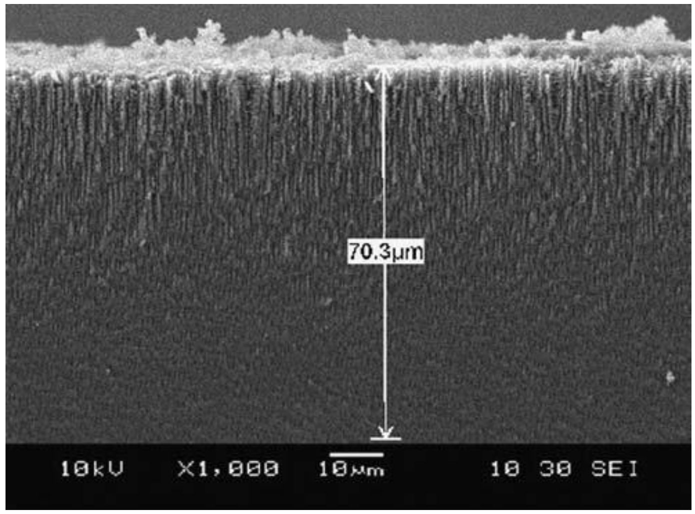

Fig.2. SEM cross section of porous silicon prepared by electrochemical etching

SEM images are showed the structure and morphological of the surface of porous silicon. The pore on the silicon surface has changed the characteristic of porous silicon.

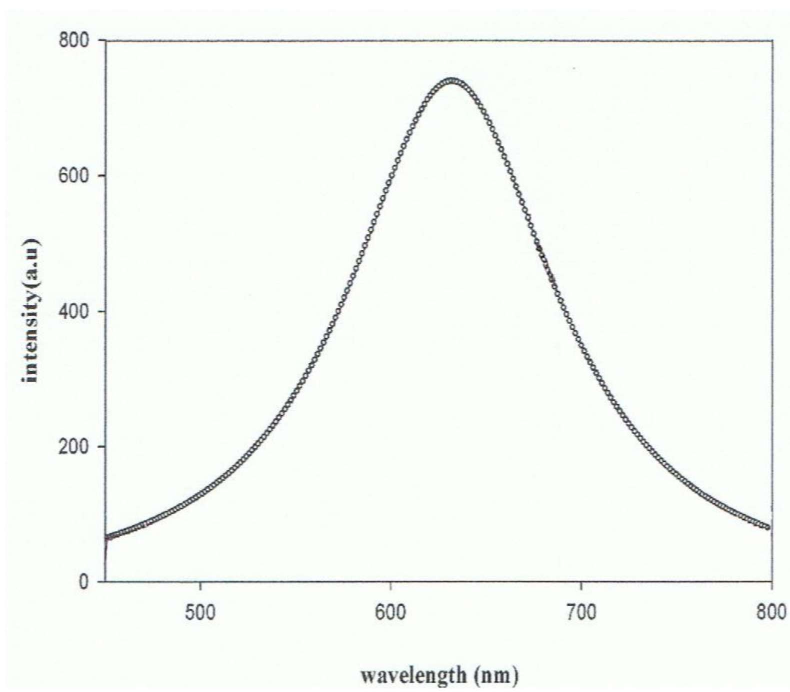

Fig.3. Photoluminescence spectra of porous silicon prepared by electrochemical etching

Fig.3 shows PL of porous silicon, the energy band gap of the porous silicon is 1.77eV and it is higher than the energy band gap of bulk silicon which is 1.1eV. So, it is proved that the porous silicon is better to be used for optoelectronics devices more than bulk silicon. Furthermore, the photoluminescence properties of porous silicon used to convert Infrared into visible region light, so that it improves the efficiency of solar cell. In addition, porous silicon has highly textured nature. Hence, it will enhance light trapping and reduces reflectance losses.

Raman spectroscopy is the measurement of the wavelength and intensity of inelastic scattered light from molecules. This is used to determine the optical properties of the porous silicon.

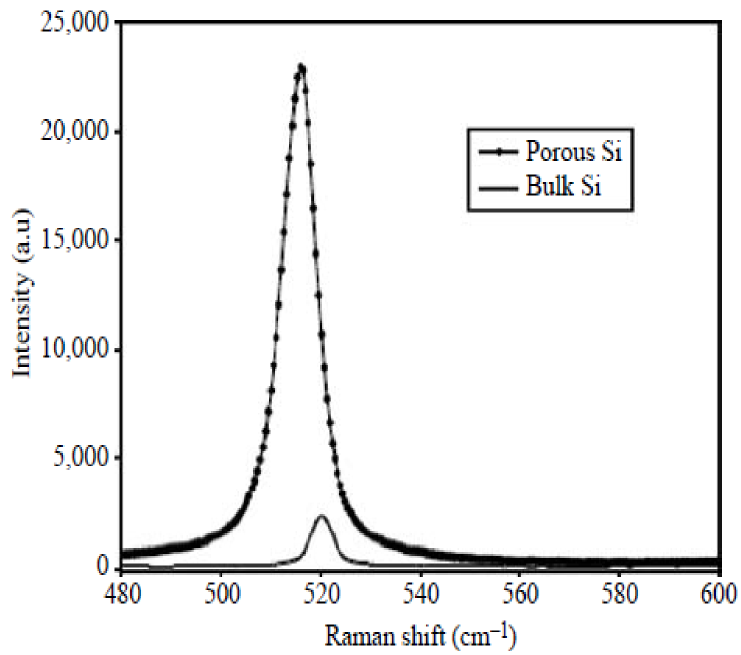

Fig.4. Raman spectra of porous silicon prepared by electrochemical etching

Fig.4 shows the intensity of Raman of PS and bulk silicon. The bulk silicon shows a sharp peak at 522cm^{-1} with full width at half maximum (FWHM) of 3.0cm^{-1}. PS showed a broadening and shifted to lower frequency located at 517cm^{-1} with FWHM of 8.2cm^{-1} as compared to the bulk silicon which is attributed to the quantum confinement effect on electronic wave function of silicon nanocrystals (Adam et al., 1996).The stronger Raman intensity of PS is due to change of its lattice vibration. The laser scattering of Raman on the surface of the porous silicon used to vibrate and produce the excitation energy. The Raman scattered light occurs at wavelengths that are shifted from the incident light due to the energies of molecular vibrations. For porous silicon, the broadening and shifted to lower frequency indicates the presence of porosity in nanosize. FWHM of the Raman peak is related to the lifetime of the phonon. This means that the lifetime of the phonon for porous silicon is much longer than bulk silicon because porous silicon has higher peak than bulk silicon.

Increasing in open circuit voltage without significant loss in short circuit current of solar cells is shown in Table 1.It can be concluded that the porous surface texturing properties could be enhanced and increased the conversion efficiency of silicon solar cells.

Table 1: I-V Measurement for Bulk Silicon and Porous Silicon.

Samples	V_m (V)	I_m (mA)	V_{oc} (V)	I_{sc} (mA)	P_{in} (μW)	FF	Efficiency(η)
Bulk silicon	0.292	6.03	0.37	6.04	527	0.79	3.34%
PS	0.26	5.09	0.34	5.1	300	0.77	4.41 %

Fig.5 shows that porous silicon has higher I-V characteristic than bulk silicon. The efficiency of the cell at the maximum power point can be calculated by using the efficiency formula. Calculation for the bulk silicon shows that the efficiency is lower 3.34 %. While for the PS, the efficiency is higher than the efficiency of bulk silicon which is 4.41%.

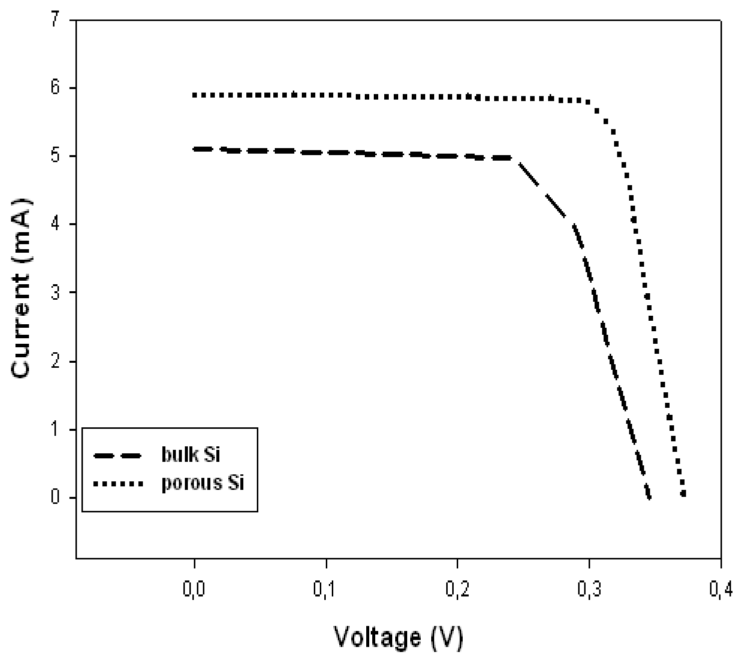

Fig.5. I-V characteristic of bulk and porous silicon

The anti-reflective coating for the porous silicon make the solar cell surface texturing reduce light reflection, as shown in Fig.6. Anti-reflective coating increased the light-trapping.PS layer implies the possibility to enhance the solar cell that forms light trapping centers which lead to high intensity of luminescent. Furthermore, for the bulk silicon, the solar cell that absorbs the light reflected back the some of the light. Hence, the quantum efficiency of bulk silicon is low (Wisam, et al., 2009).

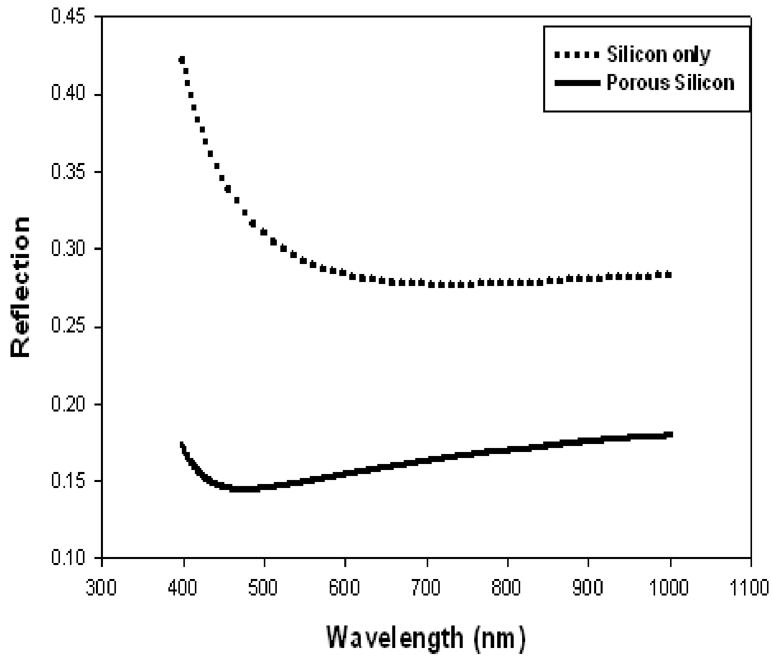

Fig.6. Reflectance spectra for silicon as-grown and porous silicon

4. Conclusion

The characteristics of porous silicon also can be studied by carry out SEM to observe and analyze surface of the porous silicon whereas the optical property using PL, and Raman spectroscopy. The silicon wafer should go through RCA cleaning to ensure no oxide layer left on the silicon wafer which can affect the reading obtained.

Porous silicon is differing from silicon because it contains pores. Porous silicon is attractive material for solar cell compare to the bulk silicon due to the characteristics of porous silicon has accomplished.

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