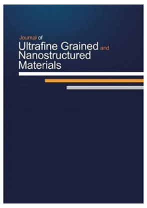


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# Effect of Silicon Nanowire on Crystalline Silicon Solar Cell Characteristics

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**ABSTRACT**

Nanowires (NWs) are recently used in several sensor or actuator devices to improve their ordered characteristics. Silicon nanowire (Si NW) is one of the most attractive one-dimensional nanostructures semiconductors because of its unique electrical and optical properties. In this paper, silicon nanowire (Si NW), is synthesized and characterized for application in photovoltaic device. Si NWs are prepared using wet chemical etching method which is commonly used as a simple and low cost method for producing nanowires of the same substrate material. The process conditions are adjusted to find the best quality of Si NWs. Morphology of Si NWs is studied using a field emission scanning electron microscopic technique. An energy dispersive X-Ray analyzer is also used to provide elemental identification and quantitative compositional information. Subsequently, Schottky type solar cell samples are fabricated on Si and Si NWs using ITO and Ag contacts. The junction properties are calculated using I-V curves in dark condition and the solar cell I-V characteristics are obtained under incident of the standardized light of AM1.5. The results for the two mentioned Schottky solar cell samples are compared and discussed. An improvement in short circuit current and efficiency of Schottky solar cell is found when Si nanowires are employed.

**Keywords:** *Fabrication; Nanowire; Silicon; Solar Cell.*

## 1. Introduction

Photovoltaic devices are still more expensive than traditional power source to be vastly used as the domestic energy suppliers. Increasing the efficiency of commercial solar cell is a solution to reduce the electrical energy cost which widely considered by the researchers. Recent research shows that Silicon nanowires (Si NWs) are excellent light absorber which could enhance the solar cell efficiency [1]. There are several methods that could be used for depositing or growing of Si NWs such as vapor-liquid-solid reaction, pulse laser deposition, oxygen-assisted-growth, vapor-solid-solid and electron less chemical etching. Among them, synthesis of Si NWs by chemical etching of Silicon is simple and economical, which can easily be employed in the standard cell fabrication process. Recently, Silicon nanowire-based solar cells are fabricated on metal foil, where the Silicon nanowires were synthesized using a standard technique of chemical vapor deposition. The solar cell characterization results have been shown a current density of 1.6 mA/cm$^2$ where the area of the cell was 1.8 cm$^2$. Also, broad external quantum efficiency has been reported with a maximum value of 12% at 690 nm [2]. It is believed that by using Si NWs, the optical reflectance of the Silicon nanowire solar cells is reduced by one to two orders of magnitude compared to planar cells, which is responsible in light absorption enhancement of proper PV devices. Si NWs are also applied with polymer material in solar cells. Erik C. Garnett fabricated the Silicon nanowire Schottky junction solar cells using n-type Silicon nanowire arrays and a spin-coated conductive polymer as passivation layer (PEDOT) [1]. An external quantum efficiency up to 88% has been reported demonstrating the positive effect of employed NWs with a surface passivation. Furthermore, fabrication of a radial type junction Silicon nanowire solar cell has been reported using wet chemical etching method [3]. The researchers calculated a conversion efficiency of ~7.1% and an external quantum efficiency of ~64.6% at 700 nm. Other types of crystalline solar cells also considered to study the effect of Si NWs employment. Dinesh Kumar fabricated $n^+$-p-$p^+$ structure solar cell on black Silicon substrates consisting of Silicon nanowire arrays prepared by Ag induced wet chemical etching process in aqueous HF–$AgNO_3$ solution [4]. Si NW arrays surface has low reflectivity (5%) for the entire spectral range (400–1100nm) of interest for solar cells.

In this paper, Si NWs are synthesized using a low cost simple method and characterized. Two Schottky type solar cell samples are fabricated on Si and Si NWs and the resulted devices are characterized by I-V measurement in dark and under incident of AM1.5 light. The results are compared and discussed.

## 2. Experimental details

### 2.1. Synthesis of Silicon Nanowire

Boron-doped mono-crystalline Silicon substrate with the resistivity of 3 to 10 Ω-cm and (100) orientation is used as the base material. The thickness of p-Si wafer was approximately 360 µm. The samples with the area of 1 $cm^2$ were cut and used for synthesis of Si NWs and solar cell fabrication.

The substrates were first ultrasonically cleaned in acetone and ethanol during 5 min, then rinsed in DI-water and dried with $N_2$. To form the vertically aligned Si NWs with ordered length, the cleaned Silicon substrates were dipped in an aqueous $AgNO_3/HF/H_2O$ solution with the ratio of 4:34:162, for 3 min, at room temperature. The concentration of $AgNO_3$ was set to 1 mol/Lit. By the employed method, etching of silicon and deposition of silver occur simultaneously, at the wafer surface. Through an exchange reaction, the galvanic deposition of thin silver films is initiated by the formation of silver nuclei. The metal ions are simultaneously reduced from the valence band of the semiconductor by electron transfer.

The process is an electrochemical redox reaction one, which is formulated as follows [5]:

$$Ag^+ + e^- \rightarrow Ag$$
$$Si + 6F^- \rightarrow SiF_6^{2-} + 4e^-$$

Subsequently, the sample was washed in concentrated nitric acid, for 2 min, to completely remove the Ag dendrite that may be remained on the surface and in between Si NWs. Finally, the sample was immersed in deionized water and dried with $N_2$.

### 2.2. Solar Cell Fabrication

To have the solar cell samples, a Schottky structure as shown in Fig. 1 is used. The broad back metal contact was made by Ag sputtering on rear side of the Si and Si NWs substrates, and then annealed at 120˚C, to form the backside Ohmic contact. Base on the literature, the employed annealing temperature is enough to convert the Ag contact on mono-crystalline Si substrate to an Ohmic one [6]. The front Schottky contact was made by sputtering of ITO, as the transparent conductive layer. As it is shown in Fig. 2, the work function of ITO is suitable to form Schottky contact on p-Si surface. The mentioned values in Fig. 2 are calculated based on characterization results that will be further presented in section 4. Finally, the Ag metal contacts were sputtered through a circle patterned mask to form the output accessible contact on ITO/Si and also on ITO/Si NWs samples.

### 2.3. Characterization methods

Morphology of NW Si sample was examined by scanning electron microscopic (SEM) (Model

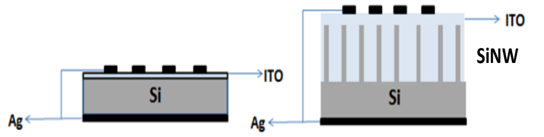


Fig. 1- Schematic diagram of Ag/ITO/Si Schottky solar cell, with and without Si NWs.

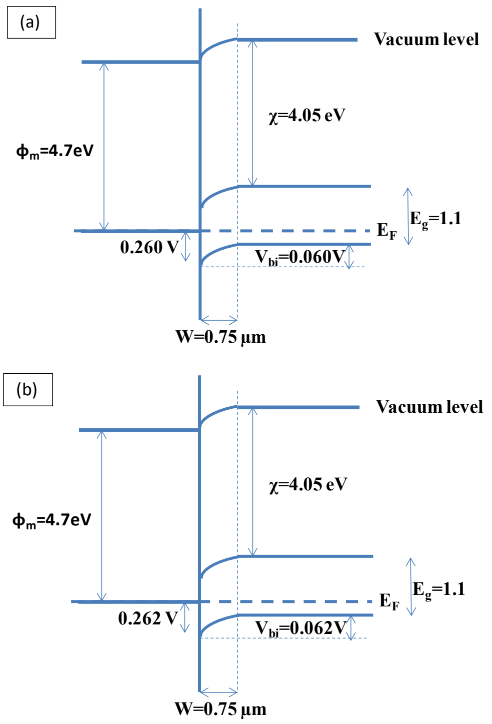


Fig. 2- Band energy diagrams for Schottky contact between ITO on (a) Si and (b) NW/Si substrates.

MIRA3 TESCAN). Also, energy-dispersive X-ray spectroscopy (EDX) was done to analyze chemical composition of the synthesis nanowires. The fabricated samples were characterized using current-voltage (I-V) technique in dark and light conditions. To measure the solar cell properties, the standard light of AM1.5 is used.

## 3. Theoretical Aspects

I-V curve of a solar cell is superposition of the curves in dark and light conditions. The incident light has the effect of shifting the I-V curve down into the fourth quadrant where power can be extracted from the diode. Illuminating a cell adds to the normal "dark" currents in the diode, so that, the diode law becomes [7, 8]:

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right)-1\right]-I_L \quad (1)$$

Where $I_0$ is the dark saturation current, V is the applied voltage across the terminals of the diode. q is the value of electron charge in Coulomb, k is Boltzmann's constant equal to $1.38\times10^{-23}$ j/K, and T is the temperature in Kelvin. $I_L$ is referred to the light generated current.

Efficiency (η) of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as follows [8, 9]:

$$P_{\max} = V_{OC} I_{SC} FF \quad (2)$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \quad (3)$$

Where FF is the fill factor of the I-V curve and is defined as the maximum power divided by the product of the produced open circuit voltage ($V_{OC}$) and the short circuit current ($I_{SC}$) [9]:

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}} \quad (4)$$

$V_{OC}$ and $I_{SC}$ can be obtained from experimental I-V measurement curve under light illumination.

## 4. Results and Discussion

Fig. 3(a) shows the cross-sectional SEM image of vertically aligned Si NW arrays with the length of 1800 nm. The top view image of Si NW arrays sample is also shown in Fig. 3(b) which indicates that the nanowires are uniformly and completely covered the Si surfaces. Si NWs of desired length can be made by controlling the etching time. The sample surface appeared black after removal of Ag layer and was completely free from any metal impurities after cleaning.

Fig. 4 shows the EDX analysis of the Si NWs. It is seen that all the Ag by products are removed from the nanowires surfaces and the wafer is completely cleaned.

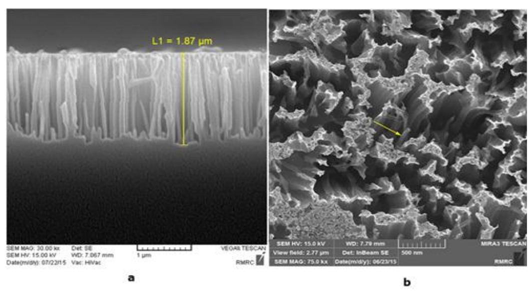


Fig. 3- (a) SEM image of Si NWs cross-section. (b) surface morphology of Si NWs

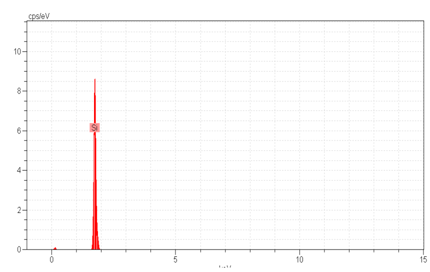


Fig. 4- Profile of EDX measurement for the synthesized nanowires

Table1- Comparison of Si and NW Si solar cell characteristics

| | $V_{OC}$(V)±0.1mV | $I_{SC}$ (mA/cm²)±10nA | FF | n | $I_o$ (mA/cm²)±10nA | η% |
|---|---|---|---|---|---|---|
| Si solar cell | 0.2 | 1 | 0.527 | 1.65 | 1 | 1.58 |
| NW Si solar cell | 0.2 | 1.5 | 0.524 | 1.7 | 2 | 1.85 |

The Schottky properties of the ITO/Si junction is obtained from I-V characteristics for Si and Si NWs samples, in dark condition, which is shown in Fig. 5. As it is seen, the barrier height of Si without nanowires is a slightly higher than Silicon with nanowires. The obtained values of 0.260 V and 0.262 V, for the two samples, indicates that the employing nanowires have nearly no effect on ITO/Si barrier height characteristic.

To calculate the solar cell output parameters, standardized light of AM1.5 is used and the I-V curves were again measured for the two samples. Fig. 6 shows I-V characteristics of Si and Si NWs solar cell, in forward bias. A shift of the I-V curve is due to the incident light which is characteristic of photovoltaic devices. It means that in fabricated junctions, the depletion layers forms on Si and Si NWs, near the junctions, where the photocarriers are generated. The measured short circuit current for Si NWs sample is about 2 mA/cm² which is more than the same for planar Si sample (1.5 mA/cm²). However, the open circuit is 0.2 for Si and Si NWs samples. It remains constant. The efficiency value of the solar cell samples were calculated using the mentioned theory in section 3. The solar cells output parameters and the calculated efficiency are summerized in table 1.

It is seen that ITO/ Si NWs solar cell has 17% higher efficiency than planar one which is corresponded to the better absorption of light when the Si NWs are employed.

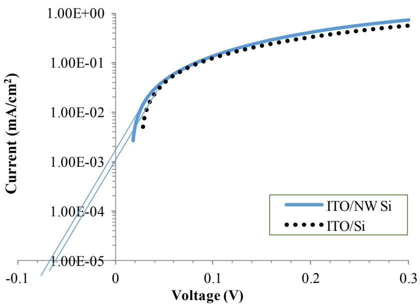


Fig. 5- I-V characteristics of Ag/ITO/Si Schottky diode, in dark condition, with and without Si NWs.

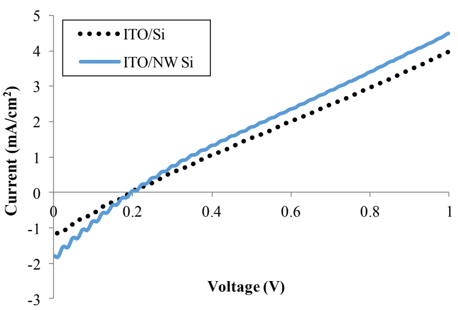


Fig. 6- I-V characteristics of Ag/ITO/Si Schottky diode, illuminated with AM1.5 standardized light, with and without Si NWs

## 5. Conclusion

To study the effect of nanowire on Solar cell characteristics, Si NWs are synthesized using a simple etching method on monocrystalline p-type Silicon wafer. The SEM images of synthesized nanowires showed that the nanowires are well directed in vertical position and have approximately 1800 nm length. The schottky contact using ITO, as the transparent conductive layer, were fabricated and characterized, too. As a depletion layer is formed on surface of the planar Silicon and also over the Si NWs, the photocarriers are generated, when a proper light incidents on the samples. I-V measurement curves show that the obtained short circuit current of Si NWs solar cell is enhanced by a factor of 1.33 and results 17% improvement in solar cell efficiency. It should be indicated that the increased light absorption of the nanowires is responsible for the efficiency improvement.

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