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Silicon nanowires solar cell

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ABSTRACT

We made an amorphous-silicon (a-Si) solar cell with a nanowire-array structure on stainless steel(SS) by plasma enhanced chemical vapor (PECVD) deposition. This nanowire structure has an n-type Si nanowire array in which a-Si intrinsic layer and p type layer are sequentially grown on the surface of the nanowire. The highest open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}) for AM 1.5 illumination were 620 mV and 13.4 mA/cm^2, respectively at a maximum power conversion efficiency of 3.57%.

INTRODUCTION

Recently there has been significant interest in the photovoltaic properties of silicon nanowires (SiNWS) [1-6] for the development of high efficiency and low-cost solar cells. Radical junction nanowires based photovoltaic structures, in particular, provide potential advantages of more efficient charge collection[7,8] and natural anti-reflective structure that allows light trapping and thus enhanced absorption.[9-11]. A radial p-n junction structure made of rods array exhibited improving photo-generated carrier collection for material with short minority carrier diffusion lengths[12] theoretically. SiNWs solar cells based on such a radial p-n junction structure have been reported. experimentally [2, 4, 13]. However, much effort is still needed to improve SiNWS cells with performances exceeding to that of the existing crystalline silicon photovoltaic technology.

In this work, we reported radial n-i-p structure SiNWs solar cells on stainless steel by PECVD.

EXPERIMENT

SiNWS solar cell fabrication begins with first cleaning the SS substrates using standard solvents, followed by sputter deposition of a 10-nm-thick Indium Tin Oxides (ITO) film. Following form of nanoscaled indium droplets by hydrogen plasma treatment[14], catalytic CVD employing the vapor-liquid-solid VLS growth mechanism[15] is used to grow n-type Si nanowires. The n-SiNWs array was subsequently coated with conformal a-Si:H i-layer (~300 nm) and p-layer (~20 nm) deposited in situ to create the radial n-i-p structure. After a-Si:H layers deposition, the array was sputter coated with a 300-nm-thick ITO layer acting as electrical contact. The detail deposition parameters of each layer are summarized in Table 1. The cell performance was characterized by photocurrent density-voltage measurement under xeon solar simulator (100mW/cm2, calibrated by a standard silicon solar cell) at room temperature.

Table1． Deposition parameters for SiNWS solar cell

	H treatment	***n-SiNWS***	***i layer***	P layer
Substrate temperature (^{0}C)	400	400	150	70
Pressure (Pa)	200	200	133	500
Power (mW/cm^2)	100	50	50	100
	H_2	SiH_4:H_2：PH_3	SiH_4:H_2	SiH_4:H_2：B_2H_6
Gas flow (sccm)	60	6：60：0.06	6：60	1：100：0.03

Figure 1(a)shows SEM image of n-SiNWS. The white dot is indium (EDS not shown here) acting as catalysts. The structure and composition of the SiNWS is shown in Figure 1（b）.

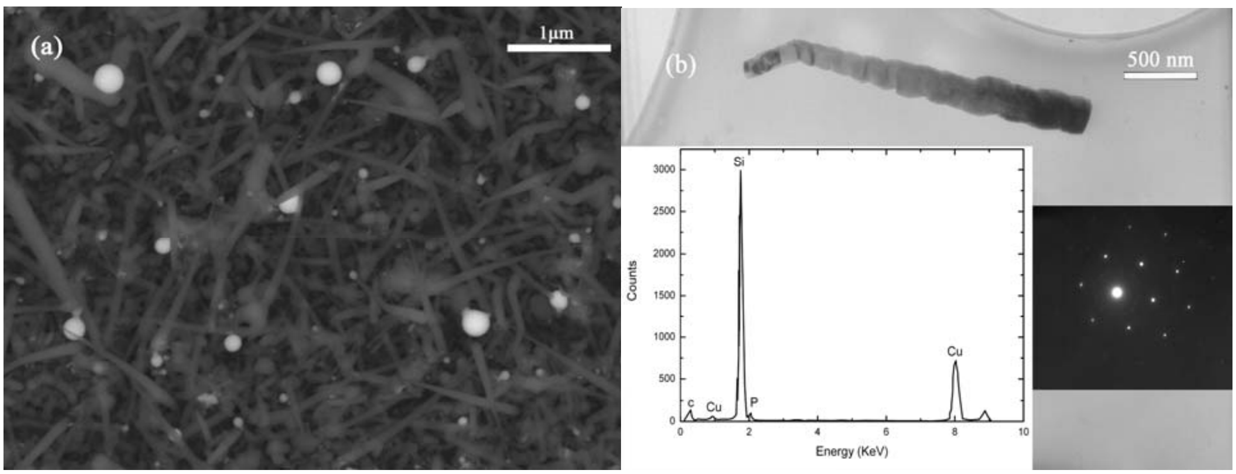

Figure 1. (a) Back-scattered electron image in FE-SEM of as-synthesized SiNWs. The white dots show indium (In) catalysts on tops of SiNWs. (b) TEM image of a n-type SiNW. Seleted-area electron diffraction pattern (left inset) taken from the nanowire showing the single crystal SiNW. EDS (left inset) taken from the SiNW stem showing the presence of Si and traces of P due to P-doped.

Figure 2（a ）is the scheme of n-i-p junction SiNWS solar cell. Figure 2（b）shows image of the cell. Compared to Figure 1 the diameter of the nanowires increased due to the SiNWS coated with conformal i- and p-type a-Si:H and ITO thin film layers.

RESULTS AND DISCUSSION

The typical light (under AM1.5 equivalent conditions) current-voltage curves of such cell is Voc = 0.62 V, Jsc = 13.36 mA/cm^2, Eff = 3.57 % and FF = 0.43, as shown in Figure 3 (solid triangle). To investigate the effect of n-type SiNWs on the cells, a planar thin film cell is fabricated on a bare SS (no pre-deposited ITO on SS) substrate under the same i, p layer deposition condition as SiNWs cells. The current-voltage curve of the thin film cell is also shown in Fig. 3 (Solid Square). The SiNWs solar cell shows a ~60% enhancement in Jsc over its planar

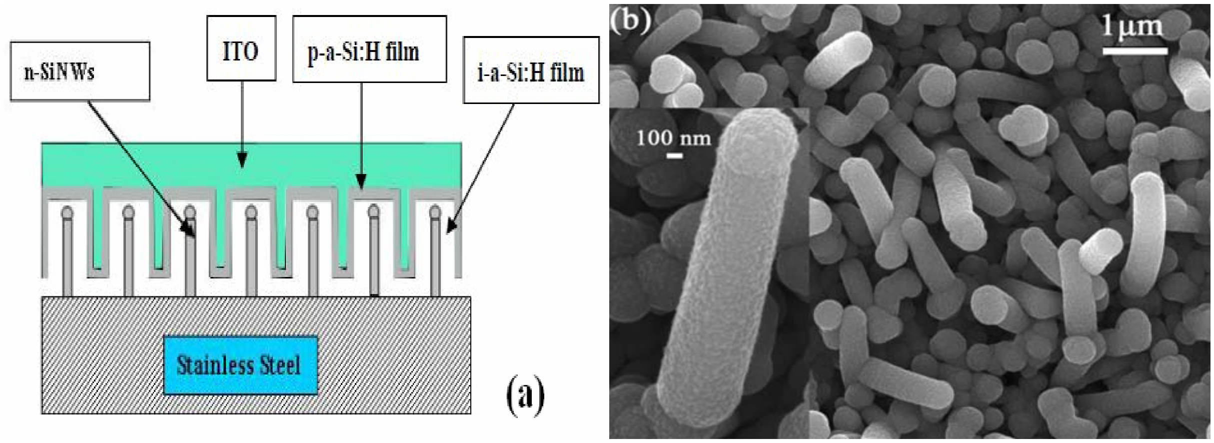

Figure 2 (a) schematic cross-sectional view of the SiNWs solar cell architectue. The nanowire array is coated with conformal i- and p-type a-Si:H thin film layers. (b) Scanning electron micrograph (top view) of a typical SiNWs solar cell on a stainless steel substrate ,including a-Si:H and ITO layers with insets showing a cross-sectional view of the device

counterpart 8.27 mA/cm^2 due to its strong broadband optical absorption and effective collection of photogenerated carriers. However, the open-circuit voltage of the SiNWs cell is smaller than that of the planar cell due to the larger junction area of the SiNWs cell [16].

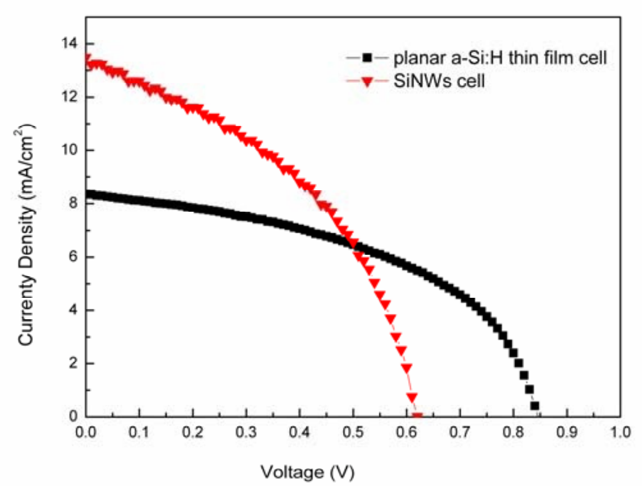

Figure 3 Measured I-V characteristics of a SiNWs solar cell (solid triangle) and a corresponding planar silicon thin film cell (solid square)

We tried to explain the improvement of Jsc as followed: Compared radial p-n structure, we supposed the layer of intrinsic a-Si:H plays an important role in this radial n-i-p structure SiNWs solar cells. First, the absorption coefficient of intrinsic a-Si:H active layer is higher than single crystal silicon by one to two orders of magnitude in the range of visible wavelength. Thus the 300 nm i-layer absorbed the most of sunlight . Secondly, the radial electric field allows for more effective collection of photogenerated charges. Finally, the SiNWs surface recombination is minimized due to the conformal a-Si:H films with good passivating properties[17]. Therefore , a promise Jsc of the SiNWs solar cells is ensured. The Quantum efficiency(QE) of the SiNWS cell is shown in Figure 4 (solid square)that exhibits the carrier collection is improved greatly compared to that of the a-Si solar cell (solid circle).

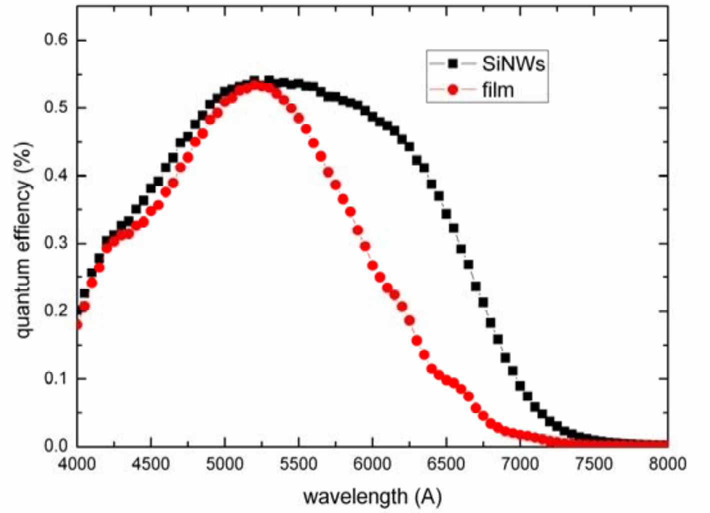

Figure 4 Quantum efficiency of SiNWS (solid square) and a-Si solar cell.

As can be seen from the Figure 4 the carrier collection is improved greatly in the range of 5500~7000 Å.

CONCLUSIONS

In conclusion, we have produced a radial n-i-p structure SiNWs-based solar cell on stainless steel foil by plasma-enhanced chemical vapor deposition. I-V and QE of such nanostructures cell were characterized. The obtained open-circuit voltage (Voc) and short-circuit current density (Jsc) under AM 1.5 illumination was 620mV and 13.36 mA /cm^2, respectively. A promise power conversion efficiency of the cells was 3.57 % that shows potential for low cost solar cells with such design.

We will focused on improving the power conversion efficiency of the cells by further passivating the silicon nanowires to increase the Voc ,optimizing NWS geometry, minimizing shunts, reducing contact resistance, and improving the i-layer quality.

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