Pencil-shaped Silicon Nanowires and their Photovoltaic Applications

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Pencil-shaped silicon nanowires (SiNWs) were synthesized by colloidal lithography and inductively coupled plasma reactive ion etching (ICP-RIE) for photovoltaic applications. Light reflectance of below 10% could be obtained by the array of asymmetric SiNW structure. The structural and optical properties including device performances compared to our previous SiNW structures synthesized by metal catalyzed electroless etching (MCEE) and nanoimprinting techniques were observed [1-2]. Good crystal quality and surface of pencil-shaped SiNWs provided an excellent solar cell junction interface. The great light trapping of their SiNW-based solar cells could enhance the conversion efficiency to 8.5%.

Synthesis of pencil-shaped SiNW samples was carried out using n-type Si(100) wafers with a resistivity of 1-10 Ω·cm and a thickness of 525 µm. Monolayer lithography of spherical colloidal silica particles (500 nm in diameter) were dispersed onto substrates [3] prior to inductively coupled plasma reactive ion etching (ICP-RIE). A p^+-Si shell layer thickness formed by chemical vapor deposition (CVD) was optimized by changing various deposition times of 3, 5, and 8 min for single junction solar cell fabrication. The substrate temperature and boron concentration were controlled at 750 °C and ~4×10^{19} cm^{-3}, respectively. Two step H_2 annealing and back surface field formation (BSF) were also applied [1-3]. Sputtering of a 200 nm-thick Al front electrode, and a 150 nm-thick Ag back contact of solar cells were performed.

Schematics of pencil-shaped SiNW formation and SEM images of SiNWs compared to MCEE- and nanoimprinted SiNWs were shown in Fig. 1. Pencil-shaped SiNW structures with a conical tip 350-nm tall and 300 nm in diameter on a 0.89 µm tall cylindrical base with a base diameter of 350 nm were constructed. Raman spectrum confirmed the single crystalline property. Electron spin resonance (ESR) signals revealed the dangling bond-type defect intensity of pencil-shaped SiNWs is higher than nanoimprinted-SiNWs and lower than that of MCEE-SiNWs. These defect densities showed good agreement with total surface area of each synthesized

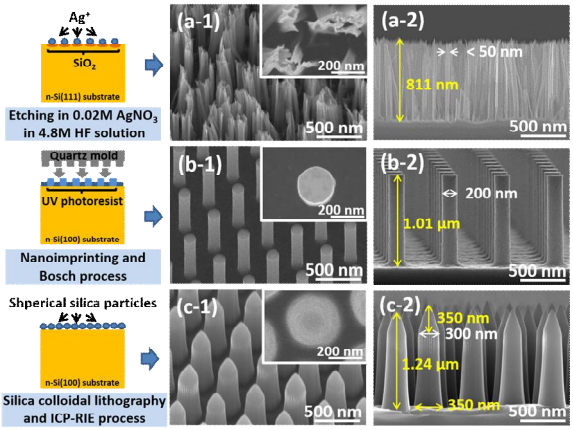

Fig. 1 30° tilted and cross-sectional SEM images of (a-1) and (a-2) MCEE-SiNWs, (b-1) and (b-2) nanoimprinted -SiNWs and (c-1) and (c-2) colloidal lithography-SiNWs, respectively. Insets show the top view of each SiNW structure.

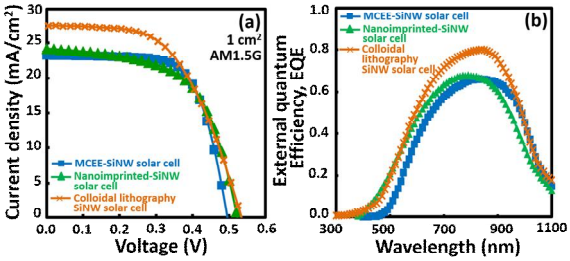

Fig. 2 (a) J-V characteristics measured under AM1.5G and (b) EQE of MCEE-, nanoimprinted-, and colloidal lithography-SiNW solar cells fabricated using two-step H_2 annealing and BSF formation.

SiNW structure which could be observed from SEM images in Fig. 1. UV-Vis-NIR spectroscopy could detect <10% light reflectance of pencil-shaped SiNWs, indicating their asymmetric structure had very strong light trapping effect. Figure 2 shows J-V characteristics and EQE of pencil-shaped, MCEE- and nanoimprinted-SiNW solar cells. The pencil-shaped SiNW solar cell gave the highest efficiency which was achieved to 8.5% with J_{sc}=28.69 mA/cm^2, V_{oc}=0.53 V, and F.F.=0.56. This great achievement was corresponding to the effective light absorption, good crystal property, and good SiNW surface quality.

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[2] W. Jevasuwan, *et al.*, JJAP, 56 (2017) 04CP01.
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