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Hybrid nanocone forests with high absorption in full-solar spectrum for solar cell applications

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Abstract. In this work, hybrid nanocone forests (HNFs) with high absorption in full-solar-spectrum are fabricated based on a plasma repolymerization technique. The HNFs combine light trapping effect of the nanocone forests with surface plasmon resonance effect of the metallic nanoparticles, thus can achieve an optimized absorption larger than 80% in the full-solar spectrum (i.e. 200-2500nm). Besides, with the hybrid nanostructures, the absorption decrease around the Si bandgap width can be narrowed greatly, while the normalized utilization efficiency of solar radiation can be increased. Therefore, usage of the HNFs as a texture structure in solar cells to obtain higher conversion efficiencies is foreseeable.

1. Introduce

To realize solar cells with high conversion efficiency, textures with high optical absorption are of importance, as they can motivate a large number of optical-induced carriers in the full-solar spectrum[1]. Due to light trapping effect, nanocone forests have been regarded as a promising texture usable in solar cells. However, most of the reported nanocone forests only can enhance absorption in a very limited solar spectral range and their generation methods are usually not compatible with conventional MEMS process[2-4]. In this work, based on a plasma polymerization (PP) technique proposed to fabricate a novel type of nanocone forests, HNFs are formed by sputtering Ag nanoparticles on surfaces of the nanocone forests. As detected, the HNFs can achieve an average absorption larger than 80% in the full-solar spectral range of 200-2500nm. By integrating the HNFs in solar cells, high conversion efficiency of the cells would be further predicted.

2. Fabrication

The process for fabricating the HNFs based on the PP technique is sequentially depicted in figure 1. Firstly, a polyimide (PI) layer is spin-coated on a Si substrate. Then, plasma bombardment is adopted to self-generate nanomasks. Later on, a reactive-ion-etching (RIE) step is employed to form Si nanocones, which is then followed by buffered oxide etching (BOE) to remove the nanomasks. Finally, Ag nanoparticles are sputtered on surfaces of the nanocone forests. Scanning electron microscope (SEM) images corresponding to the fabrication steps of the HNFs are demonstrated in figure 2.

3. Experiment and Discussion

The absorption spectra of a Si wafer with planar surface, nanocone forests before Ag sputtering and the HNFs were measured using an UV-vis spectrometer. Within the wavelength range of 200-2500nm, as shown in figure 3, the average absorption of the HNFs reaches 80.6%, which is much larger than that of the nanocone forests (70.1%) and the planar Si (32.4%). As solar radiation is asymmetrically distributed along the full-solar spectrum, among which, the visible

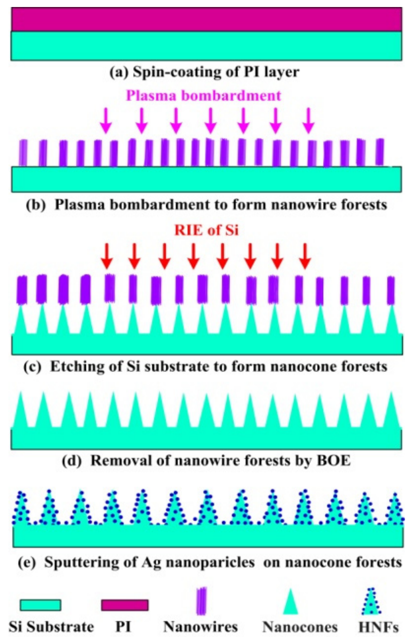

Figure 1. Fabrication process of the HNFs based on the PP technique.

light contributes slightly more than the infrared light, thus the normalized energy utilization ratio for the nanocone forests increases the most. Even though, a ratio of 84.2% can be realized by the HNFs (inset in figure 3). Compared with the nanocone forests, the larger absorption and utilization ratio of the HNFs can be attributed to the surface plasmon resonance induced by the Ag nanoparticles and the nanocones.

To demonstrate the absorption features of the three Si-based structures around the Si bandgap width, a spectral range of 1000-1200nm is chosen for the analysis. As illustrated in figure 4, the decrease of planar Si within this wavelength range is 59%, and that for the nanocone forests is 43%, while the HNFs can reduce the decrease to 6%. In other words, the HNFs have an ability to break absorption limitations caused by the Si bandgap width. Meanwhile, the absorption difference of the HNFs with Ag nanoparticles of different sizes is studied. As shown in figure 5, the absorption decrease of HNFs at the bandgap width becomes smaller when the nanoparticle sizes increase. Therefore, higher average absorption can be expected by sputtering Ag nanoparticles with larger sizes.

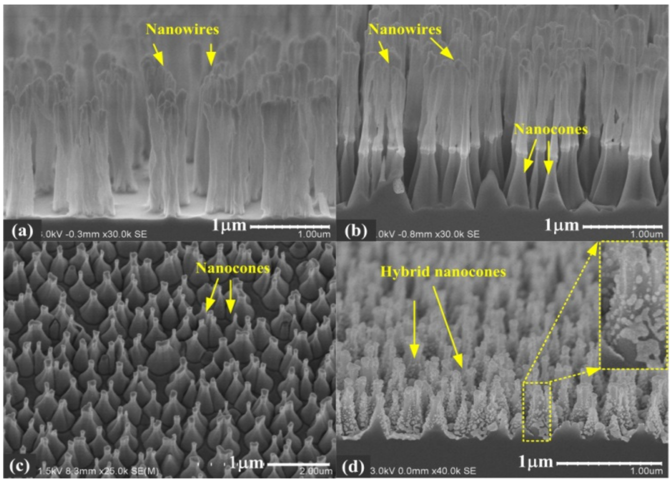

Figure 2. SEM images of nanostructure forests demonstrating formation process of the HNFs.

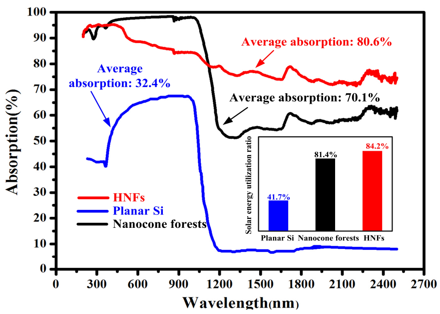

Figure 3. Average absorption and solar energy utilization ratio of planar silicon, nanocone forests and the HNFs.

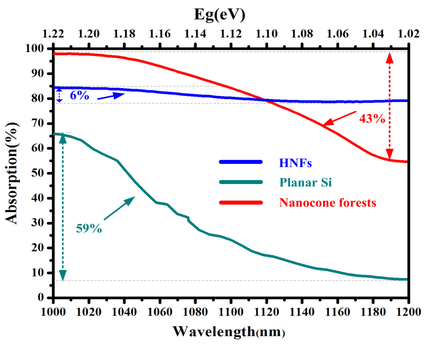

Figure 4. Absorption of the three Si-based structures in a wavelength range around the Si bandgap width (1000-1200nm).

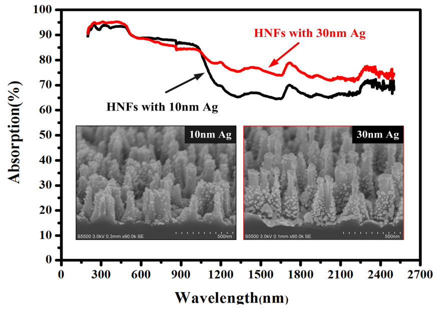

Figure 5. Absorption of HNFs with Ag nanoparticles of different sizes

Since the HNFs have brilliant optical properties, when taking their micromachining-compatible features into consideration, they can be easily integrated into Si-based solar cells. As a result, solar cells with higher conversion efficiency are expected.

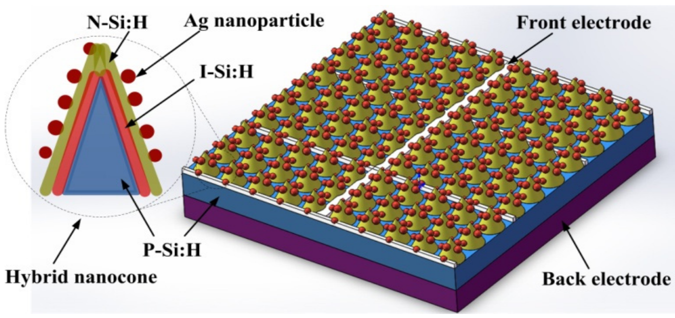

Figure 6. Schematic diagram of solar cells integrated with the HNFs.

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