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High Efficiency Silicon Heterojunction Solar Cell with Omnidirectional Light Harvesting By Hierarchical Structures

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Introduction

In recent years, solar cells have attracted considerable attention as a renewable energy source. Among various kinds of solar cells, Si heterojunction (SHJ) solar cell, composed of hydrogenated amorphous silicon (a-Si:H) and crystalline silicon (c-Si), is one of the most popular candidates due to its high open-voltage (V_{oc}) potential. For high-efficiency SHJ solar cell, good passivation is extremely important to reach high V_{oc}. The thin intrinsic a-Si:H passivates the surface dangling bond on c-Si, which is called surface passivation, leading to low density of surface states and high quality junction. Moreover, due to the large bandgap of a-Si, the large band offset between a-Si:H/c-Si interface forms a barrier to inhibit the carrier recombination, thus suppressing the saturation current, which is called field-effect passivation.

Unfortunately, the high reflective index of Si results in up to 40 % of the incident light reflected, which severely limits device performances. In this study, the uniform hierarchical structures consisted of micropyramids and nanowires, exhibiting superior antireflection (AR) ability, are applied to replace general ultra-high aspect-ratio nanostructures in order to avoid the nonconformal deposition and excessive surface defects. Then, the surface defects and metal ions contamination were minimized by defect removal etching (DRE), resulting atomic smooth and contamination-free surface. The defect removal effect was monitored through the minority carries lifetime measurements, and transmission electron microscopy (TEM) observation showed additional evidence of atomic smooth and epitaxy-free a-Si:H/c-Si interface. The results show that an excellent passivation effect can be obtained on nanostructures as long as proper DRE treated. The hierarchical structures after 60 s DRE increase the short circuit current density (J_{sc}) and maintain the high V_{oc}, thus enhancing the conversion efficiency. The hierarchical structures combining DRE is a promising way to make it possible to achieve high efficiency nanoscaled SHJ solar cells.

Result and discussion

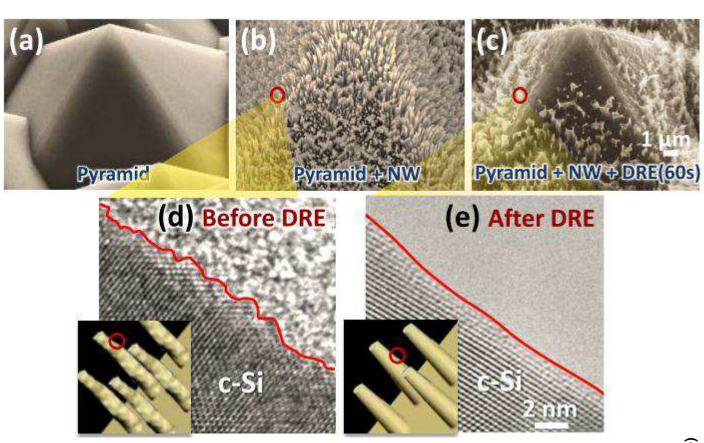

Figure 1. (a)-(c) SEM images at various stages for fabricating hierarchical structures with DRE. HRTEM images taken near the edge of the individual NW on hierarchical structures (d) before and (e) after DRE.

Figure 1(a)-1(c) show the scanning electron microscopy (SEM) images of the morphology changes in each process (recorded at the tilted angle of 45º). First, the Si micropyramids were fabricated on n-type CZ monocrystalline Si (001) substrates via an anisotropic etching process using a solution of potassium hydroxide (KOH) and isopropyl alcohol (IPA) at 85 °C. After 20-min etching, micropyramids were formed with 10 to 15 μm in width. Subsequently, the large-area and uniform hierarchical structures consisted of micropyramids and nanowires were obtained by metal-assisted chemical etching for 30 s, as shown in Fig. 1(b). Finally, the isotropic DRE was carried out to control the final morphologies and remove the surface defects. The solution is mixture of nitric acid (HNO_3) and hydrofluoric acid (HF). After the DRE, the density and length of NWs become lower and shorter, and the surface of NW becomes atomically smooth, benefiting conformal deposition of thin a-Si:H layers.

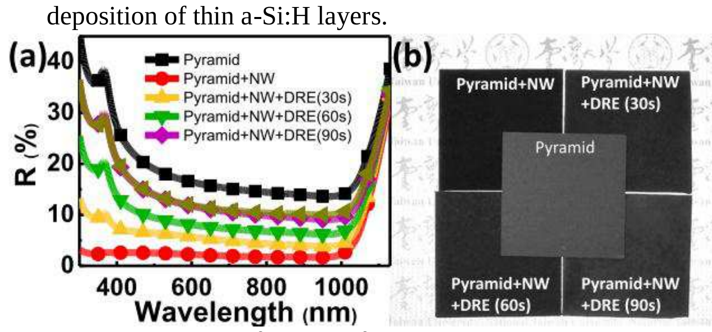

Figure 2. (a) Total reflectance of the hierarchical structures with different DRE durations compared with micropyramid surfaces. (b) A photographic image of five structures on 4 * 4 cm^2 wafers.

In order to evaluate the AR property of hierarchical structures with DRE, the R_{total} of hierarchical structures with different DRE durations in the wavelength range of 300-1130 nm was measured, as shown in Fig. 2(a). In contrast to the micropyramid structure, the hierarchical structures effectively reduce the reflectance over the broadband regions.

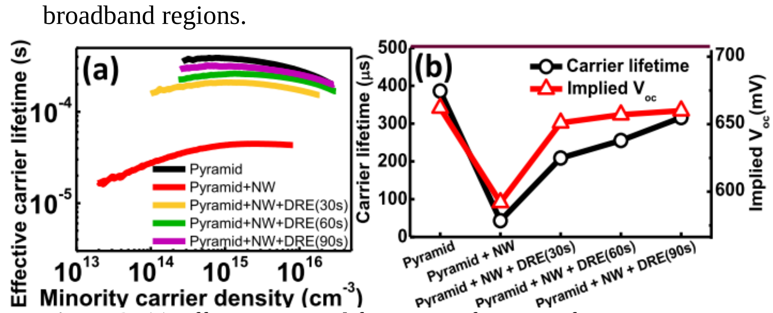

Figure 3. (a) Effective carrier lifetime as a function of minority carrier density for the hierarchical structures with different DRE durations compared with micropyramid surfaces. (b) Lifetimes at carrier density of 10^{15} cm^{-3} and implied V_{oc} of all structures.

The τ_{meas} significantly increases after 30 s DRE, and further increases with DRE duration. The increase in τ_{meas} can be attributed to the effective reduction of defect and contamination of the surface, the atomic surface roughness removal, and the atomically smooth Si surfaces creation.

Finally, we use different DRE solution (TMAH, KOH, and HNO_3) to optimize the DRE condition and obtain high τ_{meas} hierarchical structures. Fig. 4 shows that under the similar light trapping ability, the carrier lifetime can be as high as that of base pyramid after TMAH treatment.