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Improving solar-cell efficiency

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Combining electrochemical etching with texturing technology leads to enhanced photovoltaic performance.

The reflectivity of crystalline silicon (Si) is enhanced by up to 40–50% at long optical wavelengths compared to the visual range. Hence, to improve the performance of solar cells, reflection losses must be reduced. Light trapping, antireflection coating (ARC), and texturing have been applied widely to increase solar-cell (light-absorption) efficiency. Many recent studies have been devoted to improving the surface texture of Si wafers and developing ARCs, for instance, by depositing antireflection layers composed of porous silicon (PSi). These films are typically fabricated by electrochemical etching through anodizing the wafer in a solution of hydrofluoric acid and organic solvent. This technique offers several merits such as selective emission, surface passivation, and light diffusion.

Since PSi fabrication is simple and economical, it can be used for mass production of commercial solar cells. Application of PSi in photovoltaic devices has been reported and is attracting increasing industrial interest. Its main advantages include reduced reflection losses, large active areas, and its capability of downshifting light energy. Thus, the PSi layer on a solar cell's surface could act as both ARC and photoconverter. The main question is whether we can combine electrochemical etching with conventional surface-texturing technology to improve the absorption and energy-conversion efficiencies of photovoltaic devices.

We employed photoelectrochemical etching in conjunction with texturing to form nanoporous-Si layers on Si. We produced a textured layer prior to electrochemical treatment in a pilot line for solar cells. We then etched the wafer electrochemically in hydrofluoric acid containing the electrolyte under different illumination and electrochemical conditions. After anodization, we investigated the morphology of the samples prepared under different conditions using scanning-electron microscopy, and performed reflectivity measurements at room temperature at wavelengths in the range of 400–1000nm.

We measured the reflectance from the textured Si wafer and compared it to that from the textured Si after anodizing (see Figure 1). We found that the reflectance of the textured layer was much higher than that of PSi after electrochemical etching at wavelengths shorter than 800nm but not for longer wavelengths. The reflectance of the electrochemically etched and textured layer diminishes significantly for wavelengths from 400 to 1000nm compared to that of the textured layer without electrochemical etching. This means that the combined treatment retains the advantages of both processes and overcomes the inherent disadvantage of the textured layer, thus offering a viable means to improve the device's efficiency.

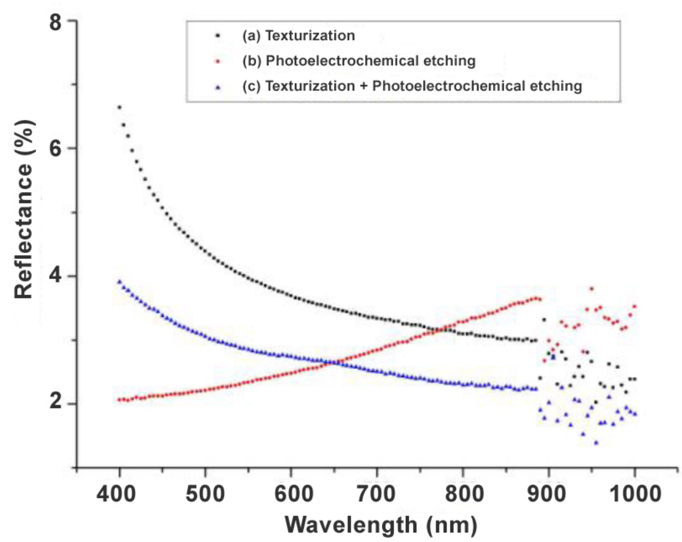

Figure 1. *Silicon-wafer reflectance.*

A morphology including a thicker PSi layer may substantially decrease reflectance losses, although higher PSi concentrations may damage the surface texture. Our experimental results show that etching for longer periods can adversely affect the morphology of the pyramids and degrade the performance of the resulting solar-cell structure. Hence, to improve the light-absorption efficiency, a properly textured surface with an optimized PSi layer is imperative.

In addition, a solution containing isopropylamine (IPA) can significantly enhance light absorption. IPA is a surfactant that is widely used to mitigate the adherence of hydrogen bubbles

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onto etched surfaces. The surface pyramids become more uniform and it can therefore be assumed that the wetting ability of IPA is very important, such that bubbles sticking onto the Si surface can prevent formation of tall pyramids. Using this approach, we managed to reduce the average reflectance to 2% (for 400–1000nm).

The pore size of the layer thickness increases with higher current density. A large pore size with a considerable depth could form 3D pn junctions through diffusion. Hence, by conducting electrochemical etching properly, 3D pn junctions can be produced and the efficiency can be significantly improved.[1] This proposed methodology, which we aim to turn into a viable fabrication approach, integrates texturing and electrochemical etching to improve solar-cell efficiency.

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