Electrochemical Etching of Silicon for Inexpensive and Effective ARCs

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ABSTRACT

Highly uniform films with excellent anti-reflection (AR) properties can be formed on any silicon substrate using a simple electrochemical etching technique. In a solar cell manufacturing process, this etching step can replace the typical wet chemical phospho-silicate glass (PSG) removal step following dopant diffusion, and therefore adds no additional wet processing. This technique is based on the selective removal of silicon atoms from the sample surface, forming a layer of porous silicon (PSi) with adjustable optical, electrical, and mechanical properties. In our investigation we have focused on the formation of thin film PSi layers on the surface of solar cell substrates without disturbing the underlying junction characteristics. Graded index of refraction films with broadband AR properties superior to double layer ARCs have been produced and studied. The simplicity and highly reproducible nature of this technique in combination with its short duration (<10 seconds) make it a strong alternative to vacuum deposited ARCs. Several promising results will be presented with an emphasis on possible manufacturing applications of this technique.

1. Introduction

The light trapping and anti-reflection properties of PSi, in addition to its simplicity of formation and broadly tunable morphology, make it particularly well suited for photovoltaic applications. It has been used as a single or multilayer antireflective coating by exploiting the tunability of the film's effective index of refraction [1,2]. By preparing PSi electrochemically, continuous control of refractive index as a function of depth can be achieved by controlling the electrochemical current density, making broadband graded index ARCs possible [3].

Although PSi is not presently utilized in an industrial solar cell setting, it offers several potential applications. The combination of a controllable index of refraction with the light trapping characteristics of PSi enables the simultaneous texturization and AR coating of solar cells independent of the crystalline orientation of the substrate. Because the electrolyte used in the etching process contains hydrofluoric acid, PSG can also be removed during this process, eliminating the need for an additional PSG removal step. The formation of PSi also involves the consumption of a portion of the surface layer of the solar cell and can therefore also be effective in the removal of dead layers remaining after diffusion [4] or preferential removal of grain boundary material [5]. There is also evidence that thin PSi ARCs can be "fired through", making this material compatible with commercial screen printing metalization [6].

Using previously fired PSG coated String Ribbon substrates [7], we have focused on thin (<120nm) PSi films that consume as little of the emitter region of these cells as possible. By demonstrating synergistic PSG removal, we propose that electrochemical etching can be directly substituted for the standard wet PSG removal step in manufacturing, eliminating the need for a back end ARC process.

2. Experiment

A matrix of PSi samples was prepared using fired PSG coated String Ribbon polysilicon solar cells. The diffused emitters had a junction depth of 300 nm and each sample had a fired Al back surface field. The typical initial etching current density of 100 mA/cm^2 was dynamically reduced to zero over a period of 3-10 seconds. For electrical characterization of these devices, Ti/Pd/Ag contacts were evaporated and patterned using a liftoff procedure.

The total specular and diffuse reflectivity of each sample was measured with a Perkin-Elmer UV/VIS/IR spectrophotometer using an integrating sphere. Scanning Electron Microscope (SEM) cross-sectional images of several samples were taken with a Zeiss Leo SEM to determine film thicknesses. Light IV measurements were made using a 1000W mercury-xenon lamp as the excitation source.

3. Results

The reflectivity of several String Ribbon substrates is plotted in Figure 1. From these data it can be seen that substantial reductions in reflection losses can be achieved with brief gradient index PSi etching treatments. The 105 nm thick graded index ARC shown in the figure was formed in 5 seconds using a process that also removed the PSG coating. With an average reflectivity of 5% from 300-1000 nm, this PSi ARC demonstrates optical performance superior to most double layer vacuum deposited ARCs.

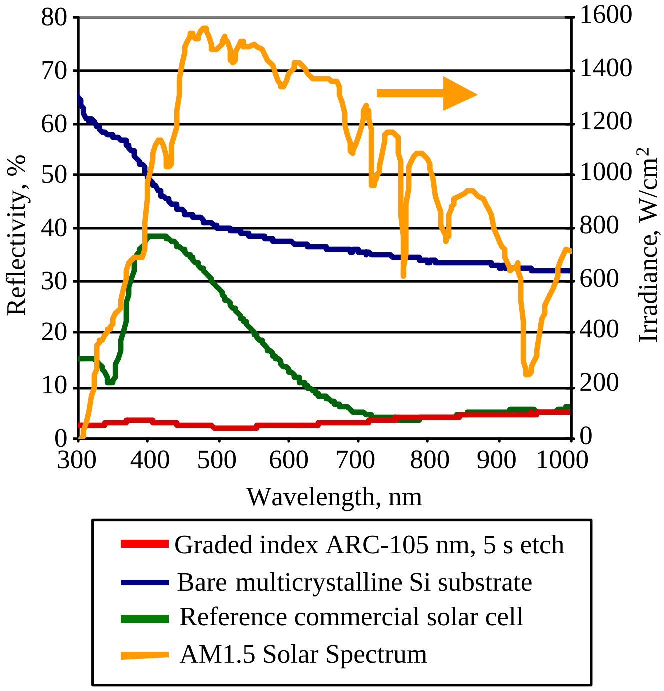

Figure 1. Reflectivity spectra of several String Ribbon solar cell substrates relative to the peak terrestrial solar spectrum.

After evaporating tri-layer Ti/Pd/Ag front contacts, the light IV data shown in Figure 2 was measured. Samples incorporating a PSi ARC exhibited a higher open circuit voltage and short circuit current, leading to a 20% increase in power output. The fill factor for the reference samples averaged 69%, while the PSi samples averaged 67%, indicating that the PSi layer introduces no substantial ohmic losses. The slight drop in fill factor is most likely due to the small insulating characteristics of the PSi film under the evaporated contacts. The contact geometry and annealing conditions are also not optimized, and further improvements could therefore be realized. Other metalization techniques, including screen-printed Ag paste will be explored in the future.

4. Conclusions

This investigation has demonstrated the feasibility of integrating PSi AR layers into commercial multicrystalline silicon solar cells. Light IV data have shown significant efficiency increases in samples incorporating PSi ARCs without significant fill factor degradation. The simplicity of PSi formation, simultaneous PSG removal, and compatibility with both crystalline and randomly oriented polysilicon materials make this material an economically viable solution for low cost, large area photovoltaic applications.

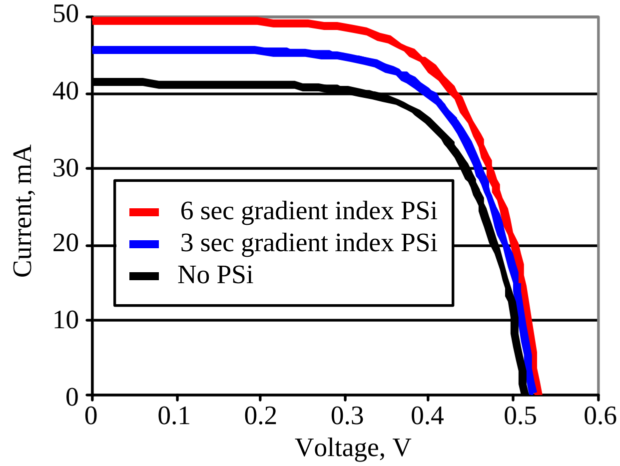

Figure 2. Light IV data for String Ribbon PSi samples prepared with a synergistic PSG removal process.

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