High-Aspect-Ratio Polyimide Pore Array Template for Thin Film Solar Cells

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Abstract:

A lightweight and flexible photovoltaic device can be created within high-aspect-ratio pores in a polymer sheet, where the geometry of radial junctions would offer a high carrier collection. By spinning and curing liquid polyimide (PI) on an oxidized silicon (Si) pillar array, a high-density PI pore array template (~ 10^5 pores) was fabricated. The features of the released polymer template were investigated using an optical microscope and a field-emission scanning electron microscopy (FE-SEM). Radial junctions of p-i-n can be achieved within the pores of the template using conformal thin-film deposition to create high-performance solar cells.

Introduction:

A conventional planar solar cell consists of n- and p-type Si layers. When the light illuminates on the top-most highly absorbing layer (e.g., p+ layer), the generated electron-hole pairs should travel through the bulk layer until they are separated at the depletion region to be harvested. While the carriers in a planar cell, whose thickness is much thicker than the minority carrier diffusion length ($L_{n,p}$), are largely lost due to the recombination, those generated in a radial junction of a diameter of < 2 $L_{n,p}$ can be separated and collected in a perpendicular direction of the illumination, resulting in higher efficiencies [1,2]. By taking advantage of this geometry, high-aspect-ratio pores created on a polymer sheet would provide desirable features including flexibility and being lightweight. In addition, the technique of a-Si thin-film deposition within the pores in the PI template can provide a much cheaper and efficient way to fabricate solar cells when compared to the cells made from a crystalline Si substrate. Using the spinning and curing methods of liquid PI on an oxidized Si pillar array, we fabricated 2.5 mm × 2.5 mm (~ 10^5 pores) high-aspect-ratio pore array PI templates. The flexible template substrate will be used for thin-film radial junction solar cells.

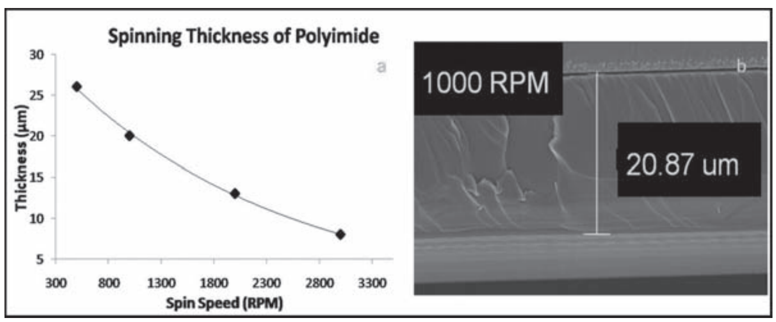
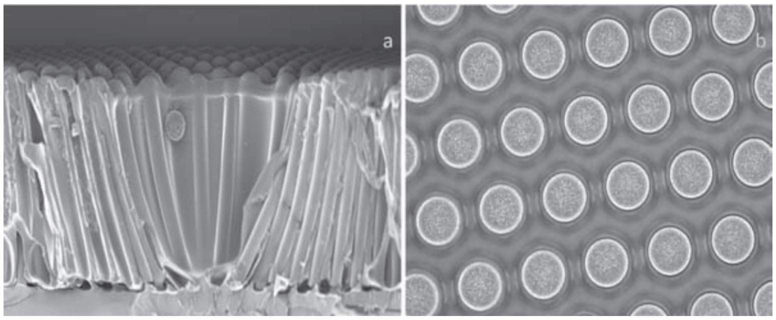


Figure 1: PI thickness vs. spin speed performed on Si planar substrates. Right shows FE-SEM image of the PI film after the spinning and curing processes.

Experimental Procedure:

A PI template was fabricated by spin-coating and curing the liquid PI [3] on an oxidized Si pillar. In order to determine the optimized condition for spin-coating, the liquid PI was spun on three planar samples with spin speeds of 500, 1,000, and 2,000 revolutions per minute (RPM), respectively, and cured in an oven at 250ºC for 3 hours. As shown in Figure 1, a thickness of 21 μm PI planar film could be achieved at the spin-speed of 1,000 RPM. Using this condition, we spun the liquid PI onto oxidized Si pillar arrays of a diameter of 20 μm, height of 25 μm, and the distance between the pillars of 5 μm (~ 10^5 pillars in 2.5 mm × 2.5 mm square) and cured the sample. The SEM image in Figure 2 (a) shows the side-view of the sample.

A reactive ion etching (RIE) process was performed for 10 minutes to etch away the PI on the tops of the pillars, exposing the oxide layer (Figure 2, b). The whole sample was then placed in a buffered oxide etchant (BOE 1:10) for two days to etch the oxide layer off the pillars, thus making it easy to release the PI pore template from the Si pillar arrays. Once the oxide was completely removed, the template was removed, using double-sided carbon tape, for the SEM analysis.



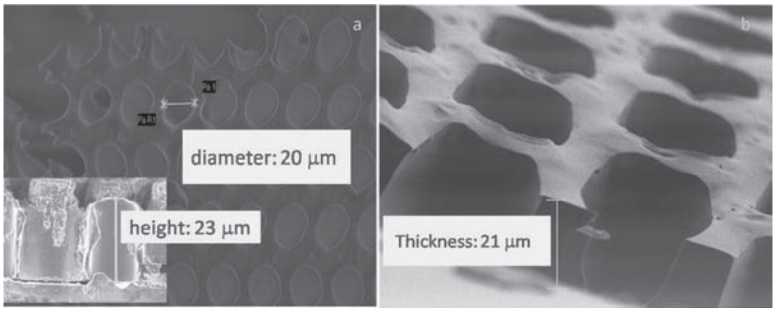


Figure 2, top: FE-SEM images of PI coated pillars (a) and RIE etched pillars (b). The pillar array of 2.5 mm × 2.5 mm that contained ~ 10^5 pillars of 20 µm-diameter, 25 µm-high and a distance of 5 µm between the pillars.

Figure 3, bottom: FE-SEM image of the top- and side-view of the released PI pore template of a diameter of 20 µm, height of ~ 21 µm, and the distance between the pillars of 5 µm in 2.5 mm × 2.5 mm square.

Future Work:

In this work, we developed a fabrication procedure to create a high-aspect-ratio PI pore template using spin-coating, curing, and releasing processes. Using a conformal thin-film deposition of a-Si, radial junction of p-i-n can be achieved within the pores of the template, creating thin film solar cells. The pore template can also be obtained by direct etching technique, such as using magnetically enhanced reactive ion etching on a metal patterned PI planar substrate.

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Results and Conclusion:

Figure 3 shows top- and side-view of the released PI pore template. Each pore had a diameter of ~ 20 µm and the distance between the pillars was 5 µm (Figure 3, b). The measured thickness was approximately 21 µm, indicating the RIE condition was just enough to open up the tops of the pillars and not etch the PI template further. In addition, the optimized fabrication process allowed us to release the whole PI template (2.5 mm × 2.5 mm) from the Si pillar array substrate. Through a series of samples, diameters of 8-32 µm PI pore array templates were obtained.

References:

[1] Zhiyong, F. et al., "Three-dimensional nanopillar-array photovoltaics on low-cost and flexible substrates" (2009).

[2] Kayes, B., et al., "Comparison of the device physics principles of planar and radial p-n junction nanorod solar cells" (2005).

[3] HD MicroSystems Product Bulletin (http://www2.dupont.com/HDMicroSystems/en_US/pdf/PI-2525_2555_2556_2574_ProductBulletin.pdf).