Patterning of the Metal Induced Crystallization of Amorphous Silicon for Silicon Wire Array Photovoltaics

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Abstract and Introduction:

Photovoltaics (PVs) are a promising clean energy alternative to fossil fuels but they are not currently cost-competitive. Sixty percent of the cost of monocrystalline silicon PV modules comes from the silicon (Si) wafer. Si PVs fabricated with Si wire arrays could eliminate the bulk Si substrate. Not only would Si wires reduce the amount of Si used, but the geometry would also allow for the decoupling of the two main processes required for a PV to work: photon absorption and carrier collection [1].

For Si wire PVs, it is preferred that the wires are vertically aligned, have controllable diameters and placement, and can be grown on a cheaper substrate like glass. Chemical vapor deposition (CVD) combined with the vapor-liquid-solid (VLS) growth mechanism is one way to meet these criteria. However, this requires a Si <111> orientated layer to grow off [2]. The aluminum induced crystallization (AIC) process is ideal for the fabrication of the Si <111> layer, as it is a low temperature process and Si <111> can be achieved with the help of an aluminum oxide (Al_2O_3) layer [3].

Since AIC also produces crystal orientations other than <111>, the objective of this project is to maximize the percentage of Si <111> islands to promote vertical wire growth. To maximize the Si <111> islands, patterned AIC substrates were investigated to confine the island growth. We were interested in determining whether it was possible to maximize the percentage of Si <111> islands by reducing the pattern size to the same magnitude as the individual silicon islands. Oxygen plasma exposure was also investigated as an alternative to air exposure to oxidize the aluminum layer, as ambient environments only produce a monolayer of Al_2O_3.

Experimental Procedure:

Samples were prepared by depositing 100 nm of Al on a quartz substrate either through e-beam evaporation or sputtering. Air exposure (30 minutes, 45 minutes or 16 hours) or oxygen plasma exposure (1, 2.5, 5 or 7.5 minutes) was then used to oxidize the surface of the Al, followed by the deposition of 100 nm of amorphous silicon (α-Si).

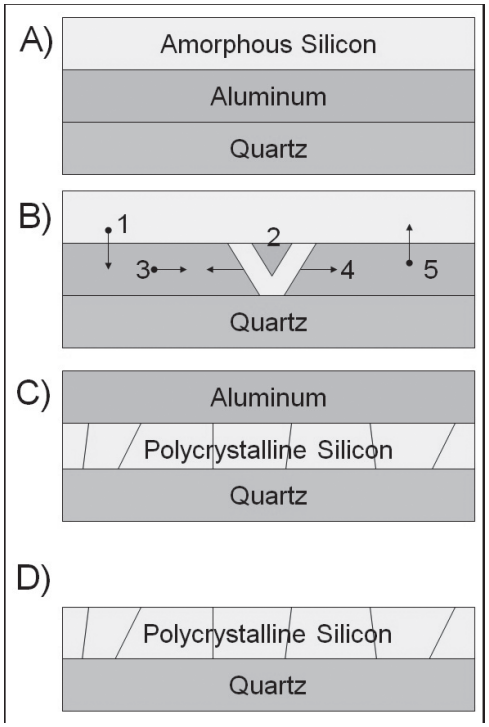

Figure 1: A) Sample before AIC, B) During AIC, C) After AIC, and D) After etching the Al.

Figure 1a represents the sample before AIC.

Patterned samples were prepared through pre-patterning, by lift-off, and the top layer of Al was oxidized by air exposure for either 45 minutes or 16 hours. The mask pattern contained close-packed hexagons with diameters of 12, 25, 50 and 100 μm. Optical microscopy and scanning electron microscopy (SEM) were used to image the samples after the annealing and etching of the Al layer.

These samples were then annealed at either 450 or 550°C for a period of 1 to 72 hours. Figure 1b shows the AIC process: during the annealing, Si diffuses into the Al layer and becomes supersaturated (1), leading to Si nucleation

sites throughout the Al layer (2). The polycrystalline silicon is confined to the thickness of the Al layer, therefore it grows laterally and there is a complete layer exchange between the Al and Si layers (3, 4, 5). After annealing the Al layer was etched using RCA2, leaving a layer of polycrystalline Si on quartz, shown in Figure 1d. These layers were then coated with 1 nm of gold to act as nucleation sites for the nanowire growth and we subsequently evaluated the amount of vertical wire growth.

Results and Conclusions:

The patterned samples prepared with 45 minutes of air exposure had smooth surfaces with no evidence of a double layer of α-Si and polycrystalline Si, which suggests continuous crystallization. Growth on these patterned samples resulted in continuous growth contained to the patterned areas, but at this time it is unclear whether there was improved vertical wire growth. Figure 2 shows an SEM image of a hexagonal pattern after three minutes of growth.

For samples where the top Al layer was oxidized using oxygen plasma exposure, greater times of oxygen plasma exposure resulted in increased amounts of vertical wire growth, with 5 and 7.5 minutes having similar amounts of vertical wire growth to samples prepared with 24 hours of air oxidation. Figure 3 is an SEM image of growth on a sample exposed to an oxygen plasma for 7.5 minutes. The amount of vertical wire growth is similar to the results in Figure 4, a sample exposed to air for 24 hours.

Future Work:

At this stage, it is not definitive whether these processes improved the formation of Si <111> grains. It is critical that orientation imaging microscopy be used to verify the orientation of the Si grains to further evaluate our results. The effect of patterning on microwire growth is also currently being explored.

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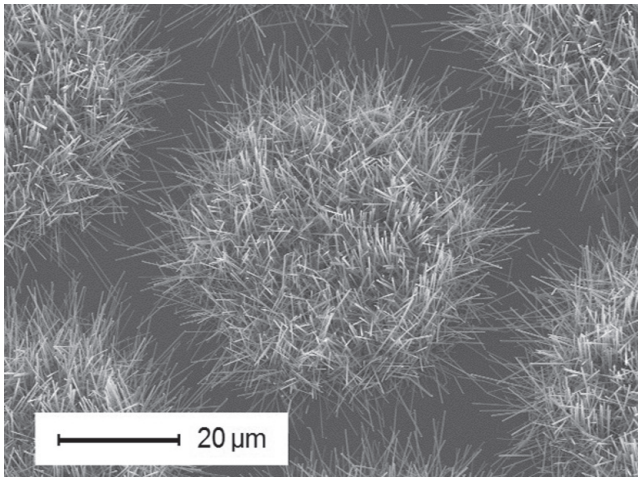

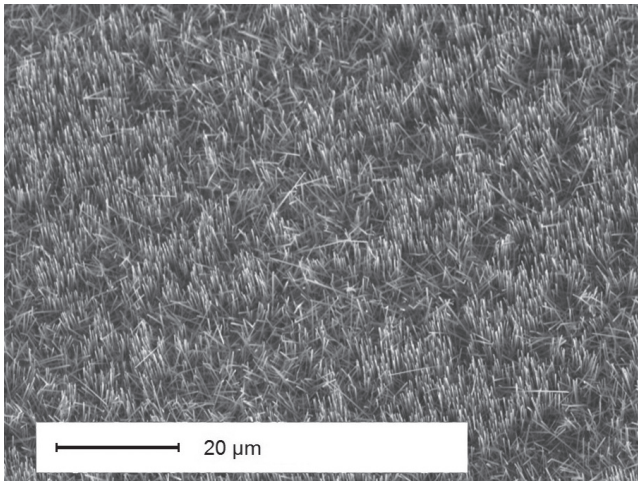

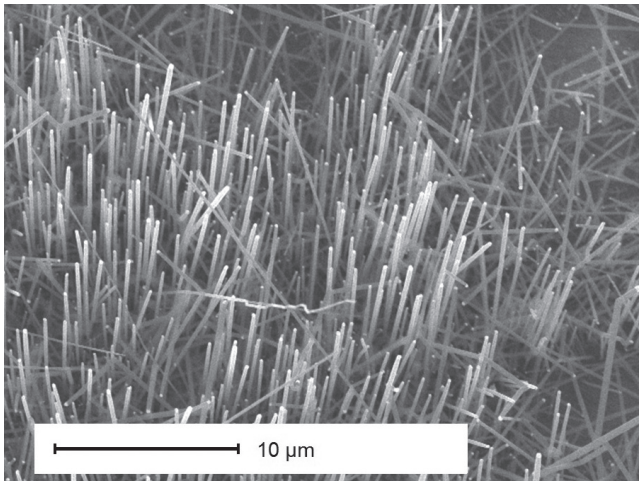

Figure 2, top: 25 µm hexagon, 24 hr anneal, 3 min growth with CVD combined with the VLS growth mechanism.

Figure 3, middle: 7.5 min oxygen plasma exposure, 24 hr anneal, 3 min growth with CVD combined with VLS growth mechanism.

Figure 4, bottom: 24 hour air oxidation exposure, the amount of vertical growth is comparable to that of the 7.5 minutes oxygen plasma exposure sample.