Aluminum Induced Crystallization of Silicon on Quartz for Silicon Wire Array Solar Cells

Natalie M. Dawley
Physics, University of Virginia

NNIN REU Site: Penn State Nanofabrication Laboratory, The Pennsylvania State University, State College, PA
NNIN REU Principal Investigator(s): Prof. Joan M. Redwing, Materials Science and Engineering, Pennsylvania State University
NNIN REU Mentor(s): Dr. Chito E. Kendrick, Department of Materials Science and Engineering, Pennsylvania State University
Contact: nmd8d@virginia.edu, jmr31@psu.edu, cuk11@psu.edu

Abstract:

Radial junction silicon (Si) wire array solar cells are being developed as an inexpensive and potentially more efficient alternative to planar crystalline Si solar cells. Currently, Si wires are grown on bulk Si substrates, an expensive commodity. Aluminum-induced crystallization of Si on quartz was studied as a low cost substitute for bulk Si wafers for wire array growth. Samples were prepared with a quartz / 100 nm aluminum (Al) / 100 nm amorphous Si layer structure and were annealed in nitrogen at 550°C to facilitate Al/Si layer transfer and Si crystallization. Crystallized Si regions up to 50 μm in size were obtained. X-ray diffraction (XRD) and Raman spectrometry analysis confirmed the formation of polycrystalline Si islands. Samples with successful Al/Si layer exchange were then tested as a substrate for Si nanowire growth.

Introduction:

Aluminum-induced crystallization (AIC) of silicon was studied as a low cost alternative to fabricate a thin (100-500 nm) silicon <111> layer on quartz. The <111> orientation is required for the growth of vertically oriented silicon wires, which are preferred for the solar cell fabrication [1].

The AIC process consists of depositing layers of aluminum (Al) and amorphous silicon (α-Si) which are then annealed below the eutectic temperature of silicon, 577°C. During the annealing process, the Si diffuses into the Al layer, at a high enough concentration nucleates and grows, forming a bottom layer of crystalline Si with an Al surface layer [2].

Experiment:

To create the crystalline Si layer, via Al-induced crystallization, 100 nm layers of Al and amorphous silicon (α-Si) were deposited on a quartz substrate using chemical vapor deposition (Semicore electron-gun evaporator). Two types of α-Si were examined, pure and hydrogenate (Applied Materials (AMAT) P-5000 PECVD Cluster tool). The surface of the aluminum layer was oxidized by controlled exposure to air before Si deposition; air exposure has been reported to promote Si <111> during the AIC process [3]. Two samples were investigated for Si wire growth, as tabulated in Table 1.

Name	Al	Air Exposure	a-Si	a-Si tool
Sample 1	100 nm	3 days	105 nm	Semicore
Sample 2	100 nm	1 day	140 nm	AMAT cluster tool

Samples were annealed in a tube furnace at 550°C for a set amount of time, under nitrogen gas flow. The Al was then removed using a commercial etching solution (Type A, Transene Co.) so that only the crystallized Si layer remained. The annealed and etched samples were then characterized. The crystallization process and surface morphology were examined using a scanning electron microscope (SEM) and optical microscope. The quality of the crystallized Si and its orientation were studied with x-ray diffraction (PANalytical X'Pert Pro MPD) and Raman spectroscopy (Renishaw micro-Raman Spectrometer).

A developed wire growth technique was then used on annealed and etched samples that included seeding the substrates with gold and annealing in a furnace with 35 sccm of $SiCl_4$ in 65 sccm of H_2 at 1050°C for 1.5 min [4].

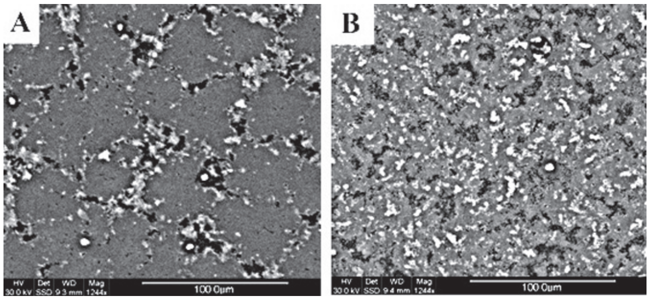

Figure 1: SEM images of A) Sample 1, and B) Sample 2, annealed for 42 hours.

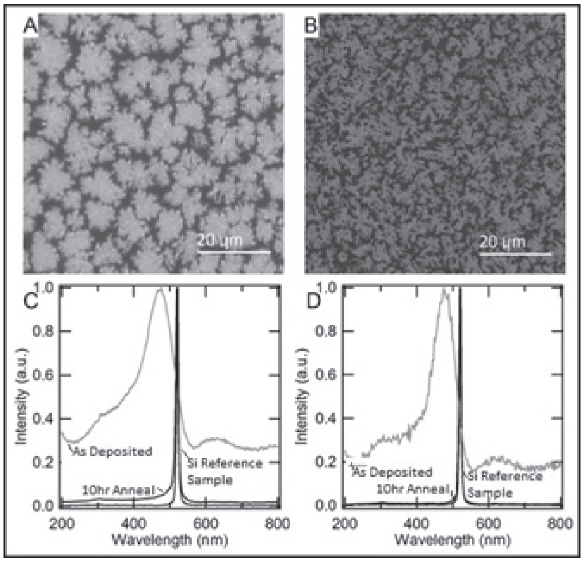

Figure 2: Optical microscopy and Raman Spectroscopy of 10hr annealed Sample1 a) and c) and Sample 2 b) and d).

Characterization and Results:

Figure 1a shows the top surface of the Semicore crystallized Si, with relatively flat, 'blotchy' nucleation islands. The hydrogenate α-Si was found to produce nucleation with porous dendritic growth and a rough textured surface as shown in Figure 1b. To examine the quality of the crystallized Si, Raman spectroscopy was done, shown in Figure 2c and d.

Both samples showed a transition from α-Si to poly-Si after the annealing process. The Raman data showed the crystallinity of the poly-Si of both samples was of high quality as it closely matched the crystallinity of commercial polycrystalline Si wafers.

To confirm the orientation of the crystallized Si, each sample was examined with x-ray diffraction, shown in Figure 3. The x-ray diffraction patterns confirmed that the Si was polycrystalline and exhibited some <111> orientation needed for vertical wire growth.

Wire Growth:

Samples were used as the base for patterned Si wire growth. Wire growth was achieved on Al-induced crystallization samples as seen in Figure 4. Wires grew in randomly oriented directions with some kinks due to the polycrystalline nature of the Si confirmed with x-ray diffraction.

Conclusion:

Al-induced crystallization was found to effectively crystallize α-Si as a low cost process. From scanning electron microscopy, it was found that the layer exchange process was still not complete after 40 hours of annealing. The annealed Si islands were found to be polysilicon from Raman measurements and x-ray diffraction. Samples were successfully used as a base for Si wire growth. Further optimization is needed of the Al-induced crystallization process.

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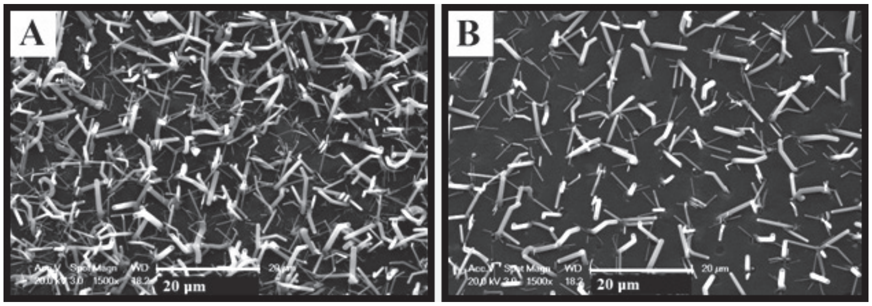

Figure 4: SEM images of Si wires grown on samples annealed for 24hrs. Image a) is Sample 1 and b) Sample 2.

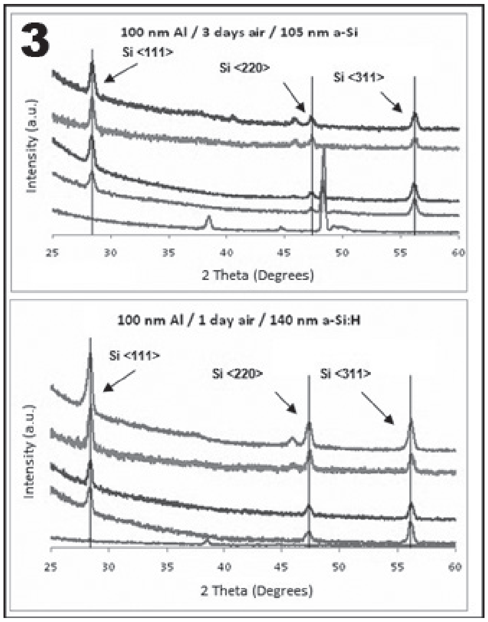

Figure 3: X-ray diffraction spectra of Samples 1 and 2 with increasing annealing times. The bottom spectrum is the as-deposited Al/α-Si. Following that is the 4hr, 10hr, 24hr, and 42hr anneal.