Demonstration of first ever metal-induced single crystal epitaxial thin film silicon solar cell

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We report the preliminary demonstration of the first ever metal-induced single crystal epitaxial thin film silicon solar cell.[1] As a key component to Solar-Tectic LLC's 1c-Si Eutectic solar technology, the demonstrated solar cell is a promising step towards the ultimate goal of achieving a breakthrough solar cell consisting of a single crystal thin film of silicon on an inexpensive substrate, such as glass or metal foil. Such a solar cell would allow for a reduction in costs by a factor of approximately three (not including BOS balance of system costs) while maintaining efficiency of conversion.[2]

A major cost component of photovoltaic cells is the cost of the substrate on which the semiconductor film capable of converting sunlight to electricity is placed. The most widely used substrate is single crystal silicon (or monocrystalline Si). These substrates developed in the microelectronics industry have been modified for application in photovoltaic technology. If a silicon film could be deposited on an inexpensive substrate, such as glass or metal foil, and with comparable quality as that found in silicon single crystals used in the microelectronics industry, the cost of photovoltaic technology would drop significantly.[2]

Here we report the success of a crucial step towards this goal: the demonstration of a single crystal thin film of silicon on sapphire substrate (Al203) at low temperature, e.g. below the softening point of glass (600˚C). Heteroepitaxial—single crystal—films of silicon have been successfully grown only on Al203 (sapphire) before. And until now these films have been grown at temperatures that are relatively

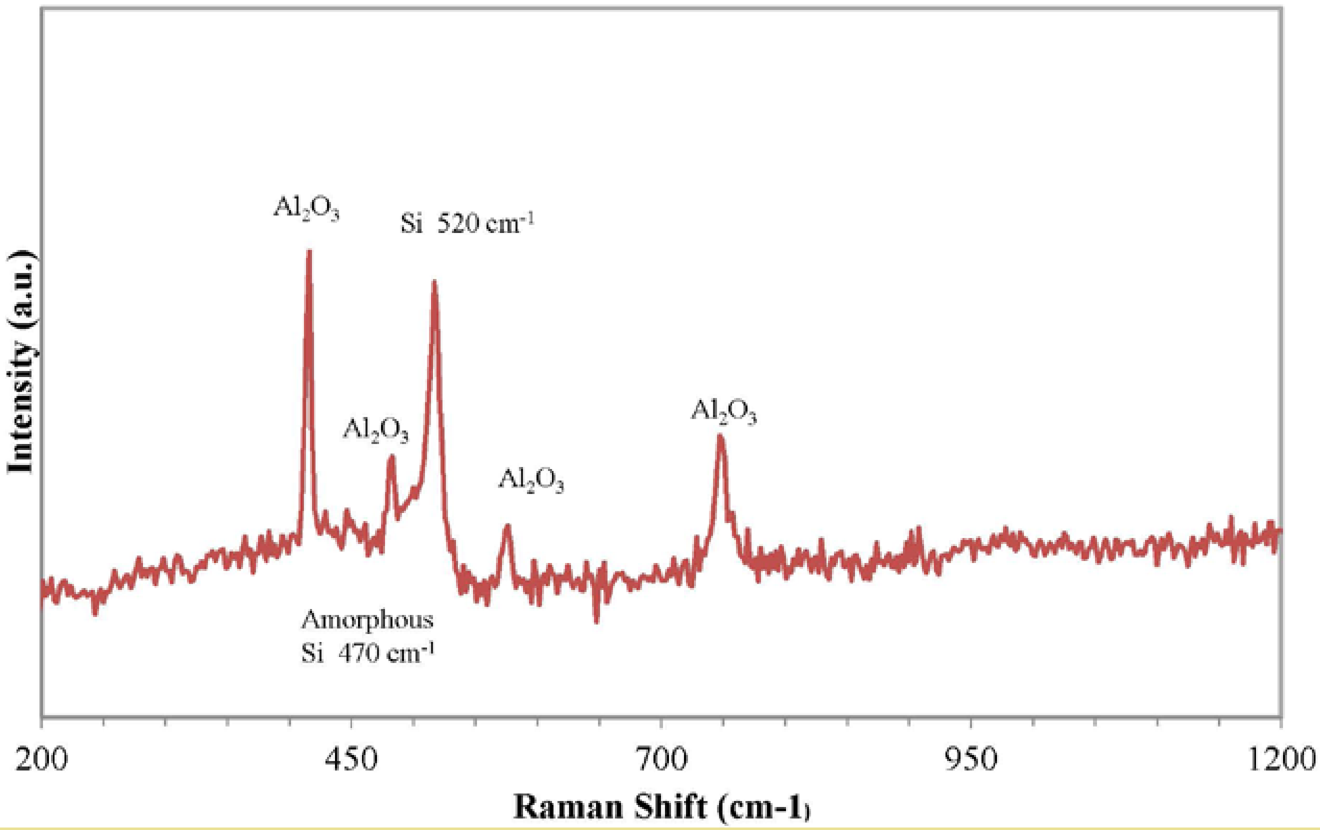

Figure 1. Raman spectrum of silicon on sapphire Al, Si deposited at 600˚C.

Figure 2. The samples. Left: Sample 1 (Al 600˚C/Si 600˚C). Middle: Sample 2 (Al 600˚C/Si 600˚C). Right: Sample 3 (Al 600˚C/Si 650˚C).

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Following one of several "recipes" disclosed in a patent application by the late Dr. Praveen Chaudhari, renowned materials scientist and winner of the 1995 United States Medal of Technology and Innovation, Solar-Tectic LLC commissioned the fabrication of a metal-induced heteroepitaxial layer.[2] That is, a thin film deposited from an Al-Si eutectic melt onto a sapphire (Al203) substrate.

This work was done under the supervision of Dr. RD Vispute at Blue Wave Semiconductors (BWS) in Maryland. Three such samples were made by electron-beam deposition (e-beam) and Solid Phase Epitaxy at BWS, two at 600˚C and one at 650˚C. (See *Figure 1*, showing Raman of 1 sample of Al-Si on sapphire).

All 3 samples were imaged at the National Renewable Energy Laboratory (NREL), Colorado, USA, with a simple microscope. (See *Figure 2*.)

The XRD of both samples 1 and 3 were similar and suggest (111)-oriented silicon. (See *Figure 3*).

To truly confirm epitaxy, a pole figure would need to be acquired—but given the similarity to previously published P. Chaudhari et al work[3], this step was postponed. In the figure there is a large peak from the sapphire substrate and, probably a few artifacts (narrow lines at ~21˚, line at 65˚). There is also a peak at ~38˚ that could be the aluminum part of the Al substrate holder.

The optical images of samples 1 and 2 look very smooth. Sample 3 had regular features that appear metallic under the microscope—it is likely that some of the Al remains in a metallic state. Sample 3 also had a smaller Si 111 peak—however, this is not a rigorous crystallographic analysis.

Samples 1 and 2 were diced into smaller pieces to fabricate 3 solar cells from them. The solar cells were made following standard NREL procedure but, importantly, without hydrogen passivation and pyramidal light trapping both of which can improve QE.[4]

The best results of these cells are: 2.86% efficiency, open circuit voltage (Voc) 449 mV, short circuit current (Jsc) 10.47 mA, and Fill Factor (FF) 63.93%. (See graphs in *Figure 4* on the following page.)

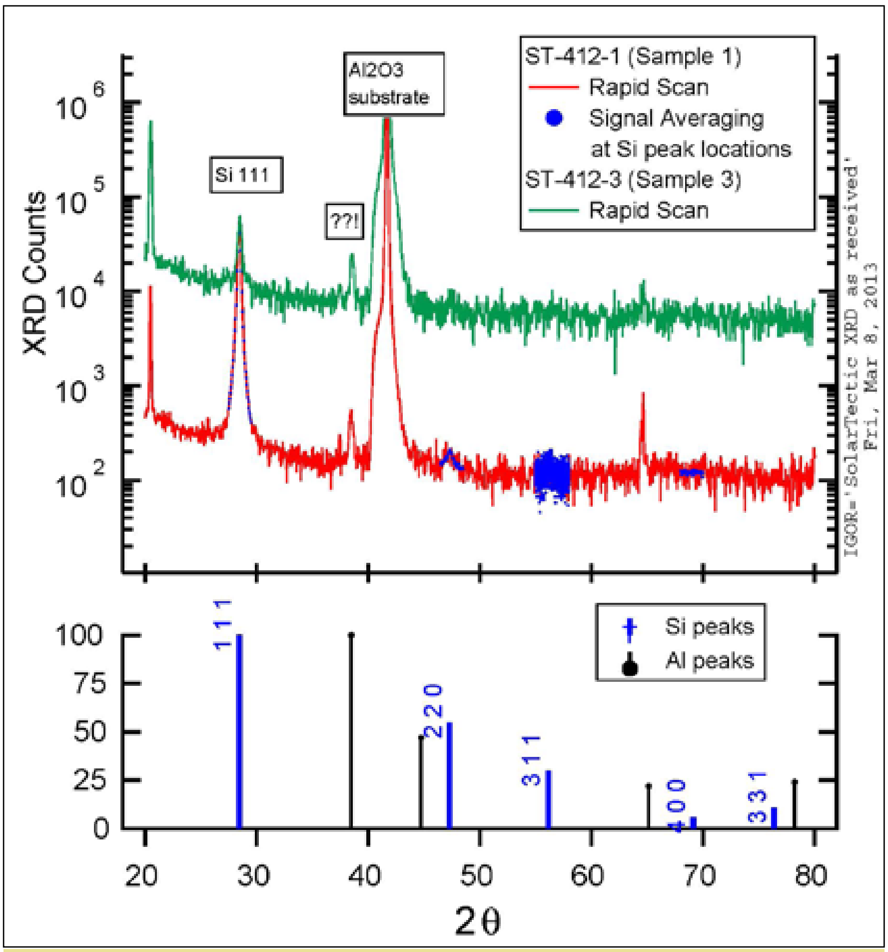

Figure 3. XRD of samples 1 and 2 (sample 3 was not used).

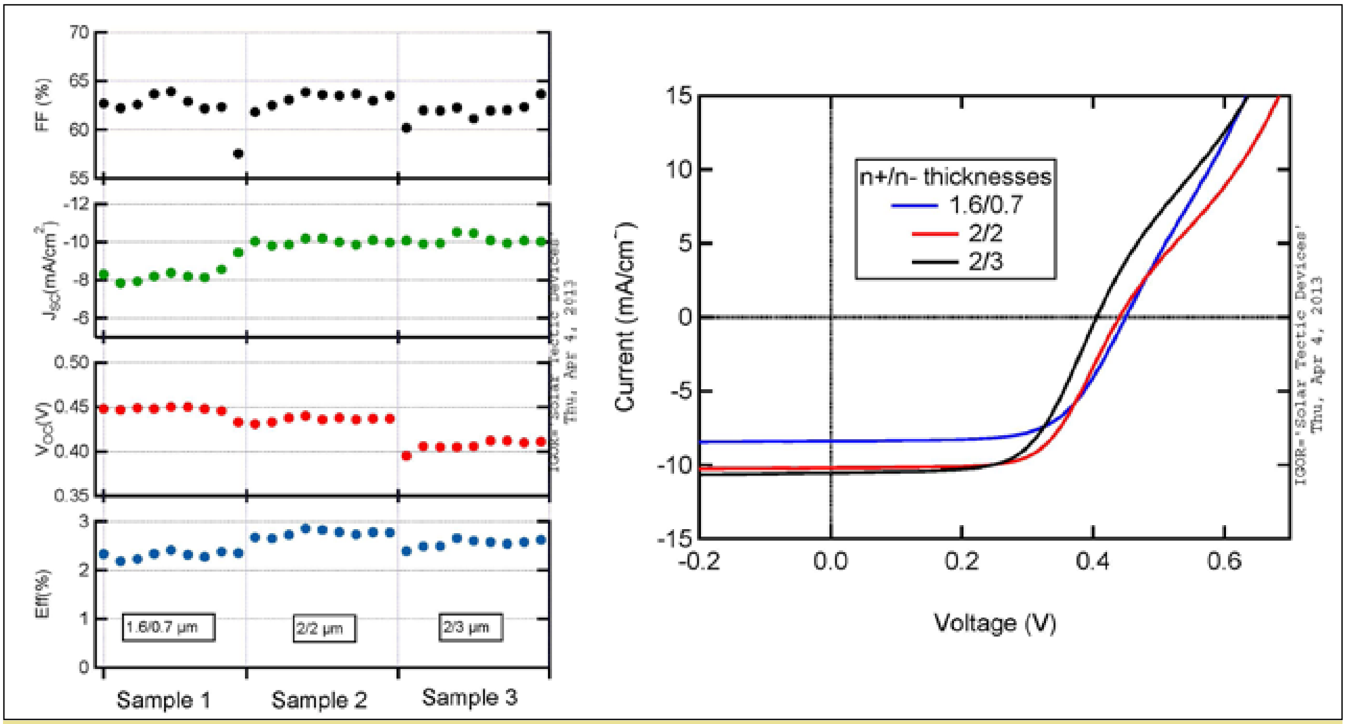

Figure 4. The results of the solar cells.

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The authors acknowledge Dr. Charles W. Teplin, Vincenzo Lasalvia and Bill Nemeth who used NREL's thin Si "seed and epitaxy" processes to fabricate solar cells from the heteroepitaxial Si on sapphire samples.

References

1. There have been and are a number of European projects doing similar work. From January 2002 to June 2005, the Hahn-Meitner Institute in Germany was the coordinator of the European Commission project METEOR: Metal-Induced Crystallisation and Epitaxial Deposition for Thin, Efficient and Low-Cost Crystalline Si Solar Cells. While efficient solar cells were processed using layers obtained from this project, the devices were polycrystalline, not single crystalline. They were also processed using ECRCVD and CVD, not electron-beam deposition as we have done. After METEOR, ATHLET was the continuation, followed today by PolySiMode and TopShot. It is the authors' understanding that up until now none of these projects has made single crystal Si from a eutectic film using e-beam. Apologies are extended if this not the case. Others have used metal induced crystallization for seed and heteroepitaxial solar cells, but to our knowledge there is no such demonstration of solar cells comprised of single crystal silicon.
2. P. Chaudhari, "Methods of Growing Heteroepitaxial Single Crystal or Large Grained Semiconductor Films and Devices Thereon", p.1, USPTO US 2010/0237272, 9/23/10.
3. P. Chaudhari et al, "Heteroepitaxial silicon film growth at 600C from an Al-Si eutectic melt", Thin Solid Films, 2010, pp. 5368-5371.
4. Teplin et al, "Pyramidal light trapping and hydrogen passivation for high efficiency heteroepitaxial (100) crystal silicon solar cells", Energy Environmental Science, 2012, p.8193.

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