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Ken Zweibel
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RE: NREL Subcontract # ADJ-1-30630-12

Dear Ken:

This report covers research conducted at the Institute of Energy Conversion (IEC) for the period Feb. 09, 2005 to Mar. 09, 2005, under the subject subcontract. The report highlights progress and results obtained under Task 3 (Si-based Solar Cells).

Task 3: Si Based Solar Cells

Safety upgrade and new equipment

For the past 6 months both the RF-PECVD and HWCVD Si deposition systems have been off-line while IEC has made extensive safety modifications during the installation of a multi-chamber DC plasma CVD system. The installation required the existing and new lab spaces to be upgraded to comply with current codes. All hazardous gases were removed from the building and thus, no Si depositions occurred during that time. In the past month, modifications and additions to the hazardous gas monitoring, sprinklers, emergency alarm interfaces, and ventilation were completed and gases were reinstalled in their cabinets. Several runs have been made in the original single chamber RF-PECVD system as well as in the new multi-chamber DC-PECVD system donated from BP Solar in 2003 as will be described below.

Grain enhancement of Si films using aluminum induced crystallization (AIC)

Work continued to analyze and model the grain enhancement due to AIC. This effort is based on the research of graduate student Ozgenc Ebil who defended his dissertation in February. A manuscript "Poly-Si seed layers prepared by in-situ Aluminum-induced crystallization" is prepared and will be submitted for publication next month.

New work on AIC is being initiated by graduate student Meijun Lu using a design of experiments (DOE) methodology. Si deposition is being planned by both HWCVD, as before, as well as e-beam evaporation.

The advantage of e-beam Si is that it avoids any H incorporation and is totally amorphous. Previous work by Ebil focused on deposition and Al-Si layer-exchange at 450°C, well below the Al-Si eutectic point of T_{eu}=577°C. Substrates were typically glass. The new work will extend the previous studies to other Si and Al configurations i.e., the inverse structure of Al on Si, other substrates i.e. 1737 glass (a high temperature glass from Corning), c-Si, and ceramic, and higher annealing temperatures, i.e. above the Al-Si eutectic. A series of Al-Si bi-layers have been prepared by e-beam evaporation, and ones on HWCVD are planned. Table 1 lists the variables to be studied. The DOE approach was used to limit the number of samples and annealing conditions needed to understand the critical dependencies and interactions. For both structures (Al/Si & Si/Al), a native oxide was allowed to form for 24 hours in air between the deposition of the Al and Si layers. The Si layers were 500 nm and the Al 400 nm to maintain a ratio of 1.2. Characterization will include AFM, SEM, glancing incidence XRD (GIXRD), variable angle spectroscopic ellipsometry (VASE), Raman and optical microscopy.

Variable	**Low (or 1st) value**	**High (or 2nd) value**
Structure	500 nm Si-on-400nm Al	400 nm Al-on-500nm Si
Annealing temperature	450°C (<T_{eu})	600°C (>T_{eu})
Annealing time	1 hr	8 hr

Table 1. Variables for DOE study of AIC annealing above and below the eutectic point.

Since there are k=3 variables with 2 values this leads to a 2^k factorial experimental design for each type of substrate. A complete randomized group of 2^k experiments on substrate 1737 glass was determined and shown in Table 2.

Samples on other substrates will also be studied. Together with the 2^3 factorial experimental designs on 1737 glass, we have made 24 samples as shown in Table 3. Note that there are more samples annealed at 600 than 450°C, which was intentional since we are more interested in focusing on the higher temperature. Additionally, a few samples will be annealed at 700°C to identify any benefit to annealing well above T_{eu}.

All 24 samples have been deposited, but only 4 samples have been annealed (the ones @450 ^oC, 1hr) and being analyzed. We are expecting to finish the annealing and sample characterization in near future.

Expt #	Annealing T (°C)	Time (hrs)	Structure
1	600	8	Si on Al
2	600	1	Al on Si
3	450	8	Al on Si
4	600	1	Si on Al
5	450	8	Si on Al
6	600	8	Al on Si
7	450	1	Si on Al
8	600	1	Al on Si

Table 2. Randomized 2^k design of annealing experiment.

Annealing T(°C)	Time (hrs)	Structure	Substrate
450	1	Si on Al	glass 1737
450	1	Si on Al	c-Si
450	1	Si on Al	ceramic
450	1	Al on Si	glass 1737
450	8	Si on Al	glass 1737
450	8	Si on Al	c-Si
450	8	Si on Al	ceramic
450	8	Al on Si	glass 1737
600	1	Si on Al	glass 1737
600	1	Si on Al	c-Si
600	1	Si on Al	poly-Si
600	1	Si on Al	ceramic
600	1	Al on Si	glass 1737
600	1	Al on Si	c-Si
600	1	Al on Si	ceramic
600	8	Si on Al	glass 1737
600	8	Si on Al	c-Si
600	8	Si on Al	poly-Si
600	8	Si on Al	ceramic
600	8	Al on Si	glass 1737
600	8	Al on Si	c-Si
600	8	Al on Si	ceramic
700	8	Si on Al	ceramic
700	8	Al on si	ceramic

Table 3. The 24 samples from the DOE design which have been deposited by e-beam evaporation and are presently being annealed.

Si-based solar cells

A series of doped amorphous and microcrystalline n and p layers as well as p-i-n devices were deposited in the single chamber RF-PECVD system to verify film properties after the lengthy shutdown and gas re-installation. Both a-Si and a-SiC p-layers were deposited. Two doping gas levels were evaluated for the n and p layers. Conductivity and optical absorption measurements are in progress. Preliminary results on 4 films are shown in Table 2. The light and dark conductivity and activation energy are very similar to previous results and indicate good bulk film electronic properties. In particular, the i-layer 41083-11 has a very low dark conductivity, high light-to-dark ratio, and a mid-gap activation energy, which are all consistent with very intrinsic, low defect film. The p-i-n solar cell is awaiting ZnO/Al contacts. The i-layer and the p-i-n device were co-deposited on Cr-coated glass substrates for SIMS. They will be sent to NREL to determine if impurity levels have been reduced as a result of reactor cleaning and new bake-out procedures.

Sample	film	Dark σ (S/cm)	Light σ (S/cm)	E_A (eV)
41083-11	a-Si i-layer	8E-11	2E-5	0.79
41084-11	a-Si p-layer	4E-4	5E-4	0.29
41085-11	a-SiC p-layer	8E-7	2E-6	0.40
41087-11	a-Si n-layer	2E-2	2E-2	0.19

Table 4. Electronic properties of doped and intrinsic a-Si films from the RF-PECVD system

An internal review of thin film Si solar cell device structures is in progress. Status and technical challenges of several approaches are being considered. This discussion will move the program in a new direction.

Best regards,

Robert W. Birkmire
Director

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