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PROCESS DEVELOPMENT

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Presentations on seven process development activities were made during this technology session. Also included in the session were three presentations on analytical subjects, and one on encapsulation as this material had relevance to PV-cell or module processing. A 30-min coffee break was included to allow time to attend a poster session on in-house research efforts.

Arco Solar, Inc., presented the status of pulsed excimer laser processing of PV cells. Laser annealing results were promising with the best AR coated cell having an efficiency of 16.1%. Better results would be expected with larger laser spot size because there was some degradation in open-circuit voltage (V_{OC}) caused by laser spot overlap and edge effects. Surface heating and photolytic decomposition by the laser was used to deposit tungsten from the reaction of tungsten hexafluoride and hydrogen. The line widths were 5 to 10 mils, and the depositions passed the tape adhesion test. Thinner lines are practical using an optimized optical system.

Another excimer laser processing presentation was given by Spire Corporation. Pulsed excimer laser annealing was successfully performed using a 50 W laser. Both polished and texturized cells were tried, however, there are serious problems with nonuniformity on texturized cells. A number of cells were produced and compared to diffusion furnace annealed cells. There was no clear economic advantage in using an excimer laser and there was a small penalty on average efficiency. The conclusion was that the excimer laser anneal process must be able to produce superior cells to be considered as a viable process option.

Diffusion barrier research at Caltech has been focussed on lowering the chemical reactivity of amorphous thin films on silicon. An additional area of concern is the reaction with metal overlays such as aluminum, silver, and gold. Gold was included to allow for technology transfer to gallium arsenide PV cells. Amorphous tungsten nitride films have shown much promise. Stability to annealing temperatures of 700, 800, and 550°C were achieved for overlays of silver, gold, and aluminum, respectively. The lower results for aluminum were not surprising because there is an eutectic that can form at a lower temperature. It seems that titanium and zirconium will remove the nitrogen from a tungsten nitride amorphous film and render it unstable. Other variables of research interest were substrate bias and base pressure during sputtering.

The MOD work at Purdue is nearly complete. Basic material efforts have proven to be very successful. Adherent and conductive films have been achieved by the investigator as well as other laboratories. A silver neodecanoate/bismuth 2-ethylhexanoate mixture has given the best results in both single and double layer applications. Another effort is continuing to examine the feasibility of applying MOD films by use of an ink-jet printer. Direct line writing would result in a saving of process time and materials. So far, some well defined lines have been printed. Future emphasis will be on reducing line width and improving ink characteristics.

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Efforts by the Westinghouse Electric Corporation Research and Development Center were aimed at achieving a simultaneous front and back junction. Lasers and other heat sources were tried. Successful results were gained by two different methods: laser and flash lamp. Polymer dopants were applied to both sides of dendritic web cells. Rapid heating and cooling avoided any cross contamination between the two junctions after removal of the dendrites. Both methods required subsequent thermal annealing in an oven to produce maximum efficiency cells.

Another Westinghouse effort has been directed toward metal patterning by use of an argon laser and Purdue's silver/bismuth MOD material. Excellent cell efficiencies were seen along with good ohmic contact and adhesion. Line widths down to .002 in. were achieved. The only remaining process drawback is line thickness. At present, a secondary electroplating process step is required to obtain sufficient conductivity.

Superwave Technology reported on their microwave-enhanced plasma deposition experiments. Advantages foreseen for use of microwaves are: higher electron plasma density by about 4 orders of magnitude, long species lifetime to allow separation of reactor and plasma generation, more control of deposition kinetics with less substrate damage, controlled film gradients or doping, lower power requirements, and lower reactive gas consumption. The feasibility of this process was demonstrated by the formation of silicon and silicon nitride films.

An updated version of the Solar Array Manufacturing Industry Costing Standards (SAMICS) was presented by the FSA Project Analysis and Integration Area (PA&I) Group. This version will run on the IBM PC-XT or compatibles, and embodies user friendly input screens and numerous "help" options. Use of this microcomputer version will still produce the "old" main frame direct cost driven analysis, although at some cost in turnaround time. A typical simulation will take about 4 h. The program allows for unattended report printout. Also available is the IBM PC (or compatibles) version of the Improved Price Estimation Guidelines (IPEG). This program allows rapid analysis of process variables using SAMICS-generated coefficients.

Another PA&I Group presentation was a life-cycle cost analysis of high-efficiency cells. Although high-efficiency cells produce more power, they also cost more to make and are more susceptible to array "hot-spot" heating. Three different computer analysis programs were used: SAMICS, PVARRAY (an array failure mode/degradation simulator), and Lifetime Cost and Performance (LCP). The high-efficiency cell modules were found to be more economical in this study, but parallel redundancy is recommended.

Springborn Laboratories, Inc., has continued their evaluation of the EVA encapsulation system. This work is part of the materials baseline needed to demonstrate a 30-year module lifetime capability. Process and compound variables are both being studied along with various module materials. Results have shown that EVA should be stored rolled up, and enclosed in a plastic bag to retard loss of peroxide curing agents. The TBEC curing agent has superior shelf life and processing than the earlier Lupersol-101 curing agent. Analytical methods were developed to test for peroxide content, and experimental methodologies were formalized.

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The poster session covered two areas of in-house research: amorphous-silicon deposition and process-variable sensitivity analysis. Amorphous-silicon deposition efforts have focussed on the basics of large chamber radio frequency (RF) plasma deposition. Significant findings include means to inhibit formation of silane polymers and the calculation of a monosilane diffusivity value one order of magnitude higher than most published values (better agreement with textbook values).

Process variable sensitivity analysis was used to define useful regions of substrate material characteristics. A region of practical material and processing specifications was defined to show areas where process research activities would have the maximum effect.