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April 19, 2004

Dr. Harin Ullal, MS3212
National Center for Photovoltaics
National Renewable Energy Laboratory
1617 Cole Blvd
Golden, CO 80401

Re: Twenty-Eighth Monthly Report #NDJ-2-30630-11

Dear Harin,

This letter comprises the monthly technical status report for ITN's subcontract # NDJ-2-30630-11, "Plasma-Assisted Coevaporation of S and Se for Wide Band Gap Chalcopyrite Photovoltaics", under the Thin Film Partnership Program. The reported work was performed during the fourth month of phase 3 for this contract (twenty-eighth month overall), which is March 7, 2004 through April 7, 2004. This report describes activities performed by ITN, as well as those performed by lower-tier subcontractor Colorado School of Mines (CSM), under the direction of Dr. Colin Wolden.

1. Program Goals and Approach

Our primary objective under this program is to determine if the chalcogen in CIGS co-evaporation can be delivered more effectively by activation with a plasma. Possible advantages of plasma-assisted co-evaporation (PACE) are

- increased utilization of chalcogens,
- decreased deposition temperatures,
- decreased deposition times, and
- increased ability to tailor S/Se ratio.

University researchers at CSM are developing and testing the fundamental chemistry and engineering principles. Industrial researchers at ITN are adapting PACE technology to CIGSS co-evaporation and validating PACE process for fabrication of thin film PV. In_2Se_3 films, which are used as precursor layers in high-efficiency CIGS depositions, were used as the first test case for the examining the advantages of PACE listed above, and significant advantages were demonstrated. Presently, the examination is being extended to the complete high-efficiency three-stage CIGS co-evaporation process.

2. Incorporation of PACE Sources Into Three-Stage Deposition

This month, important progress toward full incorporation on the PACE source into three-stage CIGS deposition was made. In the three-stage bell jar, adequate uniformity, rate control, and positioning of flux was demonstrated.

Source angle was adjusted so that flux distribution is centered at the substrate center. Because the PACE source axis is not perpendicular to the substrate, and the flux falls off both with distance from the nozzle and angle off-axis, the source axis must be directed at a spot slightly beyond the substrate to center the flux distribution. The required angle for flux centering agrees well with calculations of the flux distribution, as reported in previous months.

Uniformity over the substrate was demonstrated to be adequate. Figure 1 shows relative flux as function of position over the substrate, during the most recent source test. Uniformity is ± 20%, and has been demonstrated to be reproducible over several depositions. This uniformity is within limits needed to test chalcopyrite utilization in the CIGS process with and without plasma-assist. The uniformity is better than that obtained with the currently-utilized traditional tantalum baffled-box evaporation boat.

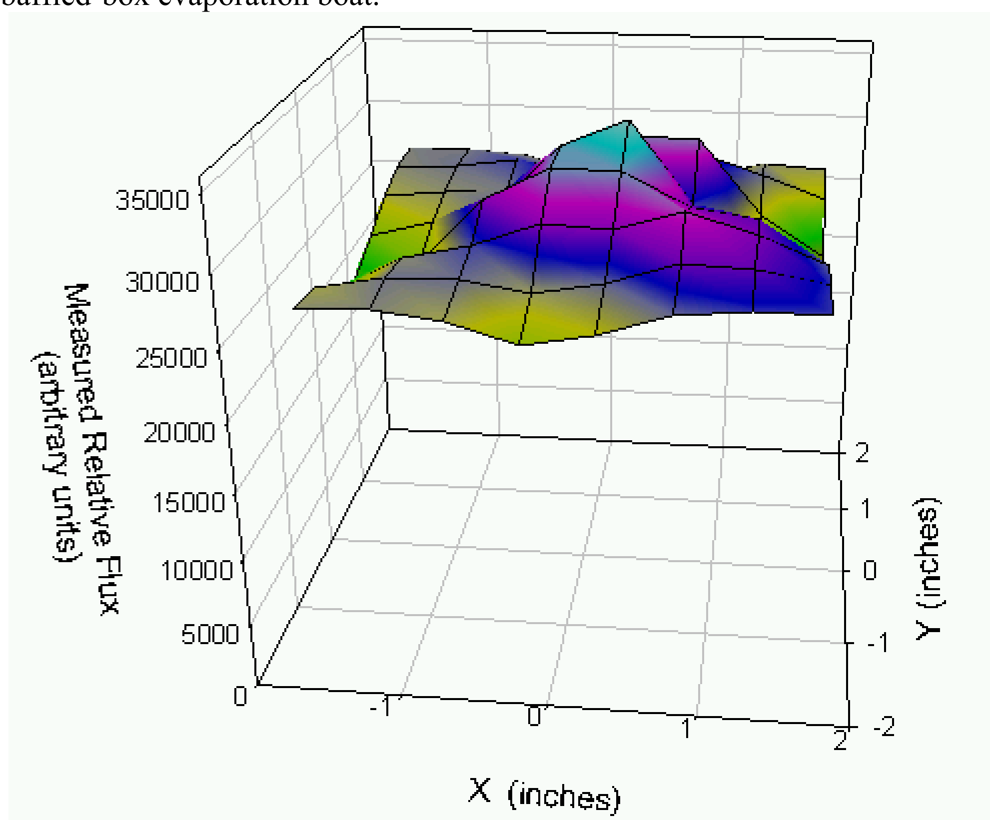

Figure 1: Flux versus position from PACE source testing in three-stage bell jar.

Rate control of the PACE source is close to meeting requirements for three-stage CIGS evaporation. Figure 2 shows Se rate as a function of time (pink line) for the PACE source in a recent test in the three-stage bell jar. During this test, the first 2000 seconds of data acquisition was used as warm-up time for the source, then the source was set at a typical stage 1 rate for about 12 minutes, and at a typical stage 2 rate for about 8 minutes, as indicated by the blue line. The source was operated using the same automated scripted recipes used for CIGS depositions/ Next month, slight adjustments will be made to the control parameters to shorten the warm-up time and decrease the magnitude of the oscillations, and the PACE source with be operated simultaneously with the Cu, In, and Ga sources.

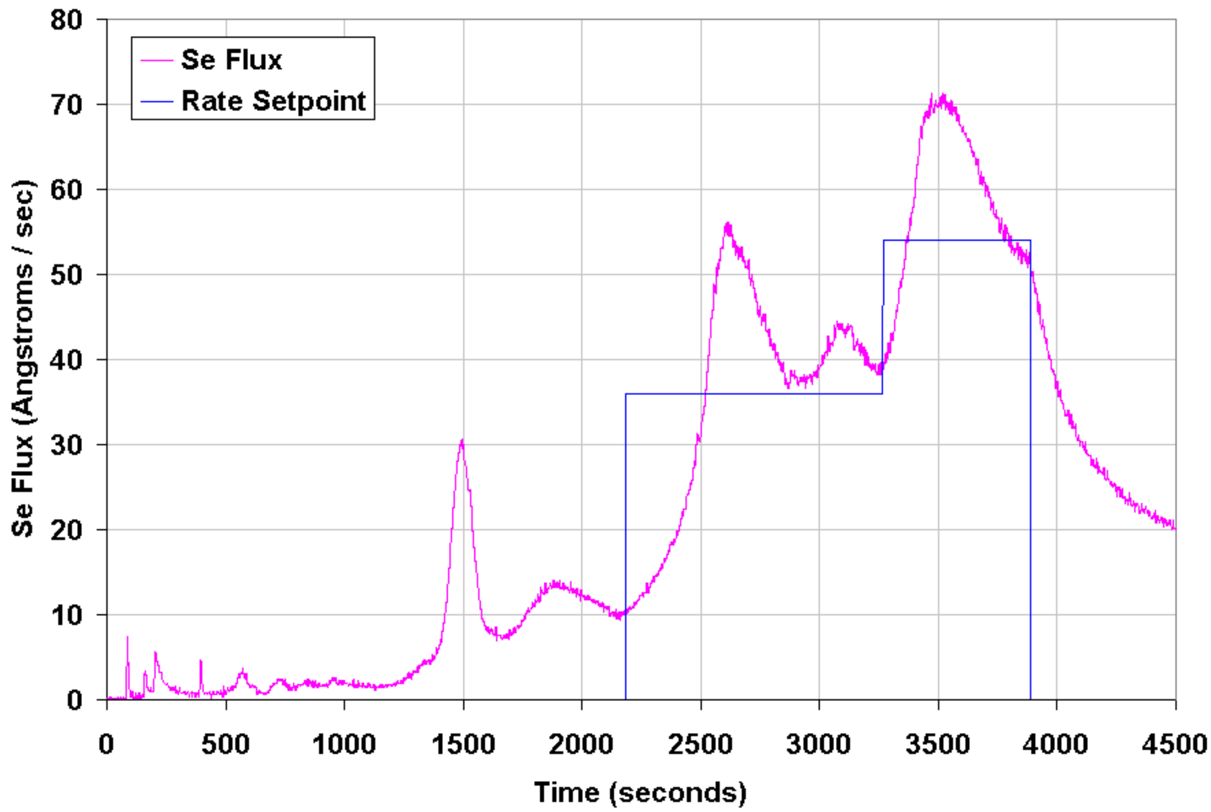

Figure 2: Se rate as a function of time for PACE source test in three-stage bell jar.

A final area of work being conducted for full incorporation of PACE into three-stage CIGS is the operation of RF electronics. Improvements were made this month to reduce reflected power, with the source operated in a test configuration outside the chamber. Further improvements are still needed before RF is added to the three-stage process.

3. Plasma-Assisted Film Kinetics

Activities related to the kinetics of plasma-assisted CIGS formation have proceeded in two areas:

- *Determination of the process window for In_2Se_3 formation in the PACE process as a function of T_s and the Se/In ratio.* The main efforts this month were modifying the PACE chamber to allow water-cooling to the ICP coil. Previously, stable plasmas were obtained in the PACE chamber, but the coil heated significantly leading to long term instability. The plasma has been regained and plans are in place to operate the newly-configured selenium source shortly.

- *Determination of the degree of temperature reduction that can be achieved with plasma processing for post-deposition selenization of Cu-In-Ga samples in the benchtop apparatus.* Plasma-selenized films were characterized by SEM and EDS. The films appear polycrystalline, with an approximate 2 μm grain size. They are of the correct composition for CIGS.

4. Team Activities

ITN and CSM participate in CIS team activities. This month, conclusions from new drive level capacitance (DLCP) data from NREL were incorporated into an outline of absorber sub-team activities. The DLCP conclusions complement the existing material nicely. The process of attaching text to the discussion, conclusions, and introduction sections was begun. When text is attached to these critical sections, the outline will be easier to read and will be distributed to all absorber sub-team participants for comments and revision. The outline should be ready for review in either May or June.

Best Wishes,

Ingrid Repins

Ingrid Repins
Principal investigator
ITN Energy Systems

Cc: Ms. Carolyn Lopez; NREL contracts and business services
Dr. Colin Wolden; CSM technical lead