BAPVC 2013 Annual Project Report

Project Title: Laser Processing to Improve CdTe Thin Film Photovoltaics Efficiency and Manufacturing

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Summary

In year 1, the project reached its overall milestone goal by demonstrating two of the four individual milestones as detailed in the statement of project objectives (SOPO). The back contact resistivity of CdTe was reduced by 20x using nanosecond ultraviolet laser irradiation (Objective C). Grain growth in CdTe layers was demonstrated by sub-bandgap infrared laser annealing of nanoscale CdTe grains (Objective A). Additionally, preliminary demonstrations show modified CdTe properties after IR laser CdCl treatment (Objective B).

Key Accomplishments

First, experimental verification of a 20x reduction in contact resistivity moves the ultraviolet laser produced back contact thrust to TRL 3. These data confirm predictions made as part our work for TRL 2 showing that a Te rich surface is created. Figure 1 shows the effects of single, 248 nm, 20 ns laser pulses of varying energy densities on contact resistivity. A paper on the material and device effects of cells with laser irradiated back contact treatment has received positive reviews at APL. Next, efforts in recrystallization of small-grained, low quality CdTe have progressed to TRL 2. The project formed a collaboration with Dr. Naba Paudel and Prof. Yanfa Yan's group at University of Toledo to obtain sputtered CdTe with smaller grains. Figure 2 shows the results of crystal coherence length calculated from the (111) CdTe x-ray diffraction peak for samples annealed with a sub-bandgap IR laser. Above a threshold power density, structural defects are annealed out and below this power threshold the results are statistically indistinguishable between starting and annealed material. We are pursuing leads on the optoelectronic effects also.

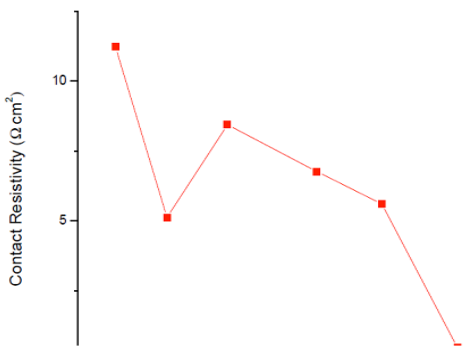

Figure 1: Contact resistivity of UV laser pulse treated polycrystalline CdTe.

In early Dec 2013 we discussed with Michael Woodhouse of NREL the possible advantages for laser processes in CdTe manufacturing and discussed specifically the laser back contact treatment since that was the most complete topic we have demonstrated. It was realized that the cost of the glass dominates the cost model and that replacing the wet back contact preparation step with a UV laser one would at best yield a small cost advantage, so unless reliability or efficiency advantages could be realized the capex for laser tools may not be justified for that step. One avenue for doing this would be to investigate if the rapid thermal quenching induced by ns laser annealing may allow the use of dopants other than Cu, the high mobility of which is believed by some to be involved in panel degradation over time. Also, a key advantage of laser or other transient annealing would be to allow the heating for example during the $CdCl_2$ treatment to be confined to the CdTe layer and thus allow the use of non-glass substrates.

Additionally, a method for depositing CdTe from aqueous solution using lower capital intensive equipment was developed and preliminary IP disclosure made within the University of

Utah. Further work is necessary to demonstrate and develop this process. A finite element model for optical power input and heat flow, including evaporative cooling from surface evaporation of Cd and Te, was developed to predict temperature within the sample and surface stoichiometry. Also, preliminary results have been obtained using a sub-bandgap infrared laser to improve module-quality materials. Experiments to accomplish the all-important $CdCl_2$ treatment step with laser annealing have been carried out, which show a clear difference of laser treatment in the presence of Cl. The use of higher-aspect ratio laser spots has been put into practice in order to give better spatial homogeneity to the laser treatments. Lastly, an *in situ* monitoring method has been developed. Current work aims determine the physical processes responsible for the observed time-dependent changes.

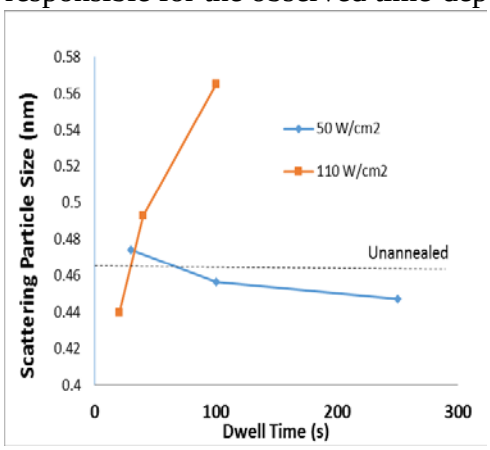

Figure 2: Crystallite size determined from x-ray diffraction vs. laser dwell time using a sub-bandgap 1064 nm laser.

Future Work

The commercial benefits of the pulsed laser treated back contact probably depend on whether or not the process will lead to higher efficiency or reliability. Experiments are underway with Prof. Ferekides' group to optimize parameters and annealing conditions to maximize solar cell performance. Assessments of reliability could be added to our project scope by the new RFP. The laser recrystallization efforts, which promise to reduce capital intensity of manufacturing by allowing for lower cost deposition methods, will move towards TRL 3 by using above-bandgap lasers, improved and verified temperature modeling, and material characterization. The $CdCl_2$ treatment step is known to play a role in grain growth for small-grained CdTe and thus the grain growth and $CdCl_2$ treatment processes may become intertwined. Investigation into the optoelectronic (doping and minority carrier lifetimes) of laser annealed and laser $CdCl_2$ treated films will commence towards an end of increased module efficiency. Laser doping and alloying at the back contact of CdTe is a separate thrust of our BAPVC proposal and plans have been made to pursue this research avenue early in the next year. Coherent, Inc. continues to support this project with the loan of fiber coupled lasers. Beam combining will be used to form high aspect ratio laser beam to anneal larger areas for the same scanning velocity to minimize takt time.

Manpower is the main bottleneck at the U of Utah to accelerating the movement of these promising early results on two of the laser processes towards industry readiness ahead of schedule and to assessing and investigating the other SOPO proposed laser processes. The addition of additional funds for 1 or more graduate students to this project would greatly accelerate progress and provide continuity of the project upon the eventual departure of the current postdoc (expected within a 1-2 year time horizon). A talented student is wrapping up a MS degree on laser annealing of CIGSe within the group and could begin immediately. With additional manpower, we could also take on topics addressing reliability effects of our laser processes, laser controlled intermixing at the CdS/CdTe interface decoupling it from $CdCl_2$ treatment, SILAR-like deposition of CdTe for lower capex, and/or laser annealing on non-glass substrates. Lastly, at the last meeting we initiated a trial experiment with Ali Javey's group to assess the efficacy of laser doping of their multicrystalline InP in order to make devices.