2018 CdTe Device Workshop
University of Toledo, November 1/2, 2018

This year's two-day CdTe Device Workshop was held on the University of Toledo campus with organization assistance from First Solar and Colorado State University. Similar to the 2017 Workshop, Day 1 had 18 presentations and was devoted to sharing results from the past year. Day 2 was primarily used to discuss future plans and priorities, and most importantly, it to lay the groundwork for collaborative projects. Slides from the presentations were not distributed as a package, but have generally been available by individual request.

The workshop this year was again focused on the device aspects of CdTe photovoltaic technology. It was by invitation with 26 participants and a small number of additional attendees, which seemed appropriate for productive interaction. Besides the organizing institutions, there were participants from the National Renewable Energy Laboratory, Reel Solar, Lucintech, University of Utah, University of Illinois at Chicago, Washington State University, Texas State University, Colorado School of Mines, Swansea University, and the University of Verona. It was particularly pleasing that three U.S. CdTe companies were represented.

Many results from recent work and suggestions for focus in the near future emerged from the workshop. The summary report here, which is not intended to be comprehensive, elaborates on some of the areas that the participants deemed both important and practical to achieve.

25% Efficiency Target. There was consensus that the CdTe community should focus on a 25% efficiency target for the relatively near term. Alternative strategies to get there were discussed, and it was recognized that a combination could the push the efficiency still higher. Note that there is an implicit assumption that the basic superstrate, single-junction structure with a CdSeTe layer in front of the CdTe will continue and that each of the approaches described below can be commercially implemented without major changes in current manufacturing processes.

- Increased carrier concentration. Several groups are working to increase the absorber hole density through substitutional doping with group-V elements, especially arsenic. An increase in carrier density of two orders of magnitude should increase voltage by slightly over 100 mV, which would provide the needed efficiency increase over the current record cells. Work to date

shows that the hole density can be increased by this amount, but it is not yet demonstrated that the increase has been accomplished without the dopant atoms also forming defects that compromise the bulk lifetime. The challenge for the community is to find the optimal dopant quantity, profile through the absorber, and process steps for its incorporation.

- Bifacial cells and panels. This approach has a similar potential for efficiency increase, in this case through the current. It has shown promise with CdTe cells, but is not as actively under current investigation as the doping projects. The straightforward principle is that if the reflected light from the ground or other panels that strikes the back side of a panel produces additional current, this increase can be 10% or greater. The amount of light available in different array configurations can be fairly easily determined, but the challenge for the device community is to design a back contact that is transparent and an absorber structure that collects a large fraction of the carriers generated near the rear of the cell.
- Electron reflection. Electron reflection at the back of a CdTe cell has the potential to increase both current and voltage by reducing the fraction of electrons that are lost at the rear of the cell. There has been some demonstration that each can be increased by a modest amount, but not at the level to significantly enhance efficiency. This strategy has some similarity to doping at the rear of the cells, but also requires that an electric field is maintained throughout the absorber under operating conditions and thus the absorber must be sufficiently thin to remain fully depleted.

Back Contact. The back contact remains a key issue for current CdTe cells as well as for any of the configurations described above. The basic problems are the mismatch of the CdTe valence band with the workfunction of most metal contacts and excessive interfacial recombination sites. The most successful approach to date appears to be a layer of Cu-doped ZnTe, but a Te or Te-rich layer at the back has also been effective. Nevertheless, the combination of residual band bending and interfacial defects continues to compromise performance, and the contact is likely to benefit from exploration of alternative layers and smoother transitions.

Actionable Secondary Metrics. In addition to metrics that follow directly from current-voltage curves, a number of other quantities are intuitively related to device performance, but often the relationship is less specific than desirable. Examples would include bulk and interfacial recombination parameters, distributions of elements, features in microscopy, luminosity, carrier densities, and band offsets. The Workshop participants saw merit in building tighter relationships of such quantities to performance and in utilizing them more frequently. In many cases even relatively simple device simulations could be more helpful, and in others the reduction of measured data to solid metrics could be much firmer. This area is particularly ripe for collaboration among labs, since individual ones often do not have the full breadth of equipment and expertise.

Community Synergy. The direct benefit of the Workshop is that many in the CdTe research community now know better what each other has been achieving and have picked up additional ideas, large and small, that can assist with their own programs. Less directly, but equally important, meeting together for two days increased the comfort level of the participants for discussing inconclusive results and for follow-up and collaboration during the coming year.

Thanks. The participants are particularly grateful to the CdTe researchers at the University of Toledo for the logistics and attention to detail that greatly facilitated the Workshop and to the McMaster endowment for providing the food and refreshment that further enriched the event.

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