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TEM-based Cathodoluminescence of a Selenium-alloyed CdTe Solar Cell

Thomas Fiducia[1], Ashley Howkins[2], Ali Abbas[1], Budhika Mendis[3], Amit H. Munshi[4], Kurt Barth[4], Walajabad S. Sampath[4], and John M. Walls[1]

[1]Loughborough University, Loughborough, UK. [2]Brunel University, Uxbridge, UK. [3]Durham University, Durham, UK. [4]Colorado State University, Fort Collins, Colorado, USA.

Abstract — **Since 2015, commercial sample holders have been available that enable cathodoluminescence imaging of semiconductors in the TEM. Despite this, issues with low signal have meant that high resolution TEM-CL imaging has so far not been achieved on a solar cell. Here, we use xenon ion milling and cryogenic sample cooling to boost signal from the TEM foil, enabling high resolution CL imaging of a bilayer CdSeTe/CdTe solar cell for the first time. The results show that selenium has a passivation effect on grain boundaries in alloyed CdSeTe material, helping to explain the superior performance of CdSeTe solar cells.**

I. Motivation and Summary

Thin-film solar cells such as cadmium telluride (CdTe) have a high defect density because of their fast deposition, small grain sizes, and closely spaced interfaces. This means that it can be difficult to identify which defects are most harmful to cell performance. As such, techniques that enable high resolution characterisation of absorber electronic properties, such as SEM-based cathodoluminescence (SEM-CL), have emerged as key tools in improving the efficiency of thin-film solar cells. However, there are some limitations to the use of SEM-CL for solar cell characterisation. Firstly, the interaction volume of the electron beam with the sample is relatively large at >250 nm, which limits the maximum resolution of the technique [1]. Secondly, it can be difficult to correlate the SEM-CL maps to sufficiently high resolution microstructural and elemental maps in the SEM, which is key for helping to attribute CL variations to the defects that cause them [2].

Cathodoluminescence measurements on thin foils in the TEM have the potential to help address both of these issues, because the electron beam-sample interaction volume is much smaller, enabling higher resolution imaging, and because the resulting images can be directly correlated to high resolution TEM micrographs of material microstructure and TEM-EDX maps of material composition. Despite this promise, and the availability of commercial TEM-CL holders, the technique has not been successfully applied to solar cell characterisation because of problems with low signal [3].

In the work presented at the conference, we use xenon ion milling and cryogenic sample cooling to increase the luminescence signal form the sample, enabling TEM-based CL imaging of a solar cell for the first time. The results show that as well as improving the optoelectronic properties of CdTe grain interiors, which has recently been discovered, selenium alloying significantly reduces recombination at grain boundaries in alloyed CdSeTe. This helps to explain the superior performance of selenium-alloyed CdTe solar cells, and suggests routes for further efficiency improvement such as through increasing the concentration of selenium at grain boundaries.

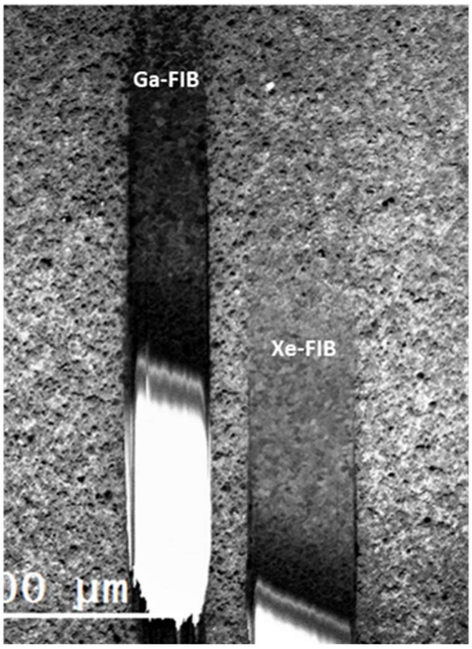

Fig. 1. SEM-based CL map of the luminescence intensity from Ga-milled and Xe-milled bevels, showing brighter luminescence from the Xe milled bevel.

References

[1] J. Moseley *et al.*, “Cathodoluminescence analysis of grain boundaries and grain interiors in thin-film CdTe,” *IEEE J. Photovoltaics*, vol. 4, no. 6, pp. 1671–1679, 2014.

[2] C. Li, J. Poplawsky, Y. Yan, and S. J. Pennycook, "Understanding individual defects in CdTe thin-film solar cells via STEM: From atomic structure to electrical activity," *Mater. Sci. Semicond. Process.*, vol. 65, no. June 2017, pp. 64–76, 2016.

[3] B. G. Mendis, A. Howkins, D. Stowe, J. D. Major, and K. Durose, "The role of transition radiation in cathodoluminescence imaging and spectroscopy of thin-foils," *Ultramicroscopy*, vol. 167, pp. 31–42, 2016.