NovaZOlar
All-non-Vacuum Processed ZnO-based Buffer and Window Layers for CIGS Solar Cell Technology

Project Duration: 06.2014 to 10.2016
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Publishable Summary

The $Cu(In,Ga)Se_2$ (CIGS) thin film solar cell technology has made a steady progress within the last decade by raising the conversion efficiency to 22.6% on laboratory scale, thus exceeding the highest efficiency for polycrystalline silicon cells, whereas standard-size CIGS modules achieve efficiencies of up to 16.5%. High efficiency CIGS cells employ the so-called buffer layer of CdS deposited by chemical bath deposition (CBD), and its presence and, importantly, treatment and utilization of Cd-containing waste present a serious environmental concern. A second potential bottleneck is the transparent conductive oxide (TCO) layer of i-ZnO/Al:ZnO, which is deposited by vacuum sputtering, whereby a non-vacuum deposition of TCO is technologically attractive.

The overall project goal was to develop a combination of Cd-free buffer and TCO material based on one material – ZnO – where the Zn(S,O) buffer is followed by a solution deposited Al:ZnO TCO contact. Four national sub-projects from Switzerland (Empa and Flisom AG), France (CNRS and EDF), Germany (ZSW and Manz) and Spain (IREC) participated in this project, which included an intense exchange of samples and knowledge for collaborative experiments. Within the consortium, the technology assessments and cost analysis were possible for both in-line fabrication on rigid glass (Manz) and roll-to-roll fabrication on flexible polymer substrates (Flisom).

For Cd-free Zn(S,O) buffers a world-record efficiency of 21.0% has been achived. A high-rate industrially relevant process for Zn(O,S) deposition was developed and implemented on 30x30 cm^2 mini-modules yielding up to 13.4% efficiency. The new high-rate Zn(O,S) approach offers a significant cost reduction in comparison to the standard thiourea route and is comparable to that of CdS. For solution-grown doped ZnO the highest cell efficiency was 18.3%, approaching the sputtered reference, whereas an effieicncy of 14.3% was possible for the solar cell made only from atmospheric processes (except the back contact). The TCO contact could be grown directly onto the Zn(O,S) layer yielding up to 16% conversion efficiency. The solution TCO was also implemented into flexible CIGS solar cells with up to 13.8% efficiency and mini-modules. The scale-up of the solution TCO process would, however, result into a cost increase of about 40% compared to the sputtered reference, which is caused by the need for thicker TCO layers imposing a long deposition time of ca. 1 hour. Finally, an experimental Raman setup has been designed for fast monitoring and non-destructive qualitative assessment of solutions and deposited layer to ensure controllable industrial processes with a high-yield.

The overall impact of this project on the current CIGS technology is to eliminate Cd-containing buffer layer in order to secure the compliance of the CIGS photovoltaic panels with any future restrictions for the use of Cd-containing components or their disposal.

Project consortium

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Participating countries and financing:

Country	**Number of organisations involved**	**Project costs in EUR**	**Public funding in EUR**
Switzerland	2	533'338	400'000
France	3	327'642	293'642
Germany	2	547'181	411'091
Spain	1	181'527	114'000
Total	*8*	*1'589'688*	*1'218'733*

Funding agencies involved and contract

Funding Agency	**Contract N° and Title**
Bundesamt für Energie (BFE)	SI/501100-01, Solution deposited ZnO-based front contacts for CIGS solar cells
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Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME)	1405C005, Electrodeposited CIGS solar cells with all-solution Cd-free buffer and window layers
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Bundesministerium für Wirtschaft und Energie	0325749B, Entwicklung flüssigprozessierter ZnO-basierten Puffer- und Kontaktschichten für CIGS-Solarzellen
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Ministerio de Economía y Competitividad	PCIN-2013-193, Nuevos procesos sin vacío para capas "buffer" y ventana basadas en ZnO en tecnologías de células solares de CIGS