POINT CONTACTS IN PASSIVATION LAYERS FOR AN ENHANCED PERFORMANCE OF THIN FILM SOLAR CELL BASED ON WIDER-BAND GAP CHALCOPYRITES

R. Nürnberg[1], N. Allsop, J. Klaer, F. Wünsch, N. Wanderka, F. Bertram[2], J. Christen[2],
M. Ch. Lux-Steiner, Th. Schedel-Niedrig
Hahn-Meitner-Institut Berlin GmbH, Germany
[1]Weierstraß-Institut Berlin, Germany
[2]Otto-von-Guerike-Universität Madgeburg, Germany

In contrast to the highly efficient low-band gap Cu(In,Ga)Se_2 chalcopyrite based thin-film solar cells, the photovoltaic performance of the wider band gap $CuInS_2$ and $CuGaSe_2$ chalcopyrite based thin-film solar cells is limited by the recombination at the heterojunction chalcopyrite-window-interface (window layer: transparent conducting oxide (TCO) usually CdS/iZnO/n-ZnO). In principle, the heterojunction should exhibit a high density of defect states at this interface due to lattice mismatch but, nevertheless, the low-band gap cells are dominated by bulk rather than interface recombination which has been explained by a low interface recombination velocity and/or an n-type chalcopyrite surface (inverted surface and buried interface) [1]. In the wider-band gap cells, the band line-up is not directly in favour of an inverted interface and there is a conduction band cliff between the chalcopyrite absorber and the buffer layer (usually CdS). This leads to a reduced barrier for recombination and, consequently, a significantly lower efficiency has been found due to interface recombination. Recent published *jV* curve analysis results of wider-gap $CuInS_2$ and $CuGaSe_2$ solar cells [2, 3] show the limitation of these cells by interface recombination over a reduced barrier. Therefore, it is of high relevance (i) to study the surface defect states of device-grade thin films and (ii) to use an appropriate passivation layer concept in order to decrease the defect states density at the chalcopyrite/window interface.

We proposed here *for the first time* a point-contact geometry at the front side of thin film chalcopyrite solar cell devices which is similar to the concept of contacts at the rear side of high-efficiency silicon based solar cells. While point contacts have previously been used only in high-quality laboratory cells the application of point contacts to industrial solar cells has recently been reached [4].

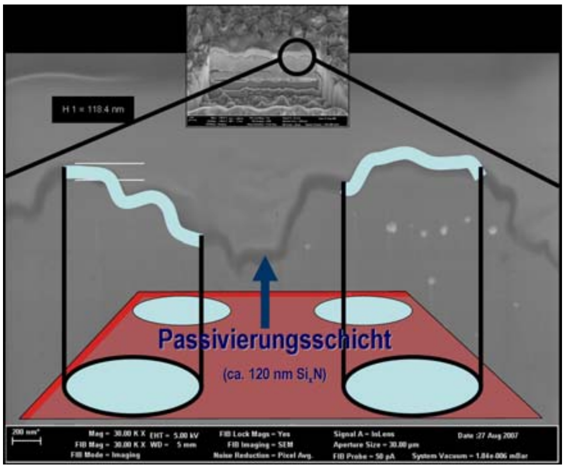

Figure 1: Cross section REM-picture of a device-grade $CuInS_2$ thin film covered by 120 nm Si_xN. The inset illustrates schematically the novel, heterogeneously constructed passivation layer (red) which covers completely the polycrystalline chalcopyrite surface. The passivation layer contains a periodic arrangement of point contacts (light blue), while the point contact diameter and the distances between the point contacts are in the range of the diffusion length of the photogenerated charge carriers in p-type chalcopyrite of 1-2 µm.

The concept includes (i) an interfacial defect state passivation and (ii) a current transport only through these point contacts that cover a few percent of the device area, while the rest of the surface is electronically passivated by a dielectric coating. In order to reduce the series resistance the contacting area is distributed over the whole device area (see Fig.1).
First attempts to prepare ultra thin Si_xN passivation layers on $CuInS_2$ surfaces have been successfully performed by means of PECVD (see Fig.1). The inset shows schematically the concept of point contacts in an appropriate passivation layer which covers completely the chalcopyrite thin film surface and allows a current transport of photogenerated charge carriers to the n-type TCO window layer only through these points. We will present the surface-, interface- and bulk-related electronic defect properties of device-grade uncovered and Si_xN-covered polycrystalline $CuInS_2$ studied by using time- and locally-resolved cathodoluminescence (CL) spectroscopy in a scanning electron microscope at T = 6 K. The focus is set on the electronic defect properties of the blank and passivated $CuInS_2$ surfaces [5].

With the assumption of (i) a reduced recombination at the *new* chalcopyrite-point-contacted-passivation layer interface compared to the standard CdS-puffer interface and (ii) a limitation of the photovoltaic performance due to recombination losses at this interface, we can postulate that the diode current density, j_o, is proportional to the interfacial surface, A_{pn} of the p-n heterojunction. With these assumptions one can estimate an increase of the open circuit voltage, V^{PC}_{oc}, by 100 mV for a heterojunction thin film solar cell based on $CuInS_2$ ($TCO/CuInS_2/Mo/glass$) by using the *new* point contact passivation layer:

$$V^{PC}_{oc} = A\, k_BT/q \ln(j_{ph}/j_o) = 2 \cdot 30\ \mathrm{mV}\, [\ln(1/F) + \ln(j_{ph}/j_o)]$$
$$= 60\ \mathrm{mV} \ln(5) + V^{CIS}_{oc}\ (\approx 700\ \mathrm{mV}) = 800\ \mathrm{mV};$$

diode quality factor A ($\approx$ 2), thermal voltage k_BT ($\approx$ 30 mV), photocurrent density, j_{ph}, proportional to the chalcopyrite surface, A_{ph} (~1 cm^2), diode current density, j_o, proportional to the chalcopyrite surface covered by a point contacted passivation layer ($F \cdot A_{ph}$= 0.2 cm^2; F: share of the point contacted area to the total area).

Preliminary 3D simulations of a conventional TCO-$CuInS_2$-hetero junction solar cell device are performed by using the WIAS-TeSCA programme [6]. The equipment of such a standard device with electrically conducting point contacts embedded in an appropriate passivation layer such as ZnS shows a beneficial effect on the solar cell performance [7]. Especially, the point contact radius and the interfacial defect density of states have been the parameters of the present model study.

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