CHARACTERIZATION OF LASER STRUCTURES IN PHOTOVOLTAIC CIGS THIN FILM SYSTEMS

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ABSTRACT: In thin film photovoltaics laser structuring is a common method to achieve the necessary monolithical series connection between neighboring cells. P2 and P3 laser scribing has also been proven to be suitable for CIGS solar cells but it is still not used in industry. There are different concepts of CIGS removal. On one hand ultra-short laser pulses are used, on the other pulse programmable industrial fiber lasers also lead to good results. The quality of the results depends strongly on the chosen parameters like laser fluence, wave length or pulse duration. Nevertheless the sample properties especially the CIGS/Mo interface characteristics are crucial for laser scribing. We investigated laser structuring on samples with and without a present $MoSe_2$ layer at the CIGS/Mo interface.

Keywords: CIGS, laser scribing

1 INTRODUCTION

In CIGS thin film photovoltaic laser scribing processes are mainly used for scribing the P1 scribe into the Mo/glass substrate. In industrial-scale cell production mechanical scribing processes are used for P2 and P3 scribes, exclusively. The main disadvantage of the mechanical scribing process is the loss of surface area due to chipping (see Fig. 1) of the CIGS layer on both sides of the P3 scribe and therefore the reduction of the achievable photo current.

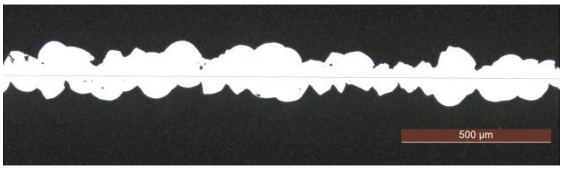

Fig. 1, mechanically applied scribe with area loss due to chipping

There are different concepts for P2 and P3 laser scribing on CIGS solar cells. So the utilization of ultra-short laser pulses in the ps or fs[i] regime leads to good results on laboratory scales. But melting of the CIGS material and the resulting formation[ii] of conductive phases on the scribe edges is still an issue. Those effects may lead to local shortcuts and low parallel resistances. The use of a pulse programmable fiber laser prevents CIGS-melt on the scribe edges due to the different nature of the ablation process[iii]. Here the energy absorption at the CIGS/Mo interface leads to an explosive ablation of the CIGS layer due to vaporized material. It is supposed that the Se evaporates first and therefore builds up high pressure. However, successful application of this process depends on the properties von the CIGS layer system. The laser irradiation has to reach the CIGS/Mo interface. So absorption at the given wavelength inside the CIGS should be low. Otherwise the CIGS will heat up and lose its transparency for the laser radiation. It is assumed that the presence of a $MoSe_2$ layer is crucial for the ablation. But the exact mechanism of the ablation still remains unclear.

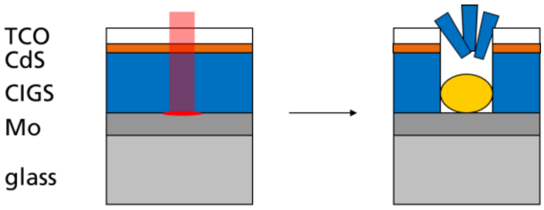

Fig. 2, ns scribe process schematically

In this work scribing was done on two samples, one with and one without a $MoSe_2$ layer. Results are compared.

3 EXPERIMENTAL

Scribing was done using a process similar to that one depicted in[ii]. The scribing process was applied to CIGS solar cells with the layer structure glass/Mo/CIGS. The scribes were investigated in terms of geometry and morphology with optical microscopy and stylus profilometry. The composition of the CIGS layer and the properties of the Mo/CIGS interface were studied with ToF-SIMS and SEM.

4 RESULTS

The results included both the successful ablation and the melting of the CIGS. Fig. 2 shows an optical micrograph of a laser scribe. The CIGS ablation was nearly complete. The Mo is visible at the scribe edge. However, there are still some CIGS residuals left on the scribe bottom. Also some cracks formed in the Mo layer. Profilometry measurements show perpendicular scribe walls supporting the assumption of brittle fracture of the CIGS layer during the laser process.

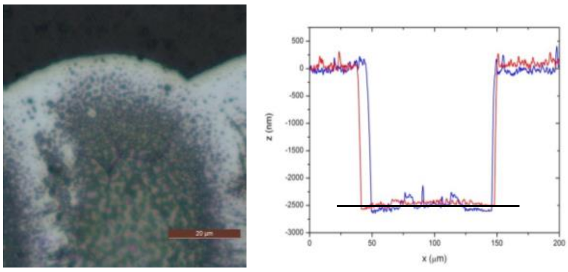

Fig. 3, process sucessful, no melting at the scribe edge but some residuals on the scribe bottom, profilometry shows sharp and vertical scribe edges

Fig. 3 shows results of an unsuccessful process. The CIGS melted on the whole irradiated area. Profilometry shows that the depth of the crater is only about 500 nm. The layer thickness of the CIGS is about 1.5 -2 µm. So there is still CIGS left on top of the molybdenum.

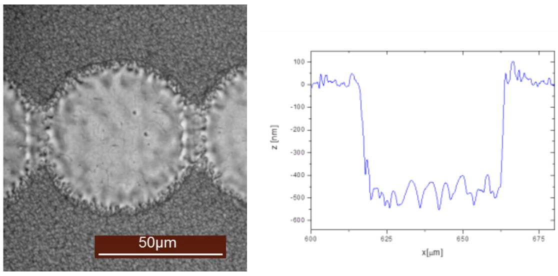

Fig. 4, melting of the CIGS-Layer, process was not successful, profilometry shows that the CIGS was not ablated completely (layer thickness 1,5 µm)

It is assumed that the successful ablation of the CIGS utilizing a brittle fracture process depends on the existence of a $MoSe_2$ layer[iii]. In our case experiments show the opposite behavior. On a sample without a $MoSe_2$ layer the brittle fracture process could be applied successfully, on a sample with $MoSe_2$ no ablation was possible (see Fig. 5).

Fig. 5 shows a cross section of a Mo/CIGS layer stack. In this case successful ablation was possible. The ToF-SIMS depth profile in Fig. 6 contains the signals of Se and Mo. The presence of an $MoSe_2$ layer can be seen usually by an overlap of both signals. In addition to that there is an increase of the Se signal in the interface region[iv].

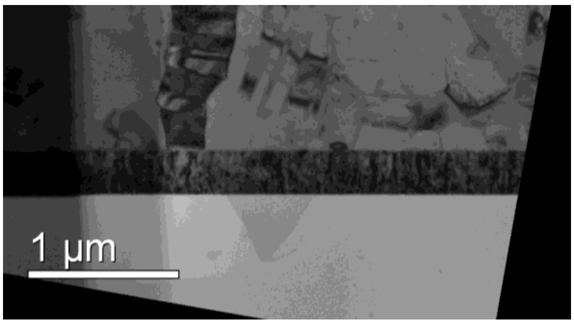

Fig. 5, crossection of the CIGS/Mo layer stack

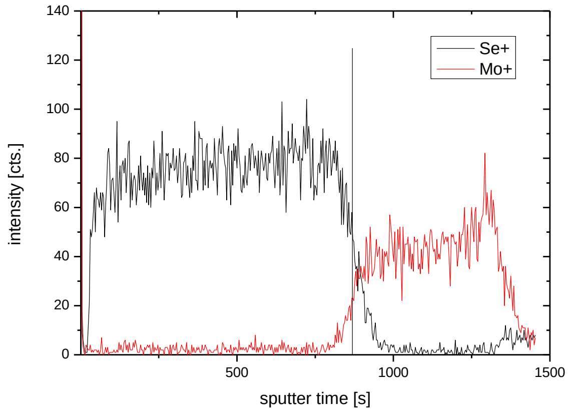

Fig. 6, ToF-SIMS depth profile, an $MoSe_2$ layer is not visible

On a sample with an $MoSe_2$ no successful application of the brittle fraction was possible. In Fig. 7 an optical micrograph of the Mo/$MoSe_2$/CIGS layer stack is shown. The $MoSe_2$ layer is exceptionally thick. Usually the thicknessis about 10 nm to 100 nm. The ToF-SIMS depth profile exhibits an overlap of the Se and the Mo signal.

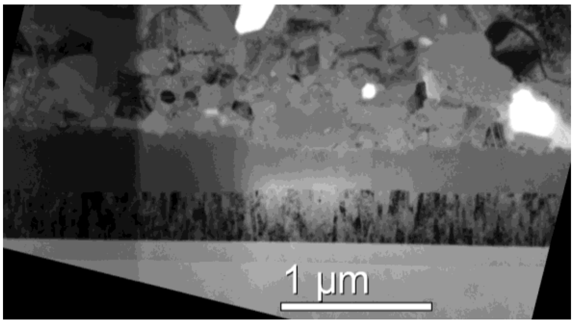

Fig. 7, cross section of CIGS/$MoSe_2$ /Mo layer stack

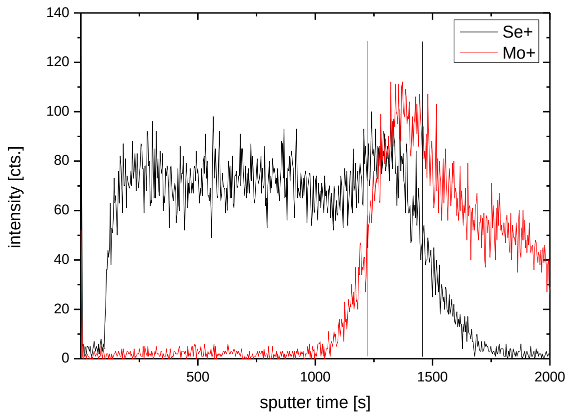

Fig. 8, ToF-SIMS depth profile, an $MoSe_2$ layer is visible

We assume that either the $MoSe_2$ layer is not crucial for successful ablation or the layer has to be below a certain thickness. The $MoSe_2$ is influencing the adhesion of the CIGS as well[v]. Furthermore, optical und structural properties of CIGS layer itself may prevent successful ablation. Absorption of laser irradiation in the CIGS layer may cause a heating of the CIGS. Thus the band gap gets smaller and the CIGS loses its transparency for the laser radiation.

5 CONCLUSIONS

Since the exact role of the $MoSe_2$ layer during the scribe process is not fully known, both the characterization of interfaces and the CIGS layer itself is crucial for optimizing the laser based structuring process. Structural and compositional characterization by ToF-SIMS and TEM provide necessary information of CIGS/Mo interface properties. Characteristics of the CIGS layer itself (depth dependent composition, sodium content) may also make an influence to the laser process.

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