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INFLUENCE OF INTERFACIAL $MoSe_2$ LAYERS ON ns LASER SCRIBING OF $Cu(In, Ga)Se_2$ SOLAR CELLS

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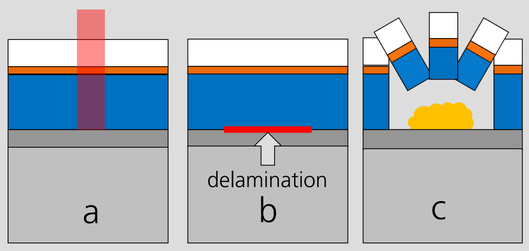
Motivation

- In CIGS photovoltaics laser processes for implementing the monolithic series connection still did not reach industrial level.
- Currently there are two methods used for laser structuring CIGS on laboratory scale, the ablation by ps [I] and fs pulses and ablation by a brittle fracture process [II]
- ns laser scribing of CIGS thin film is strongly influenced by the properties of the CIGS/Mo interface like adhesive forces and interface composition
- In this work the CIGS/Mo interface is characterized in terms of adhesion and composition. These results are linked to the ns laser scribing process

Samples and preparation

Scribing

- Two groups of samples, group 1 (1a, 1b) and 2 (2a, 2b)
- All of the samples contained the layer stack glass/Mo/CIGS/CdS/ZnO
- Scribing was done using a Nd:YAG-Laser (1064 nm) laser with a pulse length of <10 ns [Fig. 1]



[Fig. 1] three step model of ablation process: a heating, b delamination, c evaporation/ablation

Analysis

Scribe results

SEM **I**
- Scribe morphology
- Scribe edges

Investigation of the CIGS/Mo interface

TEM **II**
- Thickness $MoSe_2$
- Orientation $MoSe_2$

Pull test **III**
- Adhesive forces

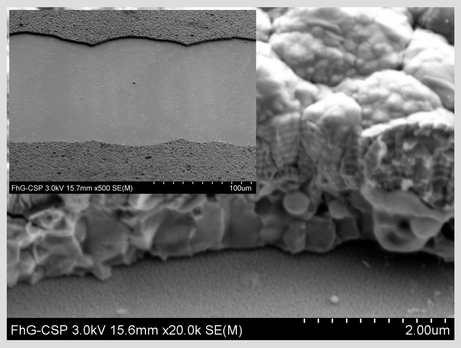
XPS **IV**
- Interface composition (Mo and CIGS surface)

Microstructural investigations

I

- Scribing of group 1 samples shows a nearly residual free removal of the CIGS
- Scribe edges are clean crack without molten CIGS
- The Mo surface is not damaged [Fig. 2]

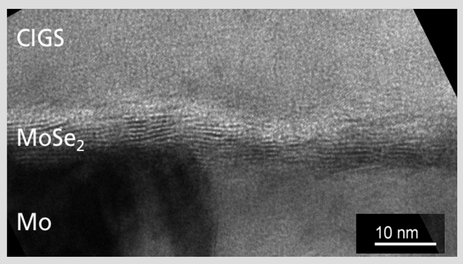
- Scribing of group 2 samples was not successful
- CIGS molten, **delamination at the CIGS Mo interface was not achieved**



[Fig. 2] P3 laser scribe sample group 1 shows clean scribe edges and no residuals on the Mo surface

II

- CIGS/Mo interfaces are investigated using TEM cross sections
  - Results show lattice planes parallel to the Mo/CIGS interface plane for 10 nm $MoSe_2$ layers
  - Thicker layers (~50 nm) do not show preferrential crystal orientation

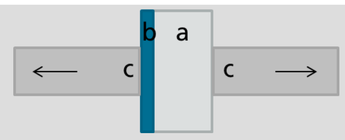


[Fig. 3] TEM cross section of the CIGS/Mo interface shows 10 nm MoSe with lattice planes parallel to the interface plane

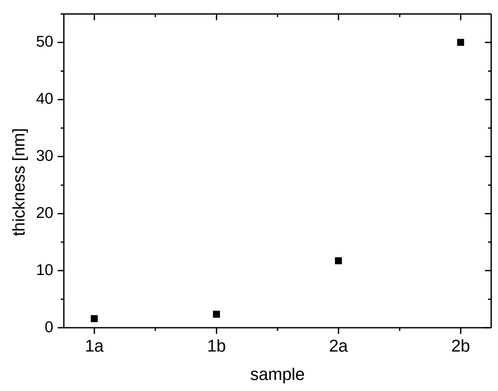
Adhesion and composition

III

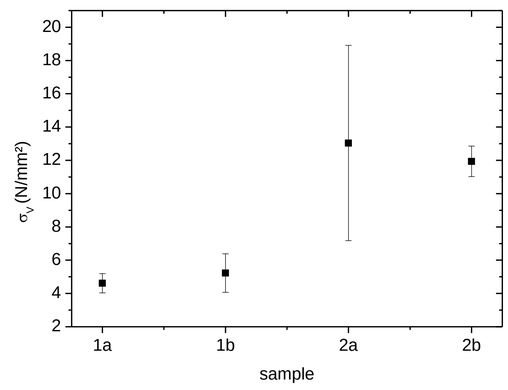
- Measurement of CIGS adhesion was done using a pull test [Fig. 4].
  - Results show higher adhesion for thicker $MoSe_2$ layers (gorup 2) but no dependence on $MoSe_2$ orientation [Fig. 5 and Fig. 6]



[Fig. 4] pull test (schematic view), a glass, b CIGS, c metal cylinders glued on the sample surface



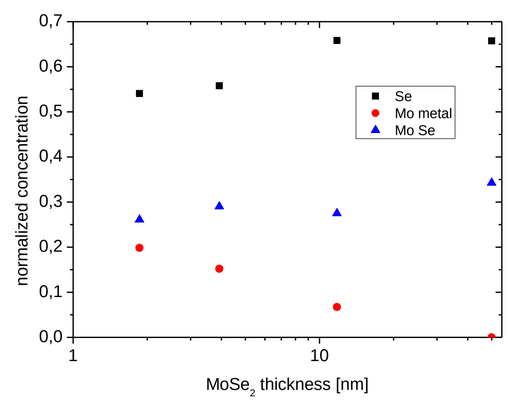
[Fig. 5] thickness of the interfacial $MoSe_2$ layers, $MoSe_2$ layers of group 1 samples are significantly thinner



[Fig. 6] measured adhesion at the CIGS/Mo interface usind the pull test method, group 1 samples show lower adhesive forces the samples of group 2

IV

- For measurement of the interface composition the CIGS was removed from the Mo surface by pulling it of
- XPS spectra show no Cu, Ga or In on the Mo surface
- Se was found on the Mo surface because of the MoSe2 layer [Fig. 6]
- No Mo was found on the CIGS surface for all samples
- **Conclusion: CIGS delaminates not within the $MoSe_2$ layer but on the CIGS/$MoSe_2$ interface**



[Fig. 7] concentration of Se, Mo (metal) and Mo ($MoSe_2$) on the Mo surface. For thicker MoSe2 layer the conentration of metallic Mo gets lower due to the low information depth of XPS

Conclusions

- Successful laser scribing was achieved on samples with low CIGS adhesion
- A pulltest setup was used to measure the adhesion quantitatively: delamination of CIGS from the Mo occures for $\sigma < 10$ N/mm²
- XPS measurements show that the delamination occurs at the CIGS/$MoSe_2$ interface, therefore the properties of this interface are assumed to be more important for adhesive forces than the orientation of the $MoSe_2$ layer
- For ns laser processes the presence of the $MoSe_2$ with a specific orientation layer is not crucial
- Other parameters which may influencing the adhesion like tensile stress or interface composition (Na, O, …) are subject of ongoing research

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