

CIGS Mini-Modules with Screen-Printed Front Contacts

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Abstract: CIGS mini-modules with different cell lengths and thicknesses of ZnO were produced, and a front contact grid were added on top of the ZnO layer using screen-printing. A polymer screen-printing ink were used because of the low heat tolerance of CIGS solar cells. The best efficiencies achieved were 9.6% for a mini-module with 5 mm cells, and 8.9% for a mini-module with 1 cm cells. Thinner ZnO gave higher short circuit current, but also lower open circuit voltage. Low voltage is believed to be caused by small shunts through the pn-junction introduced by the curing of the polymer ink.

Key Words: CIGS, Mini-modules, Screen-printing, Polymer ink.

1 Background

Transparent and conductive doped zinc oxide (ZnO) films are commonly employed in Cu(In,Ga)Se₂ (or CIGS) solar modules in order to collect the produced current. Since ZnO absorbs long wavelength photons by free carrier absorption, a ZnO layer as thin as possible would be preferable. However, if the sheet resistance of the ZnO film becomes too large, the solar module efficiency will be reduced due to resistive losses.

As shown in earlier work at the Ångström Solar Center [1,2], there is a real advantage in using a current collecting metallic grid on top of the transparent conducting oxide for CIGS modules. For those mini-modules, electron beam evaporation was used to deposit the desired grid. In the current work, this is taken one step further, and screen-printing is used as the metallization step in order to reduce the cost and increase the throughput of the metallization process. Screen-printing is the most widely used metallization method for crystalline silicon solar cells.

The main challenge when including screen-printing in a CIGS-module production process is the low heat tolerance of this type of solar cells. CIGS solar modules do not survive a heat treatment above 300°C, and conventional screen-printing pastes need a firing at 700°C or more. In order to avoid excessive heating, a polymer-based metallic ink, which only needs curing at a temperature around 150°C for a few minutes, was used in this work.

2 Experimental

CIGS mini-modules with an effective area of 10 cm × 10 cm were produced using the baseline process at Ångström Solar Center [3]. Two different cell lengths (5 mm and 1 cm) were used for the CIGS mini-modules, where the cell length is the distance from one cell interconnection to the next. The number of cells per module were 20 in the case of 5 mm cells, and 10 when the cells were 1 cm long. Both a thin and a thick layer of doped ZnO were tested on the mini-modules, giving in total four different types of samples. The current collecting grid was applied with a manual AUREL screen-printer, and then cured in a belt furnace.

The conventional cell interconnection structure used in CIGS mini-modules has three different separation scribes, shown as P1, P2 and P3 in Fig.1. This design was originally developed for amorphous silicon modules [4], and the connection from the front of one cell to the back contact of the next is pro-

vided by the ZnO layer. With a metallic grid, only two separation scribes are necessary, thus reducing the dead area on the mini-module. In this design, used in the current work and shown in Fig.2, the grid lines connect the cells.

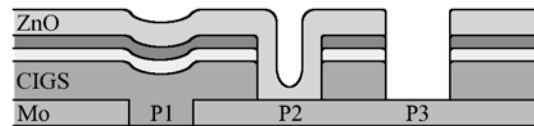


Fig.1 Conventional cell interconnection structure for a Mo/CIGS/CdS/ZnO/ZnO:Al device structure

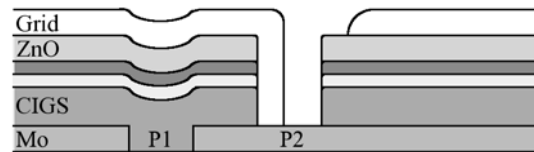


Fig.2 Cell interconnection structure with grid lines. The rest of the device structure is as in Fig.1

The performance of the mini-modules was measured with a QuickSun Solar Simulator. In some cases, contacts were also soldered on to the back contact of each cell in the mini-modules, so that I-V curves could be measured for each cell.

3 Results

The printed contacts had a resistivity of 60–80 μΩcm after curing, and the contact resistivity between the printed contacts and ZnO was in the range 50–130 mΩcm². The average thickness of the printed contacts were around 6 μm.

Tab.1 Results from the best mini-module of each type

Cell length	R_{\square} (Ω/□)	I_{sc} (mA)	V_{oc} (V)	FF	η
5mm	15	139.5	11.81	63.2%	9.5%
5mm	45	161.9	11.20	55.8%	9.6%
1cm	15	259.1	6.08	53.5%	8.4%
1cm	45	336.1	5.75	48.1%	8.9%

Several samples were prepared for each cell length and ZnO layer thickness. The characteristics of the best sample of each type are given in Tab.1. The best efficiency obtained for a module with 5 mm long cells was 9.6%, while the best result from a module with cell length of 1 cm was 8.9%. Both these

results were from modules with thin ZnO. The actual I-V curves for the modules with cell lengths of 5 mm and 1 cm are included in Fig.3 and Fig.4, respectively.

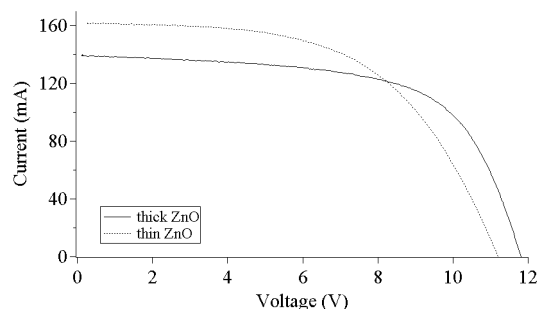


Fig.3 I-V curves from modules with 5 mm cell length

Fig.3 shows the two best results from the modules with 20 cells and a cell length of 5 mm. The short circuit current (I_{sc}) increased when the thickness of the ZnO layer was reduced, but it is seen that at the same time the open circuit voltage (V_{oc}) was reduced.

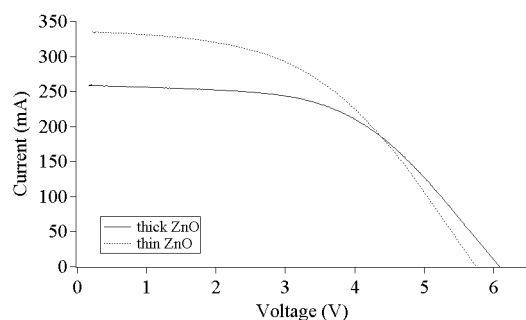


Fig.4 I-V curves from modules with 1 cm cell length

Fig.4 shows the two best results from the modules with 10 cells and a cell length of 1 cm. It is also here seen that an increase in I_{sc} when using a thin ZnO layer was accompanied by a reduction in the V_{oc} .

All samples measured had rather low V_{oc} . This was a particularly pronounced effect for samples with a thin ZnO layer, but most samples with a thick ZnO layer also had V_{oc} below 600 mV per cell. To check whether these mini-modules with low V_{oc} had any cells that had been completely short circuited, either during screen-printing or in the laser scribing of the molybdenum, IV curves for each cell in the modules were measured on several samples.

As an example, one such mini-module with 20 cells had an efficiency of 9.4%, but a V_{oc} of only 10.8 V. Typically, this module should have had V_{oc} above 12 V, and the observed reduction in V_{oc} could be explained if two of the cells had been completely short circuited. However, when I-V curves were measured on each cell, it was seen that all cells contributed, but that the cells had a wide range of V_{oc} values, from 490 mV to 570 mV, with a sum close to 10.8 V. No short circuited cells were observed on this or any other modules examined.

4 Discussion

As seen in Fig.3 and Fig.4, the I_{sc} increased when the thickness of the ZnO layer was reduced. This result was expected, because the ZnO layer absorbs long wavelength light due to free electron absorption. A thinner ZnO layer will contain

fewer free electrons, and thus less absorption will occur. The amount of extra current is in the order of a few mA/cm², which is within the expected order of magnitude.

The reduction of V_{oc} was a more unexpected result. This effect can not be explained by a change in the series resistance, because no current goes through the module in the open circuit case. It seems probable that this reduction in the V_{oc} was caused by increased shunting of the mini-modules by a reduction in the shunt resistance. This might indicate that the curing process had caused the polymer ink to partly penetrate the pn-junction. A thick layer of ZnO gave some protection against this shunting, because of increased distance between the grid and the pn-junction, and this would explain why more shunting and lower values of V_{oc} were seen for thinner ZnO layers.

When comparing the shape of the IV curves in Fig.3 with those in Fig.4, it is clearly seen that the fill factor is lower in the cases where the cells are long, and also that the IV curve is steeper close to the V_{oc} for modules with short cells. This indicates that while the series resistance is probably good enough for a module with short cell length, the resistance in the printed lines is too high for longer cells.

The resistivity of the cured polymer ink is 10–20 times as high as the evaporated metal grid, and this has to be compensated for by using thicker printed lines. The evaporated contacts have a thickness of about 3 μm , so the printed lines need to have a thickness in the order of 30 μm . Such lines are routinely printed with conventional screen-printing pastes, but the polymer ink used in this work was quite liquid, which made it spread out after printing. To get lines with a thickness of 30 μm or more, the polymer ink would need to be much more viscous.

5 Conclusions

These promising, initial results clearly demonstrate that screen-printing of a current collecting grid on CIGS mini-modules is a viable technique, although further research and process optimization will be necessary. The best results achieved are 9.6% and 8.9% for mini-modules with 5 mm and 1 cm cells, respectively. The produced mini-modules had some problems with shunting, probably due to the ink penetrating the pn-junction during the curing step, and a more viscous polymer ink will be needed to get lines of the required thickness.

Acknowledgements

The authors wish to thank Marta Ruth for making the CIGS layer for these modules, and all members of the research team at Ångström Solar Center for valuable discussion and technical support.

This work has been funded by the Nordic Energy Research through the scientific program "Solar Electricity, from Materials to Systems Integration (Nordic PV)".

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