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CONTACTING AND INTERCONNECTION OF CISCuT MATERIAL

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ABSTRACT: The specific properties of the CISCuT material ask for adapted contact materials and interconnection concepts. To control the material property and discover damages that are introduced during contacting shunt formation is followed by suitable detection methods. One method to discover shunts is a locally resolved (1mm steps) Voc-scan of the cell area at bias irradiation. Moreover, a novel shunt detection method, the Parallel Resistance Analysis by Mapping of Potential (PRAMP) is tested for the first time on CIS material. After optimization of metal composition and deposition method a sputtered (NiCrCu)Sn metallisation showed to be the most suitable contact for the CISCuT cells. As interconnection methods ultrasonic welding and thermode soldering are tested. At present the thermode soldering method derived to be most favourable for the interconnection of the CISCuT-strips. The thin copper support and high flexibility of the CISCuT strips allow to choose for a roof-tile arrangement as module design.

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1. INTRODUCTION

The CISCuT (**CuInS**$_2$ on **Cu T**ape) technology is a roll-to-roll process [1] and therefore a cheap alternative to the conventional way of $CuInS_2$ solar cell preparation. Core of the CISCuT technology is the one-sided quasi-continuous formation of $CuInS_2$ on a 1 cm wide and 100 µm thick endless copper tape.

Owing to the rather flexible copper tape CISCuT solar cells profit from a reduced fragility compared to the rigid solar cells, like the presently available glass-based crystalline silicon or CIS solar cells. On the other hand, the interconnection of the nowadays-produced 1 cm width CIS tapes asks for specific manufacturing concepts.

Instead of the grid configuration, which is usually used for larger modules, roof-tile integration is more appropriate for the small CISCuT strips. Fortunately, the copper tape directly serves as back contact. The CIS solar cell consists of an n-type Cu-In-S layer and a p-type layer on top of it to realise the junction. The front contacts are deposited on a ZnO:Al window layer, which is also widely used for conventional CIS cells.

In the European PROCIS project different metal combinations are tested as front contact for the CISCuT cells. The materials are carefully balanced with respect to the interaction with the ZnO:Al top layer and the applied interconnection method.

It was found that combinations (NiCrCu)Sn and (NiV)Ag are promising front contacts for the thermode soldering process. Al-containing contacts, like (Ni)Al, are of interest in combination with the ultrasonic welding technique as interconnection method.

Aim of this work to develop a contact scheme. Several shunt detection methods are demonstrated to identify shunts in the CISCuT material and shunts that arise during contacting or interconnection.

2. EXPERIMENTAL

A schematic drawing of the CISCuT cell structure is shown in Figure 1. A 1cm copper strip serves as support and back contact of the cell. After $CuInS_2$ deposition on the copper strip [2] masks are used to apply the following layers on a small area of (9x9) mm^2. To verify the junction a p-type Cu(O,S) layer is deposited on the n-type $CuInS_2$ by a sol-gel process. The top layer is a sputtered 1µm ZnO:Al window layer. The cell is completed by a sputtered (5x1)mm^2 front contact.

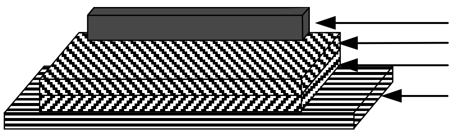

Figure 1: Schematic drawing of the CISCuT cell structure

Shunt detection tools control the CISCuT quality. To verify the reliability of specific shunt detection methods for the CISCuT cells intentionally shunted CISCuT-cells are used.

The Parallel Resistance Analysis by Mapping of Potential (PRAMP) [3] was recently developed at ECN to characterise mc-Si solar cells. Aim of this article is to prove that it is an excellent method for detection of shunt losses in the CISCuT material too. The PRAMP principle is demonstrated in Figure 2. This technique measures the potential difference between the backside of the cell and a probe that scans the top surface of the cell. The shunt detection is performed in the dark; the current is generated by applying a forward bias voltage across the cell that is low enough for a negligible current flow through a cell.

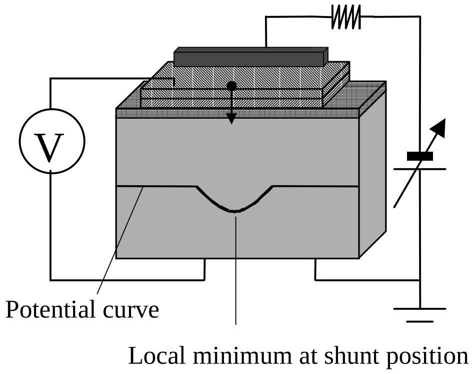

Figure 2: PRAMP principle tailored to the specific CISCuT cell configuration

The potential drop can be measured within an accuracy of 1mV. The current losses over the cell area are measured by scanning the potential of the CISCuT cell area in 0.2-mm(±0.1-mm) steps.

In this work contacting and interconnection schemes are developed. To contact the cell different application methods (electron beam deposition and sputtering) and contact materials (combinations with Al, Ag or Sn as top layer) are tested.

The detection of herewith-introduced shunts is essentially. Unfortunately the PRAMP method cannot be applied to detect shunts below the metallisation.

As low shunt resistances also influence the open circuit voltage, a Voc-mapping of the cell area gives information about both types of cell damage: on the CISCuT area and under the metallisation. The Voc-scan is performed in 1mm steps at bias illumination (light power 63mW/cm^2). With this method the PRAMP results are verified and additionally shunts that arise by contacting the CISCuT cell are located.

3. RESULTS AND DISCUSSION

3.1 Shunt detection in CISCuT cells

As already remarked, to demonstrate the working principle and to verify the reliability of the PRAMP-method an intentionally shunted CISCuT cell is used. The dimension of the cell is (9x9) mm^2. The cell is provided with a sputtered (NiCrCu)Sn bar.

The IV curve of the cell at 1-sun irradiation is fitted with a one-diode model. The calculated shunt resistance of 0.0165 S significantly reduces the open circuit voltage of the cell. For the PRAMP measurement at the contact a potential of 300 mV is applied. The corresponding current measured is 3.4 mA.

As is visualized in the PRAMP picture (see Figure 2) the potential decreases gradually with increasing distance from the contact. This is an indication for the existence of shunts in the CISCuT cell. The gradient of the area is determined by the sheet resistance ρ_S of the ZnO top layer. Consequently the collected current and thus the shunt resistance in the CISCuT cell can be derived from the potential difference in this area.

The shunts in the cell introduce a potential drop of 50 mV over the scan length of 9 mm.

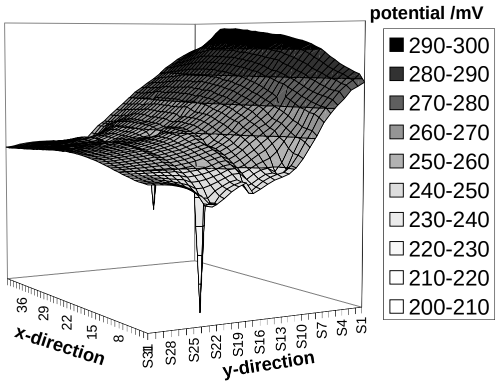

Figure 3: PRAMP mapping of a (9x9) mm^2 CISCuT cell (potential of 300 mV applied at the (NiCrCu)Sn contact)

$$\frac{dV}{dx} = 56mV/cm \qquad (1)$$

The sheet resistance of the top layer defines the potential gradient. In this case the sheet resistance of the ZnO top layer is 10(±5) Ω/square. The collected current over the whole scanned area is thus

$$i = \frac{1}{Rsh} \times \frac{dV}{dx} \times l = 5.6mA/cm \times 0.6cm = 3.3mA \qquad (2)$$

(This value coincides with the above-mentioned current of 3.38 mA measured if the potential of 300mV is applied at the contact)

The resulting value for the shunt resistance of the cell can be calculated

$$R = V/i = 300mV/3.3mA = 90.1\Omega = 0.011S \qquad (3)$$

This value has the same magnitude as the above-mentionned shunt resistance that was calculated using the one-diode model.

A detailed view of the PRAMP mapping in Figure 3 gives more information about the nature of the shunts. It is obvious that the area does not only drop going from the contact side to the opposite side. But a diagonal decrease from one corner at the contact side of the CISCuT cell (potential nearly 300 mV) to the diagonally opposite corner is registered.

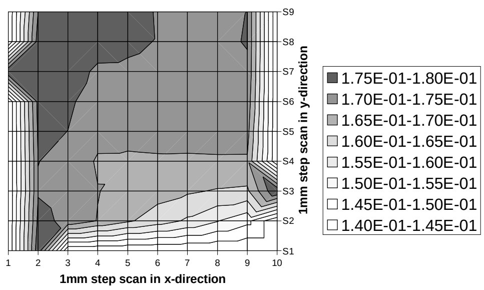

Figure 4: Voc mapping of a (9x9) mm^2 ×CISCuT cell at bias irradiation (legend: Voc in V)

The same effect was measured by an independent shunt detection method. A Voc-scan of the neighbouring CISCuT cell delivers the same diagonal course of the open circuit voltage (see Figure 4). Both measurements indicate that shunting occurs at the edges of the CISCuT cell. Following independent IV-measurement the shunting is caused by the ZnO:Al window layer [4].

3.2 Contacting of the CISCuT cells

As contact material different combinations are used: In all cases a thin nickel layer (10 nm) is deposited onto the ZnO:Al layer to guaranty the adhesion of the metal contact. Depending on the required top metal different intermediate layers are used, such as vanadium for silver application resulting in (NiV)Ag or chromium and copper for tin in (NiCrCu)Sn.

Two pathways of contact application are studied:

1. (Ni)Al layers are applied by electron beam deposition
2. (Ni)Al, (NiV)Ag and (NiCrCu)Sn are deposited using the sputtering method (see for details Table 1,2)

The photograph in Figure 5 shows the CISCuT cell with the contact bar at the edge of the CISCuT cell.

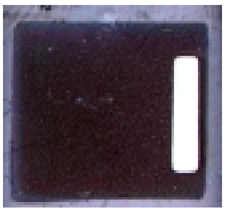

Figure 5: Photograph of a contacted 9x9 mm^2 CISCuT cell

A Voc-mapping is performed on an electron beam deposited (Ni)Al contact (see Figure 6). (In the figure only the part with the (Ni)Al contact with dimensions (9x5) mm^2 is visualized.) It is obvious that the Voc decreases going from the ZnO:Al surface to the metallisation. Directly on the contact the Voc is zero, indicating short-circuiting with the copper backside. As a conclusion electron beam deposition is not suited for contacting CISCuT cells.

In contrast to Figure 6 in the Voc scan in Figure 4 this typical contact shunt patron could not be recovered. The cell in Figure 3 was contacted by sputtering of (NiCrCu)Sn layers. So in contrast to the electron beam deposition method the sputter metallisation does not cause any distortions of the CISCuT cell properties.

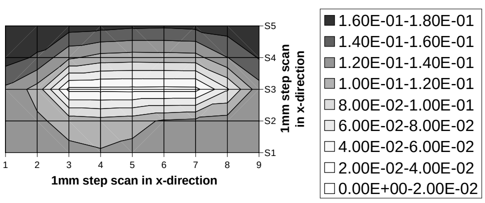

Figure 6: Voc mapping of a shunted (Ni)Al contact (legend: Voc inV)

3.3 Interconnection and module fabrication

3.3.1 Interconnection concepts

The ultrasonic welding method is tested on different metals. As reference aluminium or copper metal foil are used. Moreover, different reference materials like copper foil and glass coated with ZnO:Al could be contacted successfully (see Table I). The transfer to the CISCuT material introduces special material properties. On the flexible support several layers with individual morphology and thermal expansion coefficients are applied. These properties make the CISCuT material very sensitive to mechanical or thermal influence. Various on the ZnO:Al top layer sputtered metal combinations adhere very well and form the expected electrical contact to the cell. However, the tab application with ultrasonic welding did not succeed. In Table II different material combinations are listed that are used for ultrasonic welding tests on CISCuT material. In all cases the contact peeled off at the interface of the ZnO layer with the underlying layers. Consequently, the ultrasonic welding method cannot be applied successfully yet for the CISCuT strips.

Table I: Ultrasonic welding tests on (Ni)Al contacts using different substrates

Substrate	Contact material	Remark
Copper (100µm)	Ni(10nm)+Al(4µm)	no failure
Glass coated with ZnO:Al	Ni(10nm)+Al(4µm)	no failure
CISCuT cells	Ni(10nm)+Al(4µm)	Weld failure at ZnO/CIS interface

Table II: Ultrasonic-welding tests on CISCuT cells using different sputtered contact materials and tabs

Contact material	TAB material
Al (4µm)	Al (50µm)
Ag ((NiV)Ag)(3µm)	Cu(50µm)+Ag plating
Sn ((NiCrCu)Sn) (3 µm)	Cu(50µm)+Sn plating

In contrast, the thermode soldering method derived to be most suitable for the CISCuT interconnection. Pretinned copper tabs of 50 µm thickness are applied on (NiCrCu)Sn metallisation at 210°C. They adhere well and do not influence the cell performance.

3.3.2 Module fabrication

First modules are fabricated by interconnection of 5cm CIS strips with 5 (9x9) mm^2 cells on it (see photograph in Figure 5). On each of these cells an individual tab is applied, aiming at a parallel arrangement of the cells. (In a parallel connection in case of individual cell breakdown the strip performance does not drop to zero.) The tabs are soldered to the copper backside of the next strip. In this way the parallel-connected cells of one strip are series-connected to the other strips. Several strips are integrated in a roof-tile arrangement. In the following it is aimed to prepare roof-tile modules with cells covering the whole strip area as it is illustrated in Figure 6.

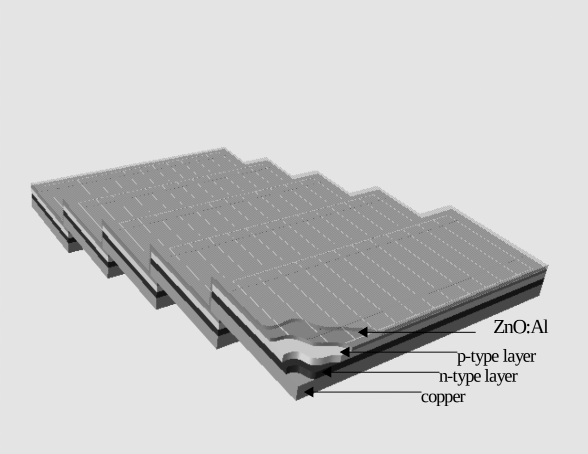

Figure 6: Roof-tile integrated CISCuT- module

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