23% METAL WRAP THROUGH SILICON HETEROJUNCTION SOLAR CELLS - A SIMPLE TECHNOLOGY INTEGRATING HIGH PERFORMANCE CELL AND MODULE TECHNOLOGIES

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ABSTRACT: Metal wrap through silicon heterojunction (MWT-SHJ) cells and modules combine the positive benefits of both underlying technologies: namely high Voc, higher Jsc and higher FF maintained before and after module encapsulation. We obtained 22.0% efficiency with low temperature Ag paste metallisation of front side and more than 23% on copper plated front metallisation. Voc values above 730 mV have been achieved, demonstrating that this architecture maintains the exceptional passivation of SHJ devices. The MWT cell and module structure offers even greater advantages when applied to SHJ solar cells: i) front side Ag consumption reduction up to a factor two; ii) low temperature cell interconnection concurrently with the encapsulation. Our record MWT-SHJ solar cells and modules are manufactured using industrially proven tools. The metallisation choice gives ample room to manufacturers to optimise based on internal cost structure and business strategy.
Keywords: Bifacial, PV module, energy performance, optical properties

1 INTRODUCTION

Several solar cell technologies have demonstrated the ability to reach more than 22% cell efficiency. In addition, new back contact module technologies are now available to overcome losses caused by the interconnection and due to the limited width of the tabs. High efficiencies and low materials consumption are the main drivers towards low-cost ($/Wp) silicon PV modules.

In this contribution we show the most recent development in the successful combination of metal wrap through silicon heterojunction (MWT-SHJ) cells and conductive foil module technology. The vast majority of the market implements module technologies based on interconnection of solar cells in strings by tabs soldered from the front of one cell to the rear of the adjacent one. To limit shading losses caused by these tabs, such interconnection leads to additional resistive losses in a string of cells thereby reducing the module performance. MWT technology provides a relatively small step from conventional cell technologies and has already demonstrated to increase the module power by 3%, and up to at least 5% is anticipated [1]. This is possible thanks to an integrated cell and module design in which conductive interconnection foil is used to reduce the cell-to-module power loss compared to conventional tabbing technology. Part of this gain is thanks to the reduced metal coverage on the front side, giving the solar cell performance a potential efficiency increase up to about 2.5% relative. Furthermore, thanks to the unit cell concept, i.e. the front metallisation grid of each unit cell is connected to a contact on the rear by a metal via through the wafer, the MWT cell structure decouples the wafer size from metallisation requirements allowing for lower resistive and/or shading losses.

Front and rear contacts SHJ solar cells have demonstrated more than 24% cell efficiency, e.g. 25.6% on interdigitated back contact SHJ solar cell [2], achieving excellent surface passivation with Voc exceeding 730 mV [3]. Furthermore SHJ has a lower temperature coefficient, resulting in higher module energy yield under high temperature conditions.

Nevertheless the low temperature Ag paste required for contact formation in SHJ devices is still today a challenge as it suffers from low conductivity resulting in high Ag consumption. Solutions such as multi-wire interconnection and multi-busbars have been introduced to tackle this conductivity issue [4,5]. MWT-SHJ architecture provides an elegant alternative solution to the reduced conductivity of low temperature silver pastes while maintaining the above mentioned advantages.

Moreover, the low-temperature process required by the SHJ solar cell is perfectly met by the soldering-free MWT conductive foil technology which uses conductive adhesive and single step curing for interconnection and encapsulation. MWT and SHJ cell technologies are also compatible with next generation thinner wafers resulting in a win-win situation both on cell and module level.

MWT-SHJ devices combine all the advantages of the individual concepts in a device with high open circuit voltage, high short circuit current and high module power thanks to reduced power loss.

In this paper, we show the most recent results of this MWT-SHJ solar cell architecture which resulted in a record efficiency of 23% using commercial n-type Cz 6 inch wafers. Furthermore we show potential efficiency gain of this architecture with respect to conventional front and rear contacts devices.

2 PURPOSE OF THE WORK AND APPROACH

In this contribution we describe recent development of MWT-SHJ solar cells and modules. We used a rear emitter cell structure to reduce recombination and shunt at the vias as previously reported [6]. Our approach is both theoretical and experimental. We used a 2D model to predict the experimental results and chose the best configuration and geometry of the MWT unit cells. The model has been then validated by fabricating working devices and characterisation (IV-curve and EL). In addition we demonstrated this approach with both low temperature Ag paste screen printing and Cu plating.

3 SCIENTIFIC INNOVATION AND RELEVANCE

To our knowledge, the solar cell performances obtained are record efficiency for both MWT-SHJ and MWT devices. The use of conventional low temperature Ag paste and low temperature interconnection methods, like conductive tape or multi-wire approaches, provide a costly solution that hinder the entrance in mass production of SHJ technology. MWT-SHJ addresses both issues. The MWT structure allows the reduction of the current to be transported thanks to the reduction of the unit cell size at virtually no costs and without the complicated hassle of upscaling to multi-busbar or multi-wire or smart-wire technologies. This allows a reduction of front Ag consumption by up to a factor two taking into account both the front side metallisation and the interconnection. We expect a similar gain from the rear metallisation. On module level, the cells are interconnected through the conductive rear side foil by means of conductive adhesives. During the lamination the interconnection takes place at low temperature concurrently to the encapsulation.

4 CELL STRUCTURE

MWT solar cells have the same architecture of a conventional solar cell with the addition that the front metal contact is wrapped through the wafer through metallised via holes, providing both emitter and base contacts on the rear side, see Figure 1 [6]. As the cell interconnection does not require tabbing, the busbar can be significantly slimmed down enhancing the light harvesting in comparison to conventional H-pattern cells.

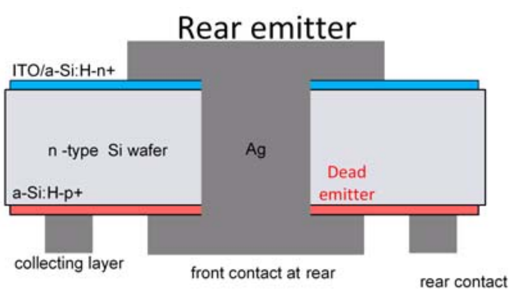

Figure 1: Schematic structure of a rear emitter MWT-SHJ solar cell. The collecting layer represents both the IWO:H and Ag rear contact

5 EXPERIMENT AND RESULTS

6" industrial n-type Cz monocrystalline full-square silicon wafers about 180 µm thick were used as substrate for MWT-SHJ solar cell fabrication. Conventional SHJ processing sequences were used for the fabrication of the solar cells: texturisation and cleaning, a-Si:H deposition by PECVD and TCO deposition. The MWT-SHJ solar cell process is the same as the SHJ process with adding a few extra steps typical for MWT cell technology [1]: vias drilling, via filling and isolation of the two metal contacts at the rear. In this experiment, the vias drilling is done before the surface preparation for the a-Si:H depositions, therefore the damage removal is done without adding any extra chemical step. In the MWT-SHJ process used, an isolation of the metal plug from the underlying Si or a-Si:H layer is not necessary. The via filling is done within the same printing step of the rear side pad.

Two types of metallisation have been used: i) low temperature silver paste by screen printing and ii) copper plating of the front metallisation. The copper plating has been entirely developed by CIC. A description of this process is will be described in a sister publication [7].

The rear side of both devices is identical and has been manufactured in two different ways: i) by screen printing of low temperature Ag paste and ii) by physical vapour deposition of a Ag blanket.

The solar cells are measured at ECN according to the ASTM-E948 norm using a Wacom class AAA solar simulator and spectral mismatch correction. IV results are shown in Table I.

Table I: IV results for MWT-SHJ solar cells with different metallisation and contacting schemes

Structure	Front metal	Jsc [mA /cm^2]	Voc [mV]	FF [%]	η [%]
H-pattern	Ag 3BB	38.9	722	77.3	21.7
MWT 4x4	Ag	39.1	726	76.6	21.7
MWT 6x6	Ag	39.2	723	77.6	22.0
MWT 6x6	Ag	39.3	719	80.0	22.6
MWT 6x6	Cu plating	39.7	731	79.8	23.1

The first three devices in Table I are manufactured in the same batch to compare the different configurations (H-pattern, 4x4 via MWT and 6x6 via MWT). Only the busbar width and number have been changed between configurations. The number and width of fingers have been kept constant (same finger metal coverage). This allowed making a direct comparison among the different configurations. The total front metal shading for the three devices is 5.4%, 3.7% and 3.4% for the 3BB, MWT 4x4 and MWT 6x6, respectively.

The fourth device in Table I is manufactured without the constraint of same finger metal coverage. Indeed by choosing for a large number of vias the unit cell area reduces and therefore the series resistance losses of the device. An optimisation of the finger width and number have been carried out to account for both metal consumption reduction and performance. This has allowed increasing the efficiency of the MWT 6x6 SHJ device by 0.6% absolute. The improved front side metallisation layout has also been combined with copper plating. Details are published elsewhere [7].

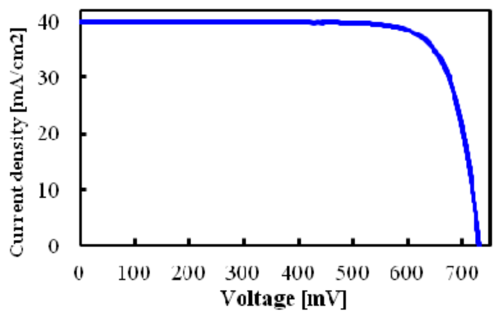

Figure 2: IV curve of the best MWT-SHJ solar cell with copper plating front side metallisation

In our MWT-SHJ, we demonstrate a Jsc that is superior to conventional H-pattern SHJ thanks to the reduced metal front coverage which results from the carrier transport being transferred to the rear side. The better cell performance is despite the fact that the measurement setups for H-pattern and MWT-SHJ solar cells are different. For the H-pattern multi-probes are usually used for the front contact of the cells. These increase the conductivity of the busbar independently of their width and thickness which results in higher FF (see table I H-pattern ref versus 4x4). This is not the case in real conditions (interconnection within the module) since the tabs used for the interconnection have a more limited conductivity than the multi-probes. MWT-SHJ measurements chucks do not use multi-probes as the current is transported to the rear side only thanks to the front metallisation. The result is that the measurements are carried out in real module conditions. In addition the FF increases on cell level since the current transport is not limited by the busbar width and by their number. The effect on the FF is even more evident on module level. Therefore a real comparison of the performance of MWT-SHJ and conventional front and rear contact cells should be carried out on module level where a reduced cell to module loss will be evident.

Figure 3 shows the dark IV-curves under negative voltage bias. Typical MWT-SHJ Irev current values are less than 0.5 A at -10 V for both the 4x4 and 6x6 configurations.

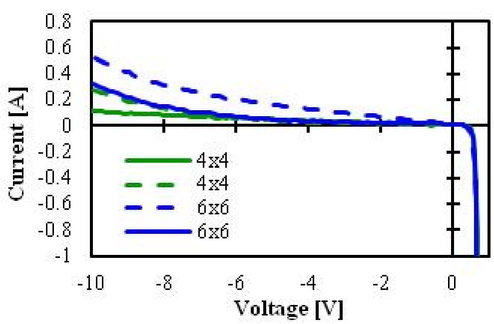

Figure 3: Reverse characteristics. of MWT-SHJ solar cells with Ag screen printing for both 4x4 and 6x6 vias configuration

In order to study the behaviour of the MWT-SHJ solar cells under low illumination conditions, we measured their performance at different illumination levels. Both H-pattern SHJ and MWT-SHJ solar cells have been measured as is shown in Figure 4. No particular difference in the illumination response for MWT-SHJ solar cells with respect to H-pattern. This indicates that the shunt and recombination of MWT-SHJ is comparable if not better than conventional front and rear contacts H-pattern SHJ devices.

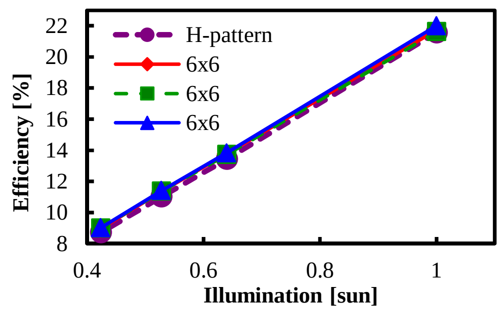

Figure 4: Efficiency as a function of the illumination level for H-pattern SHJ and 6x6 MWT-SHJ solar cells

6 CONCLUSIONS

ECN and CIC achieved 23.3% and 22.0% top efficiencies with copper plating and low temperature Ag paste, respectively. In the current configuration with LT-Ag paste and 6x6 vias we estimated a 30% cost reduction on Ag consumption with options to further reduce it to 50% with respect to 4x4 vias with no-extra manufacturing complexity. The two metallisation concepts are not yet fully optimised and there is further room for efficiency gain.

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