AUTOMATION OF SILICONE SOLAR MODULE PRODUCTION WITH LOW-COST TAPE INTERCONNECTION METHOD

Jonas Buddgård, Torgny Lagerstedt, Andrew Machirant

JB EcoTech AB

Högsätravägen 2, SE-181 58 Lidingö, Sweden

ABSTRACT: The purpose of this work is to find an accurate and high-speed method to automate module production with the tape solution. The purpose of the tape solution itself is to reduce production cost for conventional photovoltaic modules by reducing the amount of silver used in the grid on the photovoltaic cell and simplify the method of interconnection of individual PV cells. A novel method of applying bus bars and interconnecting individual cells into a module is proposed. The new method has the possibility to reduces the amount of silver by 25%. Furthermore, the interconnection of individual cells to a module is simplified, thus making the production less costly and more robust. Finally, soldering can be completed without the use of lead and at a lower temperature (150-160°C) which enables the use of cells featuring advanced temperature sensitive architecture like HJT solar cells.
We have previously disclosed the results of different long-term stability tests for this tape interconnection method but this time we will present the work of automate the tape application and stringing method with the tape method. Challenges like speed and accuracy will be tested during the spring of 2019 and the result will be presented in this work. We will also present the test results of solar modules produced with the proposed automation method.

Keywords: Automation technology; Energy conversion; Silicon solar cells; silver; module production; cost reduction; HJT solar cells

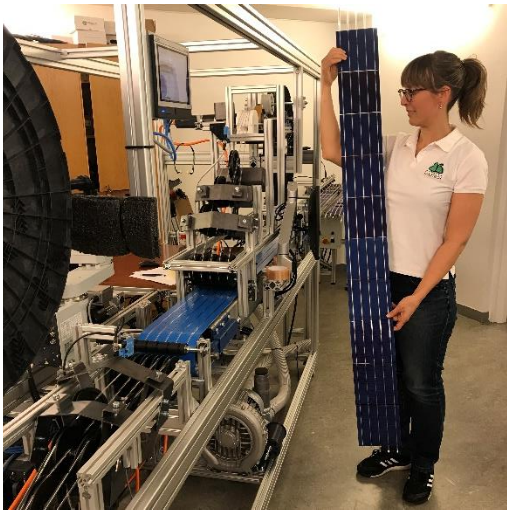


Figure 1. Picture of the developed technology for stringing solar cells with the proposed tape solution.

1 INTRODUCTION

The purpose of this work is to find a fast and accurate method for automatically apply the proposed tape on crystallin silicon cells. With other words stringing solar cells with the tape solution. The purpose of the tape solution is to reduce production cost for conventional photovoltaic modules by reducing the amount of silver used in the grid on the photovoltaic cell and simplify the method of interconnection of individual PV cells. One of the contributing cost factors for photovoltaic modules is the silver used in the grid on the PV cells. The grid consists of closely spaced narrow fingers and three to five wide bus bars perpendicular to the fingers. A novel method of applying busbars and interconnecting individual cells into a module is proposed. The new method holds the possibility to reduces the amount of silver by 25%. Furthermore, the interconnection of individual cells to a module is simplified and the process temperature is decreased significantly, from 240 to 160 degrees C, thus making the production less costly and more robust. All 60 cells in one PV module can be connected in a single step in the lamination process. Finally, soldering can be completed without the use of lead and at a lower temperature which enables the use of new high efficiency cells such as for example HJT solar cells. The decreased process temperature also decreases the risk for cracking during soldering and makes the module more robust to thermal changes. In the prototype in figure 1 we have during the spring of 2019 tested and optimized the throughput i.e cycle time and accuracy of tape placement. Finally, the produced solar modules have been tested for maximum power in a standard flasher manner.

2. EXPERIMENT

PV cells are electrically interconnected in series with the proposed tape method to form a PV module. The tape with tabbing wire is applied on both sides of the cell. The tabbing wires are cut and interrupted in such a manner that the individual cells are interconnected in series in the lamination process.
In this work, we are developing an automation method for stringing solar cells with the proposed tape method. A schematic picture of how the prototype work is shown below in figure 2.

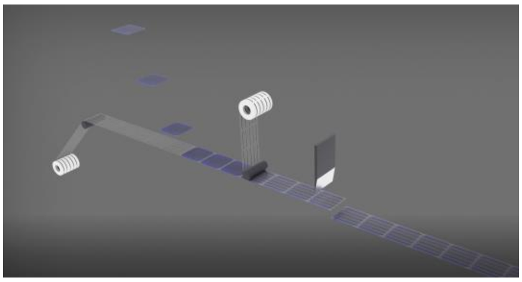


Figure 2. Schematic picture of the automation process of stringing solar cells with the tape method.

If simplified, the stringing with the tape method can be described as followed: Solar cells are placed on top of the interconnection tape that rolls out and works as an assembly line. As the cells stick to the interconnection tape and rolls out another layer of interconnection tape is laid down on top of the cells. The strings are then cut in to suitable length.
The process is continuous, and no heat is needed for fixing the cells. This means that there are no stops and starts for placing each cell and no additional time for heating and soldering of cells. By continuously rolling out the tape and placing cells on the fly by making the cell placement device accelerate to the same speed as the tape and place the cell. The stress in the tape can be easily controlled. One additional advantage with this method is that there is no need for soldering the tabbing wires to the cell bus bar, the tabbing wire are hold in place with the tape and the soldering is taking place later in the lamination process. Finally, the continuous movement and low process temperature of the machine enables high speed and accuracy but also makes the fundamental construction of the machinery simplified and less costly.

In the soldering method used today the cells are heated to of about 240 ^{0}C to solder the tabbing wires to the busbars. The temperature raise takes a few seconds and this fast increase from room temperature to 240 ^{0}C adds a risk of cracking of the thin cells. The soldering with the tape method is gentle and the risk of cracked cells is reduced because the soldering takes place in the lamination in which the increase from room temperature to 160 ^{0}C takes of about 10 minutes. Here it shall be noted that there is a trend towards using thinner cells which are sensitive to temperature gradients.

2.1 Speed and throughput

Throughput of a production equipment goes hand in hand with cost for a produced part. Therefor it is of the out most interest to secure high throughput in a production equipment. For this specific equipment the following things need to be tuned and optimized together to increase throughput. Outlaying of tape, bottom- and top tape and cell placement. During our testing we found out that there was no problem in laying out tape in a high speed with high enough accuracy. We set a limit at ±0,2 mm of tape placement. The bottle neck at this point is the cell placement. We use a scara robot arm to place the cells on the tape. At this point we could reach a maximum speed of 100 mm / second on the conveyor. If we run the machine faster than that the robot did not have the time to fetch a new cell and reach the placing positioning in time. We have some ideas on how to get rid of this bottle neck. For example, we could decrease the distance between the cell pic and place position and/or add another robot for double speed. 100 mm / second corresponds to 1,6 second per cell in cycle time. this could be calculated to a yearly production of approximately 100 MW (using 5 Wp cells running 24h/day 365 days/year).

2.2 Accuracy of tape placement

By running the machine only with tape and no cells we could easily measure the placement of each tape interval with an optical microscope and then using statistical measurements to find out the accuracy of tape placement. By doing some improvement and optimization on the tape placement device we could reach ± 0,2 mm accuracy which is good enough for this method of interconnection.

2.3 Testing of finalized modules

We produced three solar modules using the developed machinery and compared those with 3 modules manufactured with standard soldering. The result can be seen in table 1, where the first three are the taped ones and the last three are the soldered ones, and graph 1 below. The efficiency is quite similar but what is interesting is that the taped modules have slightly higher fill factor.

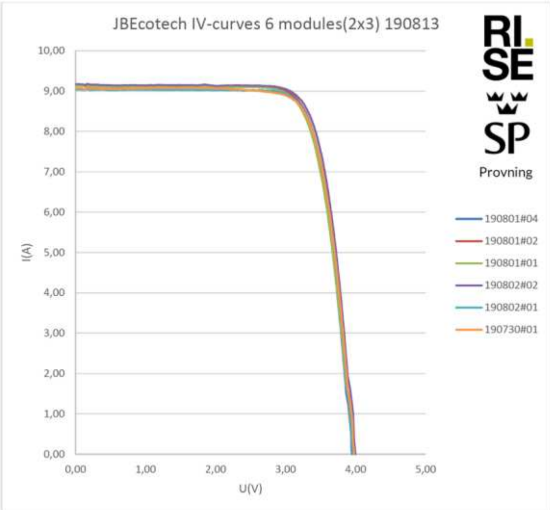
Taped modules	Soldered modules								
modulbeteckning	Seriesres.[ohm]	Isc [A]	Imp [A]	Voc [V]	Vmp [V]	Pmp [W]	F.F. [%]	Cell eff. [%]	Module eff. [%]
190801#04	3,903	9,143	8,697	3,941	3,205	27,9	77,4	19,0	13,5
190801#02	4,097	9,141	8,684	3,947	3,214	27,9	77,4	19,1	13,6
190801#01	4,290	9,140	8,666	3,955	3,222	27,9	77,2	19,1	13,6
190802#02	4,484	9,128	8,639	3,960	3,231	27,9	77,2	19,1	13,6
190802#01	4,572	9,128	8,633	3,961	3,220	27,8	76,9	19,0	13,5
190730#01	4,661	9,121	8,635	3,956	3,209	27,7	76,8	18,9	13,5

Table 1. flasher test results

Measurement method:
The solar modules where characterized by pulsed solar simulator Endeas Quicksun 560Ei class A+, A, A+, in accordance with IEC 60904-1. The solar simulator is calibrated with Isc of a reference module before measurements. The

results have bin corrected to STC in accordance to IEC 60891.

The cell size was measured to 244 cm² and modules to 0,206 m².



Graph 1. IV curve of tested modules.

3. DISCUSSION

The main reason for having the silver busbar on the PV cell in the traditional way of building modules is to increase strength in the bond between the cell and the tabbing wire. The high strength in the bond is needed because of the stress that occurs due to difference in CTE, Coefficient of thermal expansion, of different materials when the module is cycled between high and low temperatures during its lifetime of more than 25 years. The row of 10 cells soldered together is also moved from the soldering station and placed on top of the EVA sheet and top glass during production. Also, note that a turning of the row is needed. As high strength is not needed when using the tape method. Because in the tape method, the tape adheres to the cells and hold them and the tabbing wire in place before and during the lamination process. In the lamination process all the parts of a module are laminated into one unit and all the tabbing wires are soldered to the cells. Evan after lamination the tape adheres to the cells and keep the tabbing wires in place in addition to the soldered joint. In this way, the process temperature for connecting the PV cells does not have to be above 160-degree C. This means that the Delta T, from the highest temperature the PV module experience during its lifetime to the lowest for the thermal cycling test or in real life out in the sun, is decreased dramatically. By approximately 80 degrees C (240C -160C). Finally, this gives a longer lifetime for the PV module and a lower price for the electricity it will produce during its lifetime.

4. RESULTS

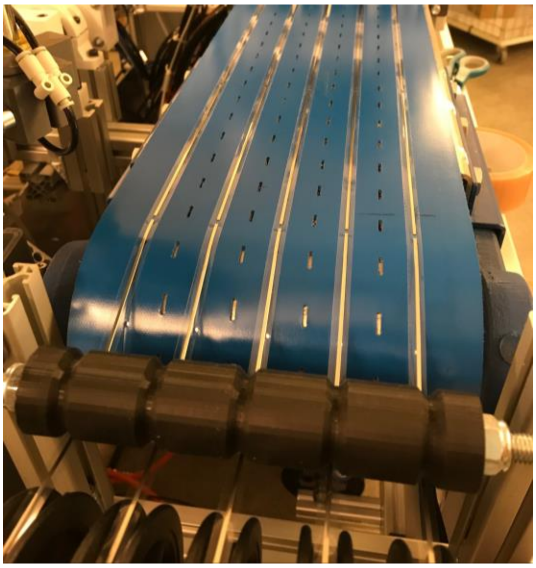
We have proven that the developed machine for making solar cell strings with the tape solution could be used for making solar cell strings in an industrial-high throughput way with equal or slightly higher output power. A clip of the machine in action can be seen at this link: https://jbecotech.se/language/en/products/

5. CONCLUSION

A machine for automation of the tape solution, a novel method of applying bus bars and interconnecting individual solar cells into modules are developed and tested. The purpose of the work is to simplify production and reduces cost in solar module production. During this work we successfully produced three solar modules at high speed with equal or higher efficiency than compared soldered modules. The tape solution and the developed equipment also have the option to use different tapes/conductors/ribbons on the front and back of the cells. This makes it easy if you like to produce modules with black coloured ribbons, round ribbons or lite reflecting ribbons, etc and still use a regular ribbon on the back of the cell.

6. PICTURES

The developed production equipment.



The conveyor pulls out the tape.

Before lamination the tape can be seen as a thin transparent film, but it disappears in the finished laminated module.

7. REFERENCES

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