Case study of failure analysis in thin film silicon solar cell

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ABSTRACT

Thin-film silicon modules are commonly produced by an alternating sequence of layer deposition and layer patterning steps, which lead to a monolithic series connected device. Most used process is laser scribing process that offers a high throughput and a small area loss. Tin oxide (SnO2) or zinc oxide (ZnO) are the most used front contact TCO in the superstrate configuration. ZnO presents better optical properties with respect to SnO2 and can be realized by low thermal and cost effective deposition processes. Electrical performance of our tandem thin film silicon cell deposited on ZnO front contact has shown higher shunt with respect to our reference process using SnO2 front contact, not explained only as difference between the two materials. In this work, a failure analysis process was followed in order to explain the origin of the difference. SEM, FIB and Auger electron spectroscopy were used in order to characterize the laser scribe that is known to be a possible cause of electrical deviation. We found residuals either on the bottom either on the later wall of P3 scribe that can explain the lowering shunt resistance and open circuit voltage observed into the electrical performances of the module.

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1. Introduction

Large area thin-film silicon panels are widely diffused in the market of photovoltaic modules. They are commonly realized by an alternating sequence of layer deposition and layer patterning steps, which leads to a monolithic series connected device (Fig. 1). Most used process is laser scribing patterning that offers a high throughput and a small area loss. The process allows a cost effective manufacturing process and is suitable for application on large area low cost substrates such as glass, plastics and metals.

Large areas (≥ 1 m²) can be processed because (a) TF deposition facilities are usually scalable, and (b) the individual PV cells of a large module can be serially interconnected without the need of time-consuming wiring. To achieve this task, three patterns (P1, P2, P3) are realized during fabrication by laser scribing. In this respect, lasers have become key-components in the production of TF PV modules.

In the superstrate configuration, the substrate is transparent and facing the incoming sunlight. The first deposited layer is a Transparent Conductive Oxide (TCO), followed by an absorber layer, and a back contact/reflectector.

Tin oxide (SnO2) or zinc oxide (ZnO) is the most used front contact (TCO) in the superstrate configuration. ZnO shows better optical properties with respect to SnO2, such as higher transmittance and more controlled high haze, leading in higher cell current. Moreover, ZnO can be realized by low thermal and cost effective deposition processes (ZnO:Al by sputtering, ZnO:B by MOCVD).

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Electrical performance of our tandem thin film silicon cell deposited on ZnO front contact has shown higher shunt with respect to our reference process using SnO2 front contact, not explained only as difference between the two materials.

In this work, a failure analysis process was followed in order to explain the origin of the difference. Scanning electron microscopy (SEM), focused ion beam (FIB) and Auger electron spectroscopy were used in order to characterize the laser scribe that is known to be a possible cause of electrical deviation [1].

2. Experimental

We have studied tandem (a-Si:µc-Si) thin silicon module fabricated in superstrate configuration on glass with SnO2 or ZnO front contact TCO. SEM cross sections were performed with a FIB dual beam (DB) FEI DA300 equipped with a Sirion electron column, a Magnum ion column and with a gas injector system used for in situ contrast layer deposition.

Auger analyses were performed using PHI Smart 200 equipped with Ar⁷⁺ ion gun for surface cleaning and depth profiling analysis.

3. Result and discussion

The electrical performance of tandem thin film silicon cell deposited on ZnO:B front contact, compared with our reference process using SnO2 front contact, is affected by a lower open circuit voltage (Voc) and worst shunt resistance (Rsh). I–V curves of modules are reported in Fig. 2. The difference with respect to the case of SnO2 cannot be explained only as effect of the work function difference between the two materials.
The front TCO layer is scribed by infrared or ultraviolet laser radiation. The industrial process for this operation is Q-switched (ns pulses) source emitting at 1064 nm or 355 nm (third harmonic), respectively.

Laser scribing is known to introduce electrical shorts with a heat affected zone around the scribe and melt phase residue [2,3], that could be a possible failure mechanism.

Infrared P1 laser scribing process has been optimized for ZnO layer and checked with electrical isolation measurement between strips. The analysis here reported was concentrated on P2 and P3 laser scribing.

Related to the failure mechanism, scribe lines of the solar cell were considered. Of course a classical fault isolation in this kind of devices cannot be performed due to the extension and the peculiarity of the device, so we try to consider scribe lines hoping that the defect is widespread. In Fig. 3 the optical picture (a) and SEM image (b) of scribe line were reported.

Normally due to their extension, optical methods were used as inspection but we consider this kind of inspection not enough accurate to observe defects. This is the reason why a SEM analysis after FIB Cut on the edge of the lines was performed.

3.1. P2 scribe line

The scribe line P2 was made to cut silicon in order to define the active cell. FIB Cross section was performed to observe the lateral wall tapering and TCO morphological properties in the area laser irradiated.

In Fig. 4 the cross section of P2 scribe is shown. In the picture the structure of the scribe and the solar cell are well visible. It is possible in fact to observe the bottom TCO layer on glass (called front contact), the silicon microcrystalline and the last conductive stack composed from a TCO thin film and last silver layer (called back contact). It is also visible a tungsten strip deposited in situ by FIB. Tungsten is used to protect the sample surface during ion beam cut and in order to have better contrast on the interface. From the overview of Fig. 4 some bubbles in the interface between front contact and back contact were observed. In Fig. 5 higher magnification photo of the area of the bubbles is reported. The interface between the front contact TCO and that one of the back contact can be observed.

A more detailed analysis of the area reported in Fig. 5 exhibits the presence of bubbles having two different natures. That one signed in Fig. 5a (that appears biggest) is actually silicon residual. The others, visible in Fig. 5b (that appears least), are instead a hole. In both cases the problem is imputable to roughness of TCO surface together with a non-optimized laser cut process. In any case the residuals are well isolated and they cannot give leakage problems even if they could have an impact in reliability. Optimization of the process by laser power density retuning is needed.
3.2. P3 scribe line

Finally P3 scribe lines were analysed. This scribe cuts the back contact in order to insulate the cells between them. In Fig. 6 an overview of the scribe line observed by SEM is reported. In particular a low magnification (Fig. 6a) together with a higher magnification (Fig. 6b) of the tapering of the wall are shown.

A higher magnification of the bottom of the scribe reveals the presence of many residuals. In particular, in Fig. 7, two kinds of residuals are pointed out. This residuals have same morphology but different size. A more detailed analysis was done using Auger electron spectroscopy in order to acquire compositional information.

Because Auger lateral resolution is unable to observe the single residuals, an acquisition area of about 1 μm² inside the scribe was defined to do analysis. In Fig. 8a, Auger spectra obtained on samples surface are showed. The peaks of oxygen (KLL), zinc (LMM), carbon (KLL) and silicon (KLL and LLM) are evident in the spectra. These peaks originated from TCO and from the residuals. In order to identify the peaks that originate from residuals, a sputtering process was done to clean the surface. After residual removal, a new spectra was acquired and the peaks were subtracted with those of the spectra of Fig. 8a. The resulting peaks are those ones that originate from residuals. After 10 min of Ar⁺ sputter, Auger spectra acquired on the same area into the scribe surface are shown in Fig. 8b. As previously described, because C and Si peaks disappeared, the residuals were consequently composed by these two elements. In addition, Auger elemental maps were acquired during sputtering process. In Fig. 9 the elemental distribution is shown. In particular the maps are the superimposition of the C maps (in green), Si maps (in red) and Zn maps (in blue). In Fig. 9a, the starting situation is reported. During sputtering (from Fig. 9b to d) an increasingly important reduction of the signals of C and Si is observed. This confirms the foregoing mentioned about the nature of the residuals.

Finally the sample was rotated in order to observe the lateral wall of the scribe to verify that this problems are confined at the bottom of the scribe only. In Fig. 10 the photos of this area are reported. As seen, the residuals are well observable into the lateral wall reducing the gap between the two conductors. This problem can perfectly explain the shunts that cause the electrical failure.

The root cause of this failure mechanism seems clearly imputable to a non-optimized laser cut process that instead of ablating surface, melts the silicon leaving the scribe full of residuals due to drops of the eroded material.

4. Conclusions

We performed a failure analysis in order to explain the differences in electrical performances between tandem cell with SnO₂ and ZnO front...
contact. A detailed analysis of P2 and P3 scribe line of a tandem thin film silicon cell deposited on ZnO front contact, has been carried out using SEM, FIB and Auger.

We found residuals both on the bottom and on the later wall of P3 scribe. These residuals can explain the lowering shunt resistance and open circuit voltage observed into the electrical performances of the module compared with our reference process using SnO₂. Because residuals were observed also in the bottom of P2 laser scribe, we retuned the laser process to recover electrical performance.

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