NOVEL METALLISATION METHOD FOR BURIED CONTACT SILICON SOLAR CELLS

R. Kopecek, K. Peter, W. Jooss, P. Fath, E. Bucher

University of Konstanz
Faculty of Sciences, Department of Physics, LS Prof. Bucher, P.O. Box X916, D-78457 Konstanz, Germany
e-mail: radovan.kopecek@uni-konstanz.de

ABSTRACT: The present paper reports on the investigation of a new metallisation method for silicon solar cells processed by dipping of grooved Si substrates into a metal melt saturated with Si at temperatures of around 900 °C. This cell concept is based on the idea of a Buried Contact Solar Cell (BCSC) replacing the time consuming wet chemical metallisation of grooves by a simpler dipping process. Solar cells with various sheet resistances of non selective emitters were processed on Cz-Si material. Fill factors of up to 78 % indicate a good electrical contact of the metal finger to the emitter as well as a sufficient conductivity affirming this method to be perfectly suitable for BCSC metallisation.

Keywords: Silicon - 1: Buried Contacts - 2: Metallisation - 3

1. INTODUCTION

The conventional Buried Contact Solar Cell (BCSC) metallisation is besides screen printing technology the major technique used for silicon solar cell fabrication. Metallisation of a buried contact can be achieved by a variety of methods but only the wet chemical process of electroless plating [1] and the filling of grooves with metal pastes [2] (e.g. by screen or stencil printing) are suitable for industrial processing at present. Within both standard BCSC methods, the front surface related processes represent the highest complexity and cost of the overall processing sequence. For the fabrication of screen printed BC metal fingers for instance an accurate alignment of the printed contact fingers is necessary. On the other hand the formation of the Ni/Cu finger contacts by electroless plating requires two wet chemical sequences which are not easy to control and are relatively time consuming. Moreover the used chemicals are harmful for the environment and the necessary disposal leads to additional costs.

In our laboratory we recently developed a completely new metallisation method for silicon solar cells processed by the dipping of grooved Si substrates into a Si containing metal melt. This cell concept is based on the idea of a BCSC replacing wet chemical metallisation of contact grooves by a simpler dipping process: a grooved, phosphorous diffused Si wafer is dipped for a few seconds into a Sn melt saturated with Si at temperatures of around 900°C. After removal, the Sn melt fills only the narrow grooves due to capillary forces whereas the surface remains unwetted. Additionally if simultaneous emitter growth could be applied the complete BSCS process would be even more simplified. This paper gives a brief description of the novel technology of cell metallisation and summarises the performance of solar cells with homogeneously diffused emitters.

2. EXPERIMENTAL PROCEDURE

The metallisation of mechanically contact grooved Cz-Si wafers was carried out in an apparatus usually used for the epitaxial growth of thin Si layers for photovoltaic applications [3]. The maximum sample size was therefore limited by the apparatus to 25mm × 50mm. The apparatus consists basically of a crucible with a Sn-melt surrounded by a quartz tube filled with hydrogen at atmospheric pressure to prevent melt and wafer surface from oxidation. Heat is generated by two separately controllable coils winded around the tube.

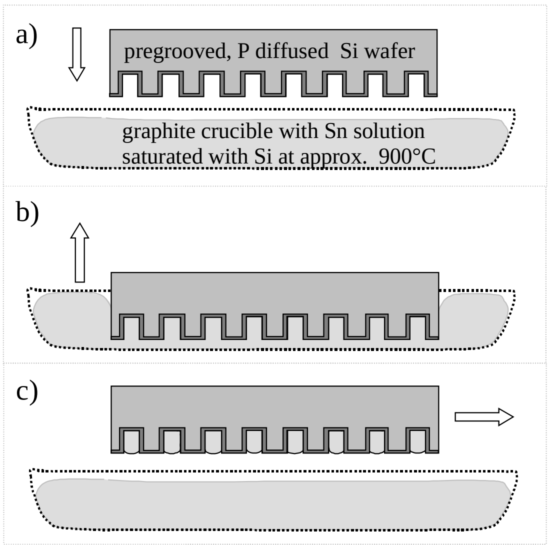


Fig. 1: *Basic process of the novel front metallisation in a Sn melt. a) A grooved and phosphorous diffused Si wafer is dipped into a Sn melt saturated with Si at a temperature of around 900 °C. b) The substrate is dipped into the melt until the grooves are completely filled. c) After metallisation the substrate is unloaded for further processing.*

Figure 1 demonstrates the basic concept of the metallisation process: a grooved, phosphorous diffused Si wafer is dipped for a few seconds into a Sn melt saturated with Si at temperatures of around 900 °C. On the one hand the relatively high temperature of 900 °C enables a good ohmic contact of Sn to the groove emitter, on the other hand it decreases the surface tension of the Sn melt enabling the metal to wetten the narrow contact grooves. After removal the Sn melt fills only the narrow grooves due to capillary forces whereas the surface remains uncovered. Experiments with different widths (30 µm-400 µm) and depths (30 µm-100 µm) of the grooves show that they get filled independently of the used geometry given that the groove surface is sufficiently smooth and free from oxide coverage. Saturation of the Sn melt with Si is necessary to prevent dissolution of Si from the wafer. At 900 °C the saturation of pure Sn is reached at 0.3 wt% Si. Since the surface tension of pure Sn melt is still high the wafer has to be dipped into the melt completely to force the metal to penetrate into the grooves. The surface tension of the melt can be decreased by the use of higher temperatures or by the admixture of a metal such as Ga.

3. RESULTS AND DISCUSSION

3.1 Groove geometry and filling

As the specific resistance of Sn (11 µΩcm) is about 6 times higher than that of Cu (1.7 µΩcm) some considerations have to be taken into account concerning the geometry of the contact grooves, in order to obtain an acceptable conductivity of the Sn fingers. Figure 2 shows a typical filling of the contact grooves processed by conventional electroless plating with Ni/Cu (a) and by our novel dipping method with Sn (b).

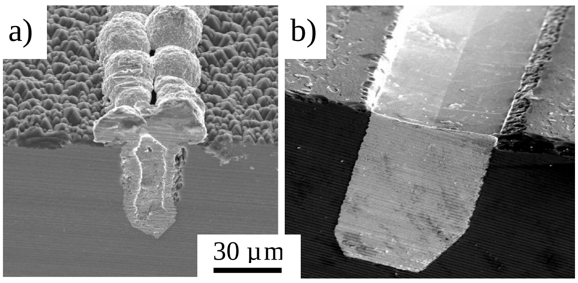


Fig. 2: *Metallised grooves of a BCSC by a) conventional electroless plating with Ni/Cu and b) novel dipping method with Sn.*

These two cross-sections differ mainly in two filling characteristics of the contact groove. Whereas the Sn-contact fills the groove completely the Cu-contact shows a gap in the middle of the groove. Furthermore the electroless plated Cu-contact has a convex surface while the Sn-contact shows a concave form. Both finger surfaces are suitable for a better light trapping behaviour in encapsulated cells.

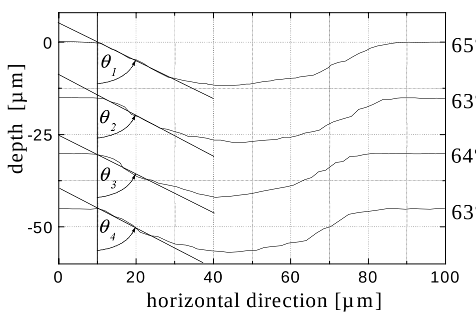


Fig. 3: *Surface profile (dektak) of four Sn finger contacts filling grooves with 70 µm width.*

Figure 3 shows a surface profile of four fingers measured on the same cell corresponding to the picture in Fig. 2b. The width of the contact groove was chosen to be relatively wide (70 µm) in order to obtain a good resolution of the finger surface measured by a dektak profilometer. The finger surface shows a typical concave form corresponding to solder wetting in narrow grooves found in the literature [4, 5, 6] with an average contact angle θ of 64° (measured on 25 fingers). As this angle does not depend on the width of the groove b in range of 10 µm-500 µm the cross-section of the finger contact shows a simple dependence on b. In order to obtain a conductivity of the contact finger of 500 mΩ/cm sufficient for a good solar cell performance a finger cross-section A_{finger} of approx. 2200 µm^2 is necessary. This can be achieved by a groove cross-section A_{groove} of 2250 µm^2 when a width of 25 µm is supposed. Therefore the depth of the groove has to be 90 µm which is only about twice as high as used for standard BCSC (25 µm×40 µm).

3.2 Cell processing and performance

Cells with three different sheet resistances (30 Ω/sq, 9.5 Ω/sq and 6 Ω/sq) with homogeneous emitter/groove diffusion were processed with and without a 300 µm wide busbar for standard I-V- and transmission line model (TLM)-characterisations. The applied processing sequence is shown below (without ARC and BSF):

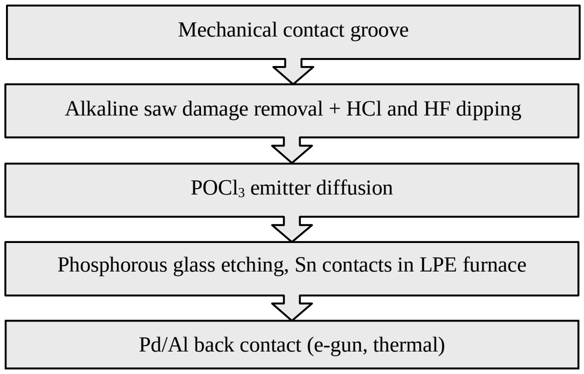


Fig. 4: *Processing sequence of the BCSC with capillary dipping method.*

First of all the Cz-Si wafer was mechanically grooved with a dicing saw using a 30 µm rectangular dicing blade followed by alkaline saw damage removal, Wafer cleaning and $POCl_3$ emitter diffusion. After P-glass etching the front contact was processed in an LPE-furnace taking an overall time of 2 minutes. Processing was completed by the back contact formation realised by evaporated Pd/Al. Two typical cells are depicted in Fig. 5.

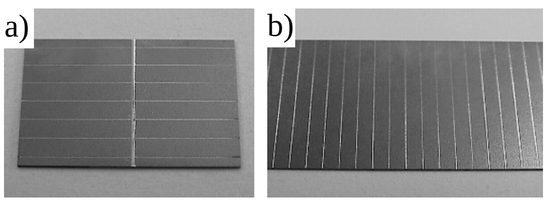


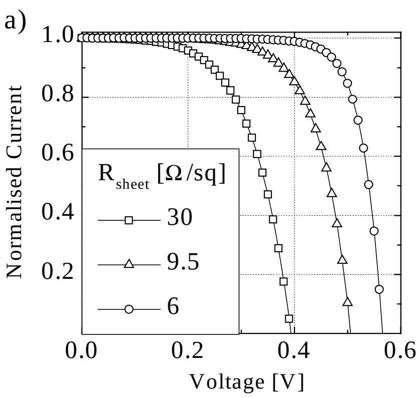
Fig. 5: *Metallised Cz-Si wafers a) with and b) without busbar for contact measurements. The solar cells are processed with a homogeneously diffused emitter/groove and a Pd/Al back contact (without ARC and BSF). The finger spacing is 2 mm in both cases.*

Resistance measurements realised by the TLM-method for all three emitter sheet resistances resulted in a good specific contact resistance ρ_c lower than 5 mΩcm^2. Table I summarises the results of the resistance measurements.

Tab. I: *Specific contact and emitter sheet resistance of three Sn-metallised substrates with different initial emitter sheet resistance.*

cell ID		C24	D13	F23
R_{sheet} (before)	[Ω/sq]	30	9.5	6.0
R_{sheet} (after)	[Ω/sq]	31	10	6.0
ρ_c	[mΩcm^2]	4.6	2.5	**0.2**

The emitter sheet resistance remains constant before and after metallisation which indicates that the surface of the Si wafer is not affected during the short dipping process.



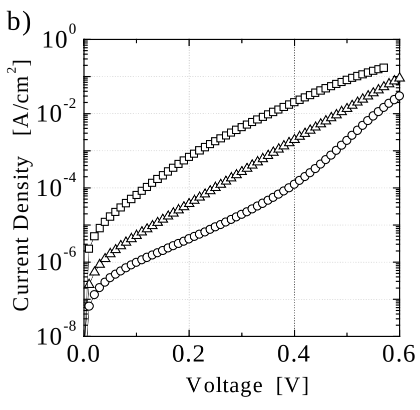


Fig. 6*: a) Normalised illuminated and b) dark I-V characteristics of three Cz-Si BCSC with different sheet resistances of the homogeneously diffused groove/emitter.*

Figure 6 shows the normalised illuminated and dark current-voltage measurements for three identically (besides emitter sheet resistance) processed cells. Table II depicts the cell parameters.

Tab. II: *Cell parameters of three Cz-Si BCSC with different emitter sheet resistances fabricated without ARC and BSF.*

cell	ID	C21	D19	F14
R_{sheet}	[Ω/sq]	30	9.5	6.0
area	[cm^2]	5.9	5.1	5.9
J_{SC}	[mA/cm^2]	21.1	17.2	14.5
V_{oc}	[mV]	393	506	566
FF	[%]	58.6	67.6	**77.7**
η	[%]	4.9	5.9	6.4

The decrease of the light-generated current with lower sheet resistance can be explained by a poor blue response caused by the presence of a dead layer. The behaviour of the I-V characteristics is similar to investigations of nickel-sintered contacts in dependence on different groove diffusion sheet resistances [7]. At high sheet resistances the degradation of voltages and fill factors is caused by the finger contacts being shunted to the base by a Schottky contact between metal and p-type substrate, created by either contact spiking or by the lack of a diffused layer in some parts of the grooves. The latter could result either from an inhomogeneous $POCl_3$ diffusion or more likely from a slight dissolution of the Si surface during the dipping process. Nevertheless the cell with the lowest sheet resistance of 6 Ω/sq has a good fill factor of 78 % which indicates a good contact between the Sn finger and the groove emitter. With the use of selective emitters (groove: 5 Ω/sq; emitter: approx. 100 Ω/sq), ARC and BSF efficiencies of up to 16 % should be feasible using this simple dipping method.

4. CONCLUSION AND OUTLOOK

We presented an entirely new metallisation concept for BCSCs realised by a simple dipping process into a silicon containing metal melt. The first solar cells fabricated on grooved, homogeneously diffused emitter/groove Cz-Si wafers show promising results proving our method to be suitable for BC finger formation. The obtained finger line resistances of around 500 mΩ/cm, specific contact resistances ρ_c of less than 1 mΩcm^2 and fill factors of up to 78 % are comparable with parameters obtained for standard BCSCs. For a further increase in cell efficiency the use of selective emitter, ARC and BSF is inevitable.

In addition, an extension of our metallisation concept for the replacement of the groove emitter diffusion is under development at the University of Konstanz. Besides the metallisation this concept includes a simultaneous epitaxial emitter growth out of a modified metal solvent. The basic steps of this procedure are shown in Figure 7.

A grooved Si wafer is dipped into a Sn melt saturated with Si containing a small fraction of n-doping elements such as P, Sb or Bi (Fig. 7 a) and b)). After the epitaxial growth of a thin emitter layer on the whole front surface the wafer is pulled out of the melt (Fig. 7 c)). The Sn melt fills only the grooves whereas the surface remains uncovered (as discussed in the article). This enables a successive growth under the finger contacts making the emitter thicker thus preventing the finger contacts from being shunted to the base due to spiking (Fig. 7 d)).

This paper describes only two imaginable concepts regarding our metallisation procedure. In fact there could be a variety of other applications which are conceivable to be performed with the capillary dipping method. For

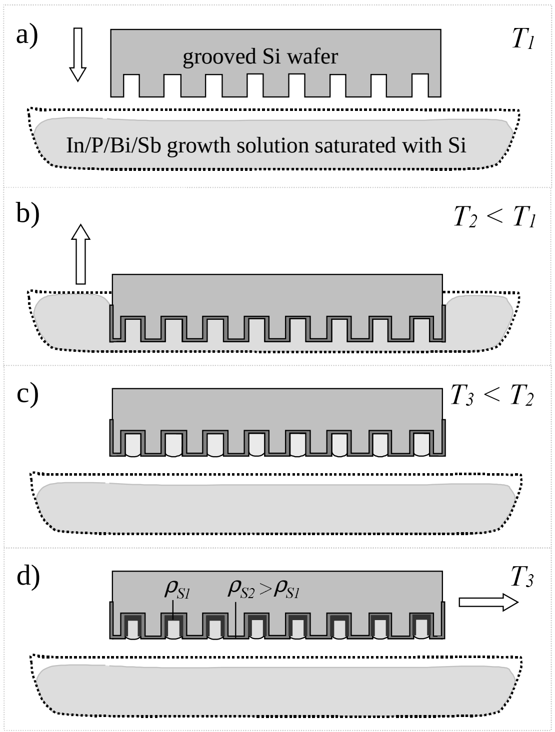


Fig. 7: *Front contact formation with simultaneous emitter growth applied for BCSCs.*

example the back contact could as well be fabricated during a dipping step if the rear side of the wafer is also grooved. The contacting material does not necessarily have to be Sn given that the dipping process is used just for contact formation without emitter growth. Many other metals and compounds with higher conductivity could be suitable for this method if the surface tension of the corresponding melt is low enough at reasonable temperatures around 900 °C and if the Si surface is not wetted.

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