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How to obtain solderable Al/Ni:V/Ag contacts

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Abstract

We investigate process sequences for obtaining solderable Al/Ni:V/Ag contacts to PERC-type crystalline Si solar cells by in-line Al evaporation. For a high cell efficiency the evaporated aluminum must be annealed at 350 °C for about 5 min. We find that annealing the Al/Ni:V/Ag metallization stack at temperatures above 150 °C destroys the solderability of the wetting layer. A solution for this problem is to first deposit the 2.5 µm Al layer by evaporation, then anneal the cell at 350 °C for 10 min, and finally sputter a double layer of Ni:V/Ag with respective thickness values of 200 nm and 25 nm. This process leads to a contact resistivity lower than 1 mΩcm^2. The solderablility is proven by a peel force greater than 3 N/mm. We present a solderable PERC cell with Al/Ni:V/Ag rear side metallization and an efficiency of 18.9%.

Keywords: Solderability; evaporated aluminum, Silicon solar cell, metallization

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1. Motivation

Evaporation of aluminum as rear side metallization for solar cells is a well know laboratory process that is used in many high-efficiency solar cell processes. Evaporated aluminum offers the advantage of a low contact resistivity to silicon below 1 mΩcm^2 [1] and is potentially cheaper than screen printing because of the lower material cost. However, the Al/Si interface shows high recombination. Another disadvantage of evaporated Al is that it is not readily solderable.

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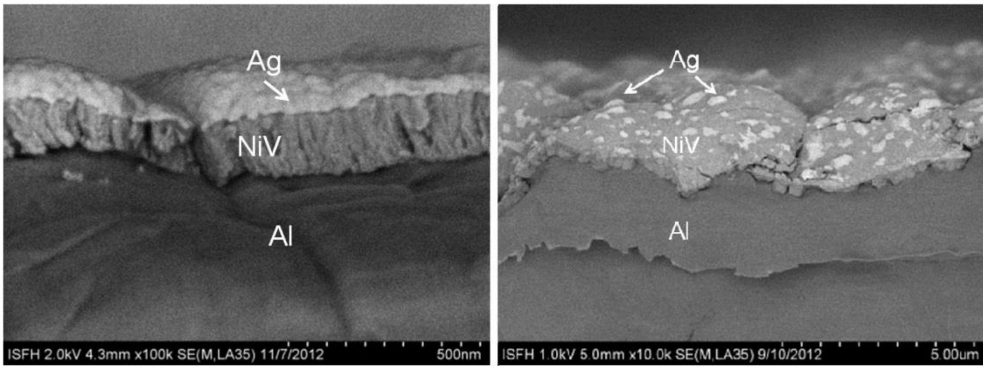

Fig. 1. Al/Ni:V/Ag meatallization stack, as deposited and solderable (left) and after a 5 min annealing at 350°C and not solderable (right).

The impact of the high recombination rate may be addressed by applying local contacts. The solderability issue can be solved by depositing additional layers onto the aluminum. Here, we investigate the Al/Ni:V/Ag stack. A scanning electron micrograph of such a stack is shown in Fig. 1. The solderability and the long term stability was recently reported in Ref [2,3]. In the mean time we observed that that the Al/Ni:V/Ag stack loses its solderability if annealed at temperatures above 150° C for longer than 1 min. Unfortunately an annealing process at 300-350°C for 1 to 10 min is required for sufficiently low contact resistance values of the Al/Si contact [1]. In this paper we therefore examine various process sequences that avoid the annealing of the Al/Ni:V/Ag stack an thus preserve its solderability.

2. Experimental

Our test structures are passivated emitter and rear cells (PERC) with screen printed front side contacts and evaporated aluminum on the rear side. The Al_2O_3/SiN passivation layer on the rear side of the cell is locally opened via laser ablation before the rear side metallization is processed. Figure 2 shows the cross-sectional view of such a cell. Reference [4] gives a detailed description of the base-line process that we use here. We evaporate the rear side metallization with a dynamic deposition rate of 7 µm m/min in our ATON 500 in-line high-rate evaporation tool from Applied Materials, using a transport speed of 2,8 m/min resulting in a layer thickness of 2,5 µm. This system has 2 additional sputter chambers for depositing Ni:V- and Ag-layers, with thickness of 200 nm and 25 nm respectively. The ATON 500 is capable of heating the wafers to a temperature up to 425°C.

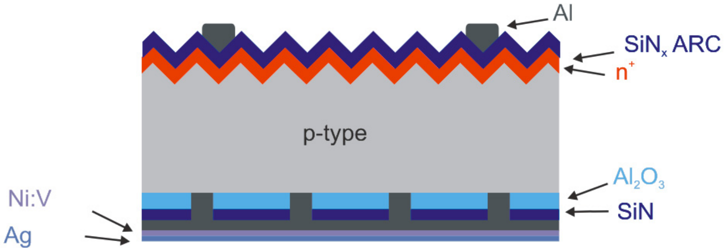

Fig. 2. Cross-section of the Passivated Emitter and Rear Cell. The front side is metallized via screen printing, the dielectric passivation layer at the rear side is locally opened via laser ablation and metallized with 2.5 µm evaporated aluminum, 200 nm Ni:V and 25 nm Ag.

We characterize the contact resistance of the Al-Si contact indirectly via series resistance measurements on the finished cell. The series resistance is measured via the double-light method [5]. We call the contact resistance “ok” if no improvement of the series resistance can be reached via annealing on a hotplate.

We also quantify the solderability by measuring the 180° peel force according to standard DIN EN 50461. For the peel force test a tin-coated cell interconnect ribbon is soldered on the metallized sample. The cell interconnect ribbon is then peeled off at an angle of 180° while measuring the force-path diagram. To pass the test a peel force higher than 1 N/mm is required, chipping of Si must not occur and the adhesion fracture has to be in the solder. Every process is tested on 3 cells.

3. Results

Table 1 gives an overview over the examined processes. Process 1 through 3 were described in the literature [1, 2]. In Process 4 we test an annealing step under atmosphere. We find an improvement of the contact resistance during annealing. However, the process breaks the Ag protection layer and thus results in an oxidation of the Ni:V layer. This ceases the solderability. An SEM micrograph of such a sample is shown in Fig. 1 on the right hand side. Process 5 anneals the metallization stack in vacuum to hinder an oxidation of the Ni:V layer. This however did, unexpectedly, not result in a reduction of the series resistance. This finding is not yet understood and occurs also in process 6 and 7.

Table 1. List of processes and associated contact resistance/Peel force. The samples were annealed at 350° for 10 min on a hotplate, or at 425° for 10 min in vacuum depending on the process.

No	*Sample metallization*	*Contact Resistance*	*Peel force > 1 N/mm*
1	Al	not ok	No
2	Al annealed	ok	No
3	Al/Ni:V/Ag	not ok	Yes
4	Al/Ni:V/Ag annealed	ok	No
5	Al/Ni:V/Ag annealed in Vacuum	not ok	Yes
6	Al/Ni:V/annealed in Vacuum/Ag	not ok	Yes
7	Al/annealed in Vacuum/Ni:V/Ag	not ok	Yes
8	Al/annealed/Al/Ni:V/Ag	ok	No
9	Al/annealed/Ni:V/Ag	ok	Yes

Process 8 uses two Al depositions. The first Al layer is annealed on a hotplate and then we deposit a Al/Ni:V/Ag metallization stack on top. This process reduces the contact resistance but does not pass the peel force test. We find that an aluminum-oxide grows on the Al surface during annealing. This oxide is a predetermined breaking point for the peeling test and is not dissolved when depositing the second aluminum layer.

Process 9 yields a reduction of the series resistance and also permits soldering. Here we anneal the deposited aluminum layer on a hotplate for 10 min at 350 °C and sputter Ni:V/Ag onto the thin aluminum-oxide that formed during annealing. The sputtered Ni:V layer shows a sufficient adhesion to the first deposited aluminum layer. The measured peel forces exceed 3 N/mm and are shown in Fig. 3. No chipping of Si occurs and the adhesion fracture is strictly in the solder.

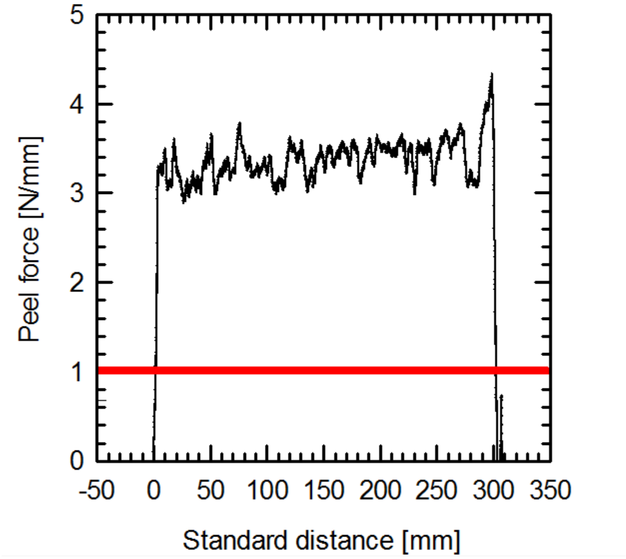

Fig. 3. Peel forces on a annealed PERC cell metallized with process 9. The red line represents the critical value for the standard DIN EN 50461.

To our knowledge this is the first process sequence resulting in solely vacuum processed solderable 156 x 156 mm^2 PERC cells that have a screen-printed front contact and an Al/Ni:V/Ag rear side metallization. The cell parameters of the best cell are displayed in Table 2. The modest voltage and efficiency is due to a large rear side metallization fraction. The metallization fraction is 3 %.

Table 2. Comparison of cell parameters after metallization and after annealing under standard testing conditions (156 x 156 mm^2, pseudo-square)

Cell type	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	η (%)	R_s (Ωcm^2)
After metallization	630	37.6	76.9	18.2	1.5
After annealing	631	37.9	79.1	18.9	0.6

4. Summary

We presented solderable 156x156 mm^2 PERC solar cells with screen-printed front side and evaporated aluminum rear side. The soldarability is achieved by sputtering a Ni:V/Ag stack after the annealing. Annealing is required for a low contact resistance. Using this process flow we obtain solderable Al/Ni:V/Ag contacts with a pealing force above 3 N/mm.

Acknowledgements

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