SERIES RESISTANCE IN DOUBLE-POLYSILICON-CONTACTED SILICON SOLAR CELLS.

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ABSTRACT

Series resistance values between 0.38 and 0.5 Ωcm^2 have been obtained in solar cells contacted with polysilicon to both surfaces. 2.6% of the front area is contacted with a silicon/ heavily doped polysilicon/ metal structure to replace the conventional metal contact. The same technology has been applied to the solar cell backs to replace conventional back-surface-field (BSF) structure . The devices were fabricated in 4" wafers, and a VLSI polysilicon emitter technology was applied to fabricate polysilicon contacts. The polysilicon-silicon interface was produced using either an HF etch or RCA clean before polysilicon deposition, and half of the wafers were implanted with fluorine to assess the passivating effects on the polysilicon-silicon interface. The drive-in time of the impurities from the polysilicon into the silicon was also varied. The main results are that the series resistance is generally lower in fluorinated samples, both HF and RCA.
The contibution to the total series resistance of the back side structure is evaluated by sustracting the front contributions independetly measured.

INTRODUCTION

Polysilicon emitter technology is widely used in high speed bipolar transistors for VLSI circuits. The use of this technology in polysilicon emitter contacted solar cells in obtaining a low series resistance values has been recently reported [1].
Improvements in the red spectral response (RSR) and moderate improvements in open-circuit voltage were also shown introducing a silicon/heavily doped polysilicon/ metal structure at the back surface compared with control conventional BSF cells [2]. The origin of these improvements is atributed to the low recombination value on the polysilicon / silicon contact.
The objective of this work is to quantify the contribution of the back polysilicon contact to the total series resistance .

EXPERIMENTAL PROCEDURE

A number of devices were fabricated in 4" wafers. using a VLSI polysilicon emitter technology to contact the emitter surface of solar cells and to replace the conventional high-low junction or back-surface-field (BSF) to produce a device structure such as shown in Figure 1. The fabrication process included an initial oxidation to grow a 500 nm thick field oxide. After opening the active area , a 100 nm thick oxide was grown. To create a single crystal emitter, Phosphorus was implanted to the front surface and annealed at 950° C. The depth of the single crystal emitter is 0.22μm and the surface concentration $5x10^{18}$ cm^{-3}.

The polysilicon emitter devices are very sensitive to the polysilicon/silicon interface, and the experiment included two different treatments: some of the wafers were given an HF clean and the others an RCA. These treatments were given to both , front and back surfaces, prior to an amorphous silicon layer deposition at 560°C in a LPCVD system.

Three implants were then given to the devices. On the fronts polysilicon was implanted with Arsenic (10^{16} cm^{-2}), on the backs the polysilicon was implanted with Boron (10^{16} cm^{-2}).
Additionally fluorine was implanted in one half of each wafer, and only to the fronts. Fluorine implantation has been shown to be beneficial to passivate interface states and to promote interfacial oxide break-up

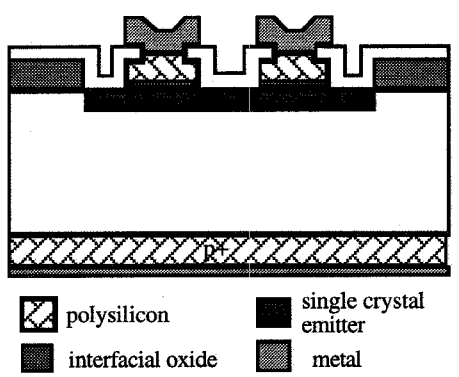

Figure 1. Cross section of the polysilicon BSF cells.

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25th PVSC; May 13–17, 1996; Washington, D.C.

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Polysilicon was patterned, and a new thin oxide was grown after removal of all previous oxide . During this oxidation the polysilicon implants were annealed and impurities driven in. The importance of this anneal in the interface morphology was assessed by using several furnace times, all at the same temperature: 850° C.

The process splits considered the three main variables: (a) surface treatment prior to polysilicon deposition , was either an HF etch or RCA clean ,(b) Fluorine implant in half of the wafers, only to the fronts (fluorinated devices are labeled as " f " in the figures, and unfluorinated devices as "nf") and (c) drive-in time of the impurities from the polysilicon into the single crystal silicon was varied from 40´to 120´.
(see Table 1).
Control wafers were also processed in which a conventional back surface field was created by a solid source boron diffussion

Wafer	Interface treatment	Fluorine Implant	Drive-in time at 850°C
7 f	HF	yes	40'
7 nf	HF	no	40'
8 f	RCA	yes	40'
8 nf	RCA	no	40'
9 f	HF	yes	80'
9nf	HF	no	80'
10 f	HF	yes	120'
10 nf	HF	no	120'

Table 1. Summary of the main parameters considered

SERIES RESISTANCE

The series resistance, normalized to cell area, can be estimated by

$$r_s = P_{total} / J_L^2 \tag{1}$$

where J_L is the light-generated current density at the maximum power point , and P_{total} includes all the power loss components normalised to cell area. rs is given in Ωcm^2 and Ptotal in W/cm^2

The total power loss can be splitted in its main components as follows [3]:

$$P_{total} = P_{sheet} + P_{front-contact} + P_{finger} + P_{bus} + P_{base} + P_{back-contact} \tag{2}$$

the expressions for each component being the following:

$$P_{sheet} = \frac{1}{3} J_L^2 b^2 R_{sheet} \tag{3}$$

$$P_{front-contact} = J_L^2 b \left(R_{sheet} \rho_c\right)^{\frac{1}{2}} \tag{4}$$

$$P_{finger} = \frac{\frac{2}{3} J_L^2 a^2 b \left(\rho_f\right)}{tw} \tag{5}$$

$$P_{Bus-Bar} = \frac{\frac{1}{3} J_L^2 a\ n^2 b^2 \left(\rho_f\right)}{tw_b} \tag{6}$$

$$P_{base} = J_L^2 \rho_b l \tag{7}$$

where R_{sheet} is the diffused emitter sheet resistance, ρ_c is the specific resistivity of the front contact, ρ_f is the resistivity of the metal, and ρ_b is the base resistivity . The active area is 2nab, w is the width of the fingers, w_b is the bus bar width, t and l are the thickness of the metal and the wafer respectively (see figure 3).

Using equations (3) to (7), the various contributions to power loss associated to the series resistance can be calculated.

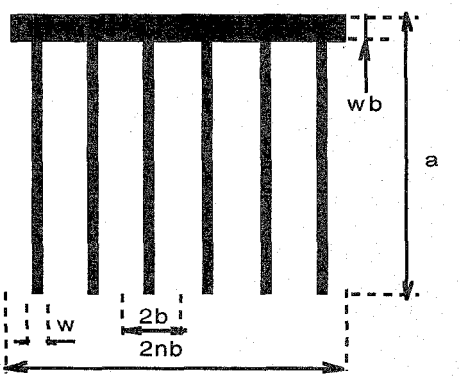

Figure 3. Contact grid patern.

The contributions of the front diffused emitter layer , metal fingers, bus bar and base resistance are measured from independent test structures of sheet resistance.Substracting these components from the total power loss in the conventional BSF devices leads to the value of the power loss component from the front polysilicon contacts. Then, the power loss resulting from the back contact, P_{bc}, can be estimated, by

$$P_{bc} = P_{total} - P_{sheet} - P_{front-contact} + P_{finger} + P_{bus} - P_{base} \tag{8}$$

and the resistance associated with the back contact, normalized to cell area, r_{bc}, is then given by

$$r_{bc} = P_{bc} / J_L^2 \tag{9}$$

This resistance comes from the silicon/ polysilicon/ metal structure whose components are: resistance of the metal,

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the polysilicon-metal interface resistance, the resistance associated with the polysilicon and the silicon-polysilicon interface resistance.

RESULTS

Systematic measurements were carried out on a number of devices in each wafer and then averaged values were computed for the total series resistance.

I(V) characteristics and series resistance measurements were made using a standard procedure, and then the results compared with a more recent method [4].

Figure 4 shows the values for the total specific series resistance for both types of devices: conventional BSF and polysilicon BSF. The results are plotted against the drive-in time of the impurities from the polysilicon to the single crystal silicon.

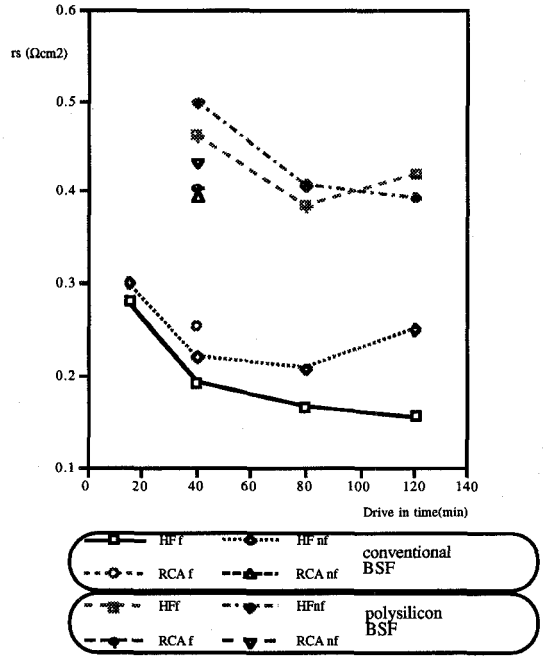

Fig.4 Total measured specific series resistance (Ωcm^2), in conventional and polysilicon BSF cells.

Values between 0.38 Ωcm^2 and 0.5 Ωcm^2 have been obtained which are of the same order as state of the art solar cell values [4]. It can also be seen that the fluorine produces a reduction of the series resistance in all HF samples and in most of the RCA samples.This general trend is only broken for the longest drive-in time of 120 minutes

Thid results are consistent with most of the published data on polysilicon contacts: fluorine implantation promotes interface oxide break-up and passivates interface states. These effects seem to also depend on the thermal budget.

The sheet resistance values for the diffused emitter are shown in table 2.

Wafer	Rsheet (Ω/square)
7f	1900
7nf	1900
8f	1750
8nf	1750
9f	1575
9nf	1575
10f	1300
10nf	1300

Table 2. Diffused emiter resistance measured

Using these values, and dividing the expressions (5), (6) and (7) by J_L^2, the specific resistances of each contribution to the total power loss can be calculated. The front polysilicon contact resistance is computed according to the procedure described in previous paragraphs. Figure 5 is a plot of the resistance of the polysilicon front contact plus the resistance of the front diffused emitter

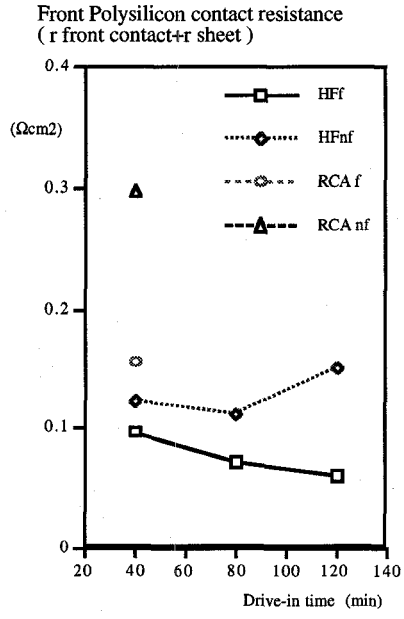

Figure 5. Specific resistance associated to the emitter.

Finally the range of values for the specific resistance associated to the back contact structure rbc given in equation (9), is shown in figure 6 .

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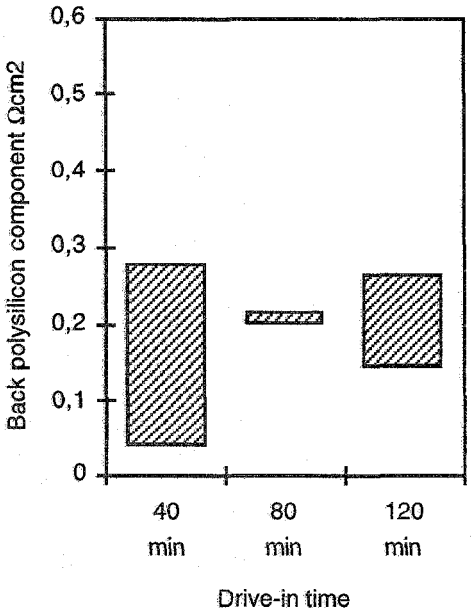

Figure 6. Specific resistance of the back contact structure.

This component should in principle be independent of the Fluorine treatment which is only given to the front surface. It would depend on the anneal and drive in time because this step also serves to activate the back polysilicon impurities and to drive-in them into the base layer. The results shown in Figure 6 indicate that at 80 minutes all the values obtained fall into a short range, tipycally around 0.2Ωcm2. On the contrary at 40 minutes the range of values found is much greater with tipycal values for HF devices around 0,25 Ωcm2. For 120 minutes the range of values broadens again. In all these samples .

CONCLUSIONS

From the results outlined, several conclusions may be drawn.

The qualitative effect of the fluorine on the series resistance is as expected from results reported for other devices [5, 6]. In particular, the fluorine promotes the oxide break-up even for temperatures as low as the ones used in this work. The fluorine step reduces the series resistance in all cases except for the longest drive-in time in RCA samples.

The drive-in time of 80´in the HF treatment gives the lowest values of the total series resistance.

The measured polysilicon front contact components are of the same order as recently reported results [7].

The contribution to the total series resistance of the back polysilicon contact is estimated to be tipically around $0.2\Omega cm^2$

(*) Work supported by a JOULE II project nºCT92-0023 of the Comission of the European Union.

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