FIRST RIBBON GROWTH ON SUBSTRATE (RGS) SOLAR CELLS WITH SELECTIVE EMITTER

U. Hess[1], S. Joos[1], S. Seren[1], G. Hahn[1], T. Weber[2], P.-Y. Pichon[3], A. Schönecker[3]
[1]University of Konstanz, Department of Physics, P.O. Box X916, 78467 Konstanz, Germany
[2]SolarWorld Innovations GmbH, P.O. Box 1711, 09587 Freiberg, Germany
[3]RGS Development B.V., P.O. Box 40, 1724 ZG Oudkarspel, The Netherlands
Author for correspondence: uwe.hess@uni-konstanz.de, Tel.: +49 7531 882060, Fax: +49 7531 883895

ABSTRACT: Ribbon Growth on Substrate (RGS) technology is a cost-effective approach in terms of silicon usage per watt peak. The wafers are cast directly out of the melt onto reusable substrates. This process omits material losses which occur e.g. by wire-sawing in standard blockcast wafering techniques. Also the wafers can be cast at a high production speed in the order of one wafer per second. However, the material suffers from various crystal defects and has grain sizes between 0.1 mm and 1 mm. To develop and adjust new cell designs, we investigate the effect of a selective emitter structure on RGS cells. To realize a selective emitter the etch-back approach is used. It is found that the expected gain of j_{sc} is accompanied by losses in the fill factor. These effects compensate each other in such a way, that no significant increase in solar cell efficiency is observable up. These first experiments with selective emitters on RGS wafers results in efficiencies up to 12.4%.
Keywords: Ribbon Silicon, Selective Emitter

1 INTRODUCTION

1.1 RGS Wafer Production

Fig. 1 shows the principle of Ribbon Growth on Substrate (RGS) [1] wafer casting. The wafers are cast directly out of the melt onto reusable substrates. The decoupling of the pulling direction and the crystallization direction results in a very high production speed in the order of one wafer per second and the wafer thickness is adjustable. However, due to the fast crystallization the material suffers from crystal defects and has grain sizes in the order of ~0.1-1 mm.

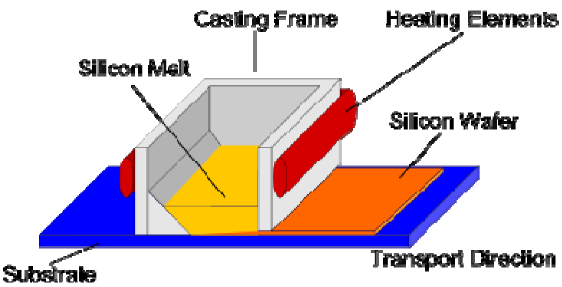

Figure 1: RGS wafer casting principle.

In the past a laboratory scale R&D installation at ECN (the Netherlands) was used to investigate and optimize the casting process. The results of crystallographic investigations and solar cell results were used to plan and build a new industrial scale installation by RGS Development B.V. This new installation is operable and produces large area wafers (6”). First solar cell results reached efficiencies up to 11.4%. However, the machine is in the phase of testing and optimization. Thus, all wafers and cells presented in this publication originate from the R&D installation.

1.2 Selective Emitter

Up to now several ways to realize the selective emitter concept are used in solar cell processes. Hahn has shown [2] that common techniques result in an efficiency gain of 0.5-0.6%$_{abs}$. Some of these methods include high temperature process steps (e.g. an additional $POCl_3$ diffusion) or steps that can introduce thermal stress into the material (e.g. laser doping). However, it was shown that high temperature steps can have a detrimental effect on RGS material quality [3]. Thus, the etch-back approach [4] was chosen to realize a selective emitter on RGS wafers. In this process a highly doped emitter with a sheet resistance of 30 Ω/sq. is etched back to a higher sheet resistance (~80 Ω/sq.). The wafer areas which are designated for the contact formation are protected by an etch resist mask and remain highly doped. The etching of the emitter has to be extremely controllable (emitter thickness <1 µm). This is achieved with the formation of a porous silicon layer by the wet-chemical etch and the subsequent removal of it.

2 CELL PROCESS

Fig. 2 shows the applied cell process. Prior to this process the RGS wafers from the R&D installation are planarized. This mechanically leveling of the wafer surface facilitates the solar cell processing.

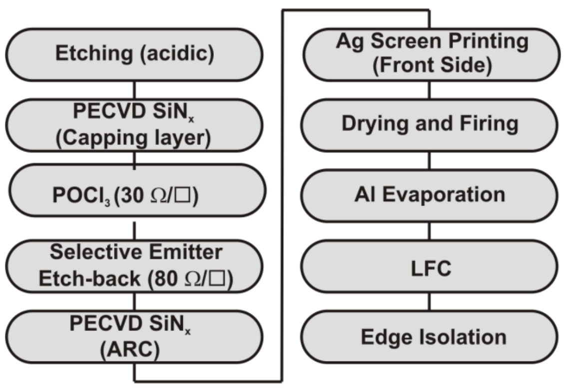

Figure 2: Applied cell process.

After an acidic etching step a capping layer on the wafer rear side is applied to ensure a single side emitter diffusion (30 Ω/sq.). According to the selective emitter structure realized by the etch-back approach an etch resist mask is screen-printed on the wafer front surface. In the next step the emitter in all wafer regions without the mask (the regions where the front metallization will not be applied) is etched back to ~80 Ω/sq. Afterwards the etch resist mask is chemically removed. Subsequently an anti-reflection coating (ARC) on the front surface is applied by PECVD SiN_x and Al is evaporated on top of the capping layer on the wafer backside (for the LFC concept). For the front side metallization an Ag grid is screen-printed and fired and the rear side is treated with a laser processing step. The LFC metallization [5] was chosen because of the beneficial effects for this material [6]. In addition, several RGS wafers were processed the same way but with a homogeneous emitter (50 Ω/sq.) instead of a selective one to be able to compare the effects on solar cell parameter level.

This process excludes a front surface texture and thus reflection is increased. In the past, several wet-chemical texturizations as well as plasma textures were applied to RGS wafers. This resulted in higher current densities but the gain due to less reflection was accompanied by losses in fill factor and voltage. It was shown [3] that the responsibility for that lies in the interaction of texturization and the relatively high amount of crystal defects (which can be made visible via an etch pit density investigation [7]).

2 CELL RESULTS

Because of the distribution of crystal defects, the material quality of RGS wafers from the R&D installation can differ in different casting runs and even from wafer to wafer. Thus, large area wafers were cut into 5x5 cm^2 wafers to ensure a maximum of comparability. The parameters of three solar cells originating from one RGS wafer are exemplarily shown in Table I. Two cells were processed with a selective emitter and the third has a 50 Ω/sq. homogeneous emitter for comparison. The best performing cells show an efficiency of up to 12.4%.

These parameters represent the trend in all obtained cell results. Table II shows the average difference of fill factor, j_{sc} and shunt resistance in respect to cells with a homogeneous emitter.

Table I: Representative cell results (cell area 5x5 cm^2).

Emitter	FF (%)	j_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)
selective	70.5	28.8	588	11.9
selective	69.5	28.9	585	11.7
homogeneous	73.7	27.9	580	11.9

Table II: Average difference of selective emitter cell parameters in respect to homogeneous emitter cells.

ΔFF (%)	Δj_{sc} (mA/cm^2)	ΔR_{Shunt} (%)
-3	+0.5	-55

The loss in shunt resistance is responsible for the loss in fill factor. For example the shunt resistance of the cells with selective emitter shown in Table I is ~250 Ωcm^2 and the corresponding cell with homogeneous emitter has a shunt resistance of ~750 Ωcm^2. The cell efficiencies are approximately identical. It seems that the losses in fill factor compensate the gain in j_{sc} nearly perfectly. A clear trend in open-circuit voltages could not be observed. Since parameters of RGS solar cells can strongly vary (compared to other materials) a larger statistic would be necessary to see such a trend.

3 ADVANCED CHARACTERIZATION

3.1 Spectral Response

Spectral Response measurements were carried out to clarify the effect of the selective emitter on RGS solar cells. Fig. 3 shows obtained IQE curves of selective and homogeneous emitter cells.

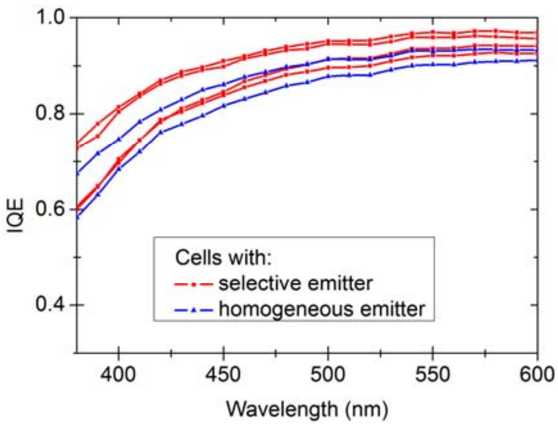

Figure 3: IQEs in the short wavelength region.

The impact of a front side emitter is best observable in the short wavelength region (~400 nm). The trend towards an increased current density of selective emitter cells is confirmed by the higher IQEs in respect to homogeneous emitter cells. Fig. 3 also demonstrates that solar cell parameters of RGS cells are subject to a broadened distribution due to lateral differences in material quality of the wafers. The gain in j_{sc} solely depends on the improvement in the short wavelength region, since in the long wavelength region (600-1200 nm) such a distinction could not be made.

3.2 Lock-In Thermography

Since the selective emitter process has lowered the shunt resistance of the cells, a Lock-In Thermography measurement (iLIT) [8] was carried out to look for hot spots, shunts and regions of enhanced recombination.

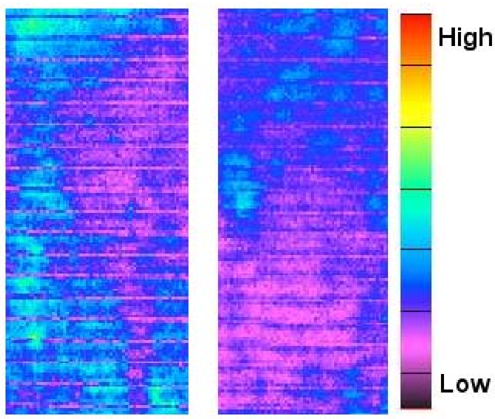

Figure 4: Magnified sections of Lock-In Thermography pictures of a) selective emitter RGS cell b) homogeneous emitter RGS cell.

Fig. 4 represents the overall trend that no single hot spots can be made responsible for the lowering of the shunt resistance, but the thermal signal is generally nearly homogeneously increased.

4 DISCUSSION

The gain in efficiency of the selective emitter structure on RGS wafers in terms of j_{sc} are compensated by losses in fill factor mainly caused by a lowered shunt resistance. The IQE curves show that the selective emitter is beneficial for a better blue response. However, iLIT shows an increased thermal signal. This is nearly homogeneously distributed over the cell which either means an increased recombination due to a homogeneous impact on the emitter or an effect on the high amount of grain boundaries and/or dislocations in such a way that a higher resolution would be needed to make this observable. Since no discrete hot spots and shunts are measureable the decrease in shunt resistance seems to be an effect of the interaction of the etch-back and crystal defects causing a local surface/emitter damage.

To reach a 30 Ω/sq. instead of a 50 Ω/sq. emitter, the wafers had the same $POCl_3$ diffusion but with a temperature increase of only ~27°C. It seems therefore unlikely that solely the stronger diffusion process introduced the lowered shunt resistances to the RGS cells. As a reference, multicrystalline wafers were also processed in the same way. Both mc cell groups with homogeneous emitter and selective emitter had an average fill factor of 78-79%.

Especially on RGS material the effect of an enhanced phosphorous diffusion along grain boundaries [9] is known. This effect is likely to be one of the leading shunt mechanisms in RGS solar cells. The emitter on the front surface is etched back to a sheet resistance of 80 Ω/sq. But if in grain boundaries or other extended defects a deeper emitter remains at a higher doping level, the probability of shunt paths along these crystal defects is higher as in the case of a lower doped emitter.

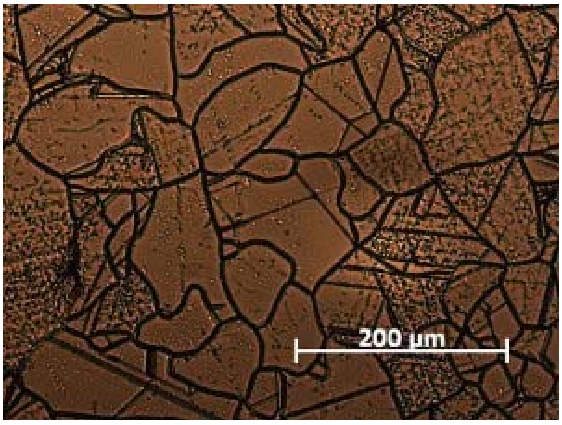

Figure 5: Polished RGS wafer treated with a Secco etch.

Fig. 5 shows a polished RGS wafer which was treated with a wet-chemical etch (Secco etch [10]) to make crystal defects visible. The grain boundaries appear as thick black lines and defects such as dislocations as black little spots. The number of these etch pits and thus disturbances of the crystal lattice vary strongly from grain to grain (resulting from the fast crystallization) and can reach a density of up to 10^4-10^6 /cm^2. Previous attempts to apply a texture to RGS cells led to losses in fill factor and open-circuit voltage. The assumption is that texturizations interact with the crystal defects in such a way that the front surface (emitter region) may be damaged. It seems to be possible that the etch-back approach for the selective emitter could have a similar problem. To etch back the emitter a layer in the range of tens of nanometers is removed, but this etching could be enhanced locally by crystal defects and could damage or at least inhomogeneously etch the emitter.

A study about the application of a selective emitter to multicrystalline wafers [11] proposed that the surface enlargement caused by the etching (especially at grain boundaries) is responsible for a drop in open-circuit voltage. Since the density of defects is much higher in RGS this behavior is enhanced.

5 SUMMARY

The first RGS solar cells with a selective emitter using the etch-back approach are presented. It is found that the expected gains in j_{sc} are accompanied by losses in shunt resistance and therefore fill factor. The gains and losses compensate each other in such a way that no significant gain in solar cell efficiency is observable. An explanation of this effect could originate from the enhanced phosphorus diffusion in grain boundaries or the damaging of the emitter by the interaction of crystal defects and surface enlargement by the wet-chemical etching solution. However, the first attempt to apply a selective emitter structure to RGS wafers resulted in efficiencies up to 12.4%.

6 ACKNOLEGDEMENTS

Part of this work was funded by the BMU in the OP-RGS (0325056) project. The supply of RGS wafers by RGS Development B.V. is gratefully acknowledged. The content of this publication is the responsibility of the authors.

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