SCREEN PRINTED INTERDIGITATED BACK CONTACT SOLAR CELLS WITH LASER FIRED CONTACTS

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ABSTRACT: In this paper we present a novel process for the fabrication of interdigitated back contact (IBC) solar cells on boron doped CZ silicon. Test cells were fabricated using laser fired contact technology for the formation of point base contacts. The technological challenges that arose during processing are identified and assessed. The best cell had an efficiency of 9.8%. A further simplification of the process is suggested. Slight adaptations can make the process suitable for emitter wrap through (EWT) solar cells.

Keywords: Back Contact - 1, Manufacturing and Processing – 2, Screen printing - 3

1 INTRODUCTION

The reduction of the cost per watt peak of solar energy is one of the main focal points of present solar cell research. It has led to the investigation of the suitability of thinner wafers for the industrial solar cell production.

Presently, the cell design featuring an emitter on the front of the cell and a screen printed full area back surface field on the rear dominates the solar cell market. This design, however, suffers from two drawbacks if the cell thickness is decreased. Firstly, a full area screen printed back surface field leads to wafer bowing if the cells become thinner making them less suitable for the back-to-front soldering used during module manufacture. Secondly, a moderate passivation quality of the screen printed back surface field will limit the cell efficiency as carriers that are generated deep in the bulk recombine at the rear surface. The trend towards larger cell area necessitates an improved conductivity of the emitter contact grid in order to minimize series resistance losses.

The IBC cell design has already proved to provide the potential of an excellent performance [1]. Commercially realized by SunPower Corp., it has surpassed conversion efficiencies of 20 per cent. Together with the HIT cell produced by Sanyo, the IBC cell holds the efficiency record for large area, single crystalline silicon substrates: 21.5% [2]. The record HIT cell was made on n-type Cz silicon and has an area of 100.3 cm^2, the record IBC cell was made on FZ silicon and has an area of 148.9 cm^2.

It is our goal to develop a fabrication process for the manufacture of IBC solar cells suitable for medium lifetime substrates. The employed technologies rely mainly on industrially established manufacturing processes and allow for moderate cell manufacturing costs.

2 CELL PROCESSING

The first test cells were produced on monocrystalline CZ wafers with a resistivity of 2 Ωcm. The cell design is shown in Fig. 1.

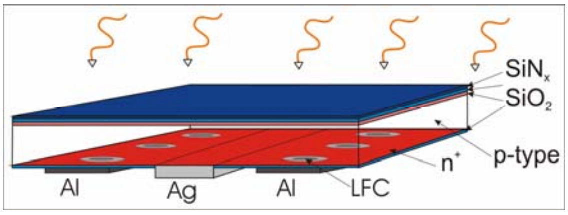

Fig. 1: Layout of the pursued IBC cell. The design features laser fired contacts, a floating emitter on the front side with a dielectric passivation through a thin layer of thermal oxide and PECVD SiN$_x$.

The processing scheme is shown in Fig. 2. Our starting material was 330 µm thick. The wafers were thinned in aqueous sodium hydroxide to 150 µm. In order to mask the areas that form the base contacts, a thin layer (75 nm) of PECVD SiN$_x$ was deposited on the rear side of the wafer and removed along the emitter regions with short pulse laser ablation. After the removal of the induced laser damage in aqueous sodium hydroxide, the wafers were exposed to a 35 Ω/sq $POCl_3$ gas phase diffusion. To avoid heavy doping on the front of the cells, the wafers were placed front-to-front in the diffusion oven.

Fig. 2: Processing scheme for IBC cells. Cells were fabricated on 2 Ωcm CZ silicon wafers with an original thickness of 300 µm.

Due to the low thickness of the wafers (at this point 120 µm) warping occurred during the diffusion causing inhomogeneous doping of the front with sheet resistivities ranging from 80 to 400 Ω/sq. Phosphorus glass and remaining PECVD SiN_x were then removed in aqueous hydrofluoric acid. After a piranha etch to clean the wafer surfaces a thin thermal oxide (approx. 15 nm) was applied for increased surface passivation. To lower front surface reflection a 65 nm PECVD SiN_x layer was deposited. Metallization of the emitter was done by conventional screen printing and sintering of commercially available silver paste. Subsequently, aluminum was evaporated along the regions that previously have been shielded from the phosphorus diffusion by PECVD SiN_x. Shadowing of the emitter contacts during the evaporation was achieved using a mechanical shadowing mask. Afterwards, laser fired contacts (LFC) were applied to contact the base. The rear side processing is shown in more detail in Figure 3.

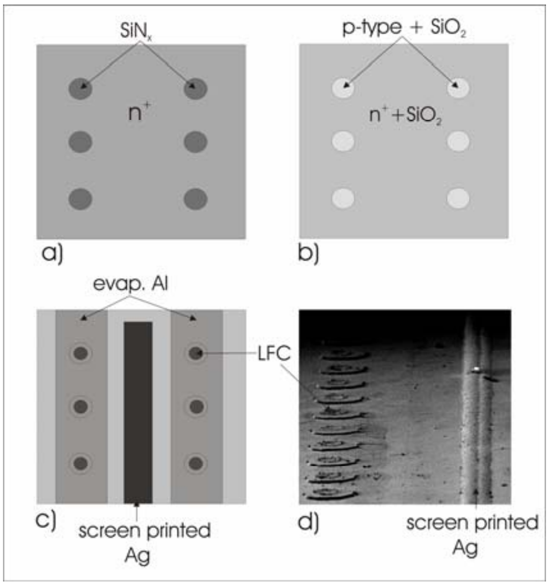

Fig 3.: Processing and design of the rear side. a) After thinning of the wafers a PECVD SiN_x layer acting as a diffusion barrier was deposited on the rear side and partially subsequently removed. Then, the wafers were submitted to a gas phase $POCl_3$ diffusion with $R_{\square}$ = 35 Ohm/sq. b) The p-glass was removed along with the remaining PECVD SiN_x in aqueous hydrofluoric acid. For increased surface passivation the wafers were thermally oxidized (d = 15 nm). c) The emitter was contacted through screen printing and firing of conventional silver paste. Then, aluminum was evaporated on top of the SiO_2 along the regions that had previously been shielded from the phophorus diffusion. The base contacts were then laser fired. d) A SEM image of the rear side is shown. The initially circular base contact regions take on a cylindrical shape (450 µm in diameter) after the removal of the laser damage.

Previous attempts at the fabrication of screen printed IBC cells involved the use of AgAl pastes to contact the base. The produced cells suffered from low fill factors caused by shunting and a high series resistance [3]. The use of AgAl paste required high sintering temperatures to achieve a good ohmic contact to the base substrate. This led to the emitter contacts penetrating the emitter and shunting it with the base. Furthermore, the use of AgAl paste required wide base contact gridline (d = 500 µm), which caused losses in J_{sc} above the base contacts.

3 EXPERIMENTAL RESULTS

To test the laser operating parameters of the LFC formation, standard screen printed cells were processed in parallel on multicrystalline substrates (0.5 Ωcm, 270 µm). For increased passivation these cells were covered with a thin (d = 15 nm) thermal oxide prior to PECVD SiN_x ARC deposition. These cells outperformed their full area screen printed BSF counterparts in terms of the open circuit voltage by several mVs (Table 1). From these results we conclude that the laser firing parameters are suitable for the rear contact formation.

	V_{oc} [mV]	J_{sc} [mA/cm²]	FF	η [%]
Full area BSF	618	33.9	.76	15.9
LFC	627	29.3	.76	13.9
LFC, mod.*	632*	33.9*	.76*	16.2*

Table 1: Comparison of best cells with a screen printed full area BSF and cells with evaporated aluminium on the rear and laser fired contacts. The cell area was 25 cm². The difference in the short current density derives from a non optimal antireflection coating. This has led to a substantial increase in the cell reflectance.
*An optimal single layer antireflection coating (modelled) would have boosted the cell conversion efficiency to over 16%.

A batch of 8 IBC cells were made using the process shown in Fig. 2 and the average and best IV measurements are shown in the table below.

	V_{oc} [mV]	J_{sc} [mA/cm²]	Fill Factor	eff. [%]
Average (8 cells)	561	27.6	.55	8.5
Best cell	572	28.1	.61	9.8

Table 2: IV measurement results of fabricated IBC cells. Shunting limited the fill factor and the open circuit voltage. The cell area was 22 cm².

The cells suffered from low fill factors caused by shunting and a high series resistance. One of the causes for low open circuit voltages and low fill factors was shunting due to incorrect firing of the emitter contacts. Thermographic imaging (Fig. 4) shows that the silver paste penetrated the emitter during sintering of the contacts shunting it with the base.

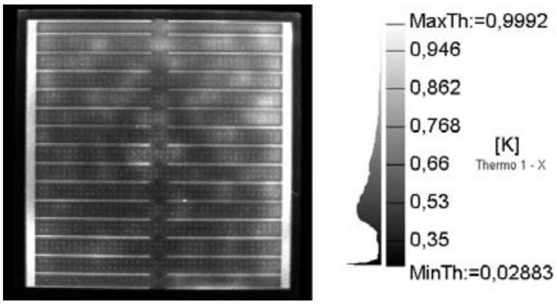

Fig. 4: Thermographic image of a fabricated cell. Light areas show an increased recombination of carriers. The emitter grid (busbars on left and right) have clearly penetrated the emitter, shunting it with the base. Between the grid lines of the emitter contacts a series of lighter colored dots can be seen. These are the base contacts formed by LFC technology.

The reason for the LFC spots showing in the Fig. 4 as centers of increased recombination can not yet be satisfactorily explained. A possible explanation is as a result of pinholes in the PECVD SiN_x coating. Areas beneath the pinholes would be n-doped during the $POCl_3$ diffusion. Laser firing of the aluminum contacts would then shunts these areas directly with the base.

While the measured efficiencies of the fabricated cells were lower than those of previous IBC cell designs, the test cells have shown the potential for high conversion efficiencies. Some technological challenges still have to be overcome.

4 CELL MODELLING

PC1D modelling of the cell shows that the devised concept offers the potential of high conversion efficiencies even for multicrystalline substrates with mediocre minority carrier lifetimes.

Carriers that are generated above the base contacts have to diffuse laterally to reach the n-doped emitter regions (Fig. 5). These areas will exhibit smaller short circuit current densities due to insufficient minority carrier diffusion lengths [4]. Therefore, it is important to minimize the area covered by the base contact regions in order to achieve high overall short current densities.

For the purpose of 1-d modelling the cell area has been separated into 1) the regions above the base contacts and 2) the remaining emitter regions. Each of these areas is modelled separately and afterwards the modelling results are averaged arithmetically. This gives an estimate of the impact of an increased base contact region on the cell performance.

LFC technology proves to be excellently suitable for the formation of minimal base contact areas as it allows for point contacts with diameters of less than 150 µm [5].

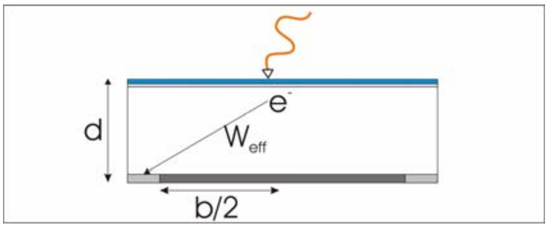

Fig. 5: Carriers that are generated above the base contacts have to diffuse laterally as well as vertically to reach the emitter regions. Thus, the upper limit for W_{eff} (necessary diffusion distance) becomes $((b/2)^2 + d^2)^{1/2}$. The median distance that carriers have to diffuse laterally is $(b/2)^{1/2}$.

As the modelling is focussed on the development of cells suitable for the industrial production, modelling parameters are chosen for typical industrial emitters and carrier lifetimes.

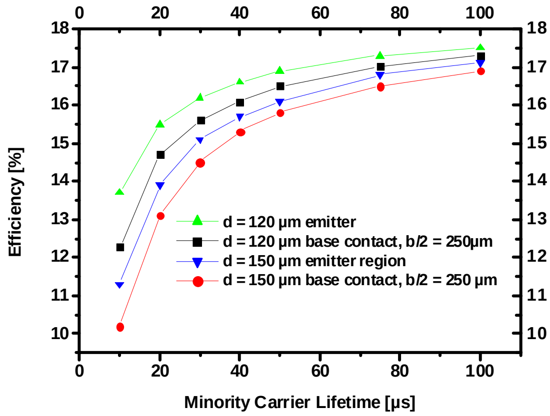

Fig. 6: Modelled cell efficiency for two substrate thicknesses (150 µm and 120 µm, $N_D = 5 \times 10^{15}\,cm^{-3}$, 3 Ωcm, τ = 30 µs) for emitter and base contact areas with a circular base contact diameter of 500 µm. The modelling parameters are: $S_{front} =$ 5000 cm/s, $S_{rear} = 50000$ cm/s, $R_{sheet,\ front} = 50\ \Omega/sq = R_{sheet,\ rear}$), untextured surface with a single layer PECVD SiN_x coating (n = 2.0, d = 75nm).

The drop in the short current density above the base contacts can be seen in the modelling results shown below. The modelled values represent a lower limit for the efficiency as a generation of the carriers near the front surface is assumed. This only holds true for very short wavelengths. For longer wavelengths the difference in the IQE between the emitter regions and the base contact regions becomes even smaller.

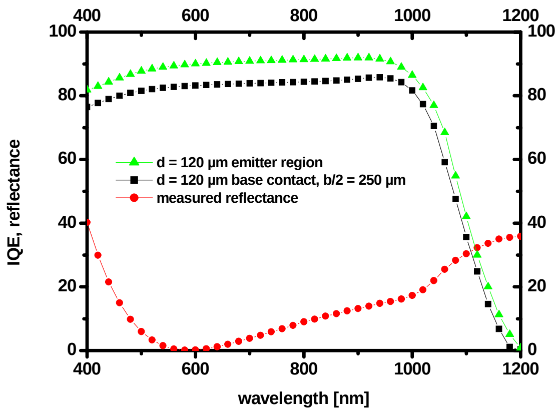

Fig. 7: PC1D modelling results of the IQE for emitter and base contact regions (τ = 30 µs). The reflectance data is taken from test cells that were coated with a single antireflection coating of PECVD SiN (n = 2.0, d = 75 nm) on an untextured surface.

4 FUTURE DEVELOPMENTS

The devised process for the manufacture of IBC cells (Fig. 2) is to be simplified further. Masking of the rear with PECVD SiN_x and a subsequent partial ablation by laser radiation can be replaced by the screen printed deposition of a diffusion barrier paste (Fig. 8). Recent developments of diffusion barrier pastes [6] can greatly simplify the fabrication process. Applied directly after cleaning and texturization of the wafers, it is a more cost efficient method that does not induce any damage to the bulk.

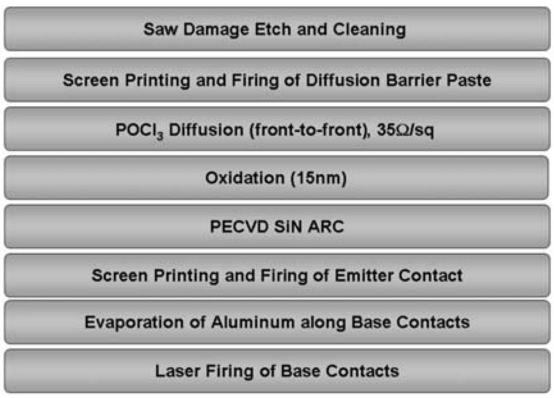

Fig. 8: Simplified processing scheme for manufacture of IBC cells on p-type substrates. Masking of the rear is achieved by the use of a screen printed diffusion barrier paste.

Due to the similiar design of the emitter wrap through (EWT) cell [7], the process is also suitable for the manufacture of EWT cells. This requires the formation of holes in the wafer prior to the processing sequence shown above. Due to the EWT cell featuring a front side collecting emitter, this process is especially advantageous for substrates with low minority carrier lifetimes.

5 SUMMARY

We have shown a processing sequence for the manufacture of screen printed IBC solar cells. The first test cells have been produced. Due to shunting and a high series resistance the cell conversion efficiency was pinned below 10%. An optimization of the firing should greatly enhance the cell performance.

1D modelling has shown that the cell design can achieve competitive efficiencies. And the cell efficiency is limited by the area fraction that is covered by the base contacts.

With slight adaptations, the process can also be applied to EWT solar cells that offer an advantage over the IBC cell design once the minority carrier diffusion length approaches the cell thickness.

6 ACKNOWLEDGEMENTS

This work was done at the University of Konstanz, Germany, as part of the Crystal Clear project funded by the European Commission`s FP6 Enery Research and Development program (contract No. SES6-CT-2003-502583).

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