SCREEN PRINTED LOW-COST IBC SOLAR CELLS – PREPARATORY INVESTIGATIONS

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ABSTRACT: In this paper we present the results of preliminary investigations on the use of screen printed emitters in interdigitated back contact (IBC) solar cells. Challenges of the individual cell concept that arise during processing are identified and assessed. Based on the characterization of different partially processed test structures we suggest approaches to overcome difficulties that arise during the processing of screen printed IBC cells.

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

1 INTRODUCTION

One of the paramount objectives of modern solar cell research is the reduction of the cost per watt peak of solar energy. Both the incipient trend towards the production of back contact cells, which allow for easier cell interconnection and higher packing densities within the module, as well as the use of thinner and larger substrates aim at this goal.

It is in two respects that the interdigitated back contact (IBC) cell features its most obvious advantages. Whereas conventional solar cell designs entail a trade-off between shadowing and series resistance losses, especially for large substrate sizes, the IBC cell knows no such compromise. Additionally, the IBC cell design profits from the use of thin wafers, which carry with them the difficulty of an increased bow for conventional, screen printed solar cells.

Aside from one commercial concept [1], the IBC cell has been mostly investigated in connection with high efficiency designs [2] and concentrator applications [3]. It is our goal to develop an IBC cell design based on industrially established manufacturing technologies. The cell should demonstrate an increased efficiency compared to standard screen printed cells, compensating for the moderately higher processing complexity inherent in the production of back contact solar cells.

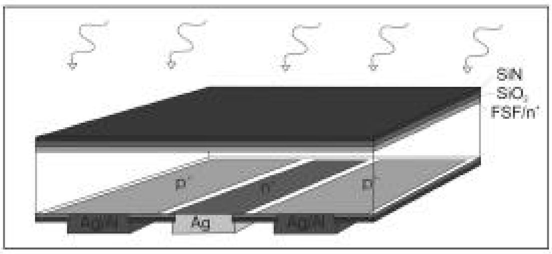

Figure 1: Design of the IBC cell on n-type doped substrate. Carriers generated near the front side must diffuse to the rear of the cell to reach the collecting junction.

2 CELL AND PROCESS DESIGN

The design of the IBC cell differs substantially from that of a screen printed cell. Processed on n-type doped substrates due to the higher minority carrier lifetimes and diffusion lengths compared with p-type substrates, the IBC cell has neither contacts nor collecting junction on the front, thus requiring all charge carriers to diffuse to the rear of the cell. This means that maintaining high carrier lifetimes and achieving excellent front surface passivation is essential.

Our present design incorporates several screen printing steps for metallization, formation of the emitter and patterning of the rear side.

The cells are fabricated on 125mm n-type CZ- and FZ-Si wafers (1.0-2.0Ωcm). In the future, the suitability of n-doped high lifetime mc-Si will also be investigated [4]. A complete processing scheme is shown in fig. 2.

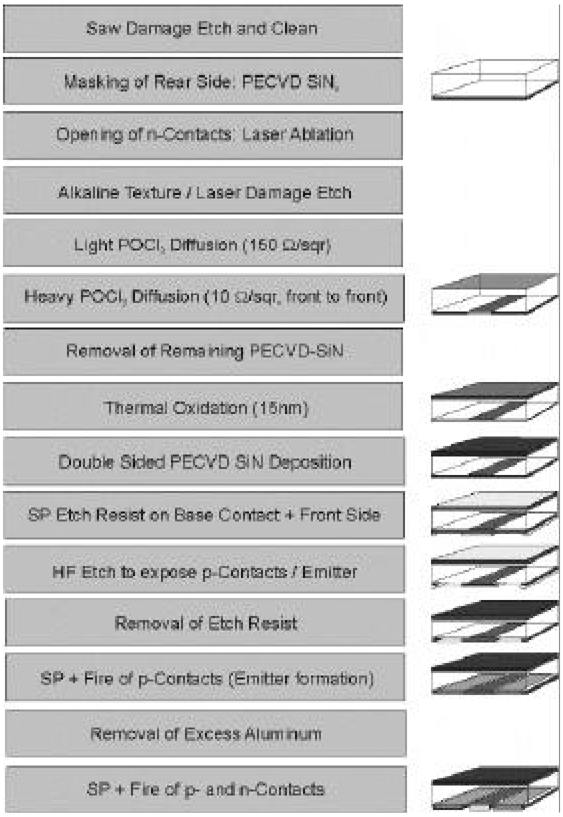

Figure 2: Process design of the IBC cell. The design relies on screen printing for patterning, emitter formation and metallisation.

At the beginning of the process, the saw damage is removed in hot NaOH. Depending on wafer thickness and minority carrier lifetime, this step, if necessary, can be combined with thinning of the wafer. After additional cleaning of the wafer, a direct plasma, low frequency PECVD SiN_x is deposited on the rear side as a masking layer.

Using a Nd:YAG laser for local ablation of the SiN_x dielectric layer, the base (n-type) contacts are opened. After the laser damage is removed in a hot Na_2CO_3 etch, which also serves to texture the front surface, the wafers are exposed to a light $POCl_3$ diffusion ($R_{sh} = 150\Omega$/sqr) for the front surface field. Following this diffusion, the phosphorus glass is removed in HF. The wafers then are subjected to a heavy gas phase phosphorus diffusion ($R_{sh} = 10\Omega$/sqr) which results in low contact resistance and recombination at the contacts and at the same time drives in the front surface field. The wafers are positioned front-to-front to prevent heavy doping of the front surface. Afterwards, the phosphorus glass and remaining SiN_x are removed in HF. Subsequently the wafers are thermally oxidised (d ˜ 15nm) passivating the front and rear surface. This is followed by a double sided PECVD-SiN_x deposition. The nitride acts as an anti-reflection coating (ARC) on the front side and a mask on the rear side. The next step is to screen print an etch resist mask on the front side and along the base contacts on the rear of the cell. The wafers are then submerged in buffered HF to etch the SiN_x and SiO_2 and expose the emitter/p-contact areas. The emitter formation is done using a full area screen print of conventional aluminium paste, heavily doping a large part of the rear side of the cell while not penetrating the SiN_x/SiO_2 stack along the areas that will eventually be the p-contacts. Excess aluminum is removed in HCl. In a last step the p- and n-contacts are screen printed and fired.

This process is designed to avoid a high thermal load for the wafers thus making it suitable for mc-Si wafers. The heavy $POCl_3$ diffusion can be replaced by a lighter diffusion if low thermal stress is critical for maintaining sufficient bulk carrier lifetimes.

Patterning of the rear side is currently done in two steps using laser ablation and a selective HF etch. Both methods feature advantages as well as drawbacks. While laser ablation often damages the bulk, it is highly accurate and facilitates alignment in subsequent processing. Although etching in HF does not lead to a degradation in bulk carrier lifetime, it requires exact alignment of the etch resist screen printed masks. Other technologies for patterning involve the use of screen printed glass frit with subsequent HF etching. We have found the combination of laser ablation and selective HF etching to be the easiest to control.

Whereas most IBC cell designs feature boron doped emitter structures, the use of local, screen printed aluminum emitters is, to our knowledge, a new approach. Full area screen printed aluminum emitters on n-type silicon wafers have already been realised in other cell concepts [5].

3 EXPERIMENTAL INVESTIGATIONS

To investigate the formation of local emitters we fabricated test structures on n-doped (1.5Ωcm) mc-Si wafers. Masking and patterning of the rear side was performed with PECVD SiN_x and subsequent laser ablation. The test structures were given a local $POCl_3$ diffusion ($R_{sh} = 35\Omega$/sqr). A second PECVD SiN_x deposition on the front served as an anti-reflection coating. We then locally screen printed and fired aluminum paste on the rear (aerial coverage about 54%) to investigate the formation of a screen printed aluminum emitters in n-doped mc-Si. Excess aluminum was removed in HCl. In a last step base contact (Ag) and emitter contact (Ag/Al) were screen printed and fired.

3.1 IV characteristics

The test structures displayed an open circuit voltage of 530mV, a short current density of 8.4mA/cm² and a fill factor of 50%. Fitted with a two-diode model the series resistance was approximately 10Ωcm² and shunt resistance was fitted to be 590Ωcm². J_{01} and J_{02} could not be reliably derived from the measurements. The low value for $J_{sc,}$ is mainly due to low substrate lifetime. The V_{oc} is significantly reduced as a result of the only partial coverage of the rear side with emitter. Assuming a J_{sc} value of 32mA/cm² a modelled value for V_{oc} of 608mV was obtained. The low fill factor is mainly caused by a high contact resistance of the base contacts due to technical problems during etching.

3.2. Spectral Response

IBC cells typically show an inverted behaviour in spectral response measurements compared to conventional cells. This is due to the collective junction being close to the rear of the cell.

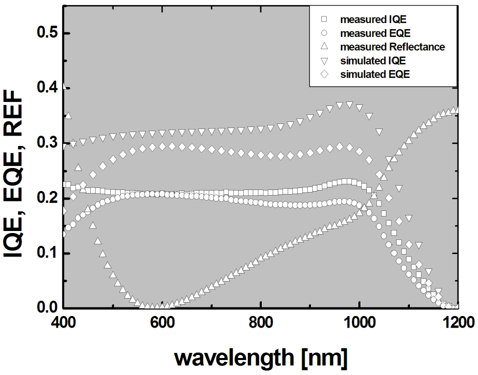

Figure 3: Measured and modelled IQE and EQE of the test structure showing similar trends. Differences in absolute value are probably due to inhomogeneities in carrier lifetime and emitter profile.

Fig. 3 shows a spectral response measurements of our test structure. For comparison, PC1D modelling has been performed. Since PC1D does not allow for a two dimensional emitter structure on the rear of the cell the modelled values have been rescaled with a factor of 0.54, corresponding to the area covered with the emitter.

Although the absolute values of the measured and the modelled curve do not fully agree, probably due to inhomogeneities in lifetime and emitter profile, both curves clearly show the same trend. For modelling a lifetime of 15µs has been assumed. QSSPC [5] lifetime measurements yielded carrier lifetimes of 14µs (measured at an excess carrier density of $10^{15}cm^{-3}$), which is clearly unsuitable for an IBC cell design.

3.3 LBIC measurements

LBIC (Laser Beam Induced Current) measurements showed the patterned emitter structure on the rear with increased carrier collection probability close to the emitter covered regions. They also showed the typical behaviour of an IBC cell, i.e. an increase in J_{sc} for longer wavelengths due to charge carriers being generated closer to the rear of the cell and, therefore, closer to the collecting junction.

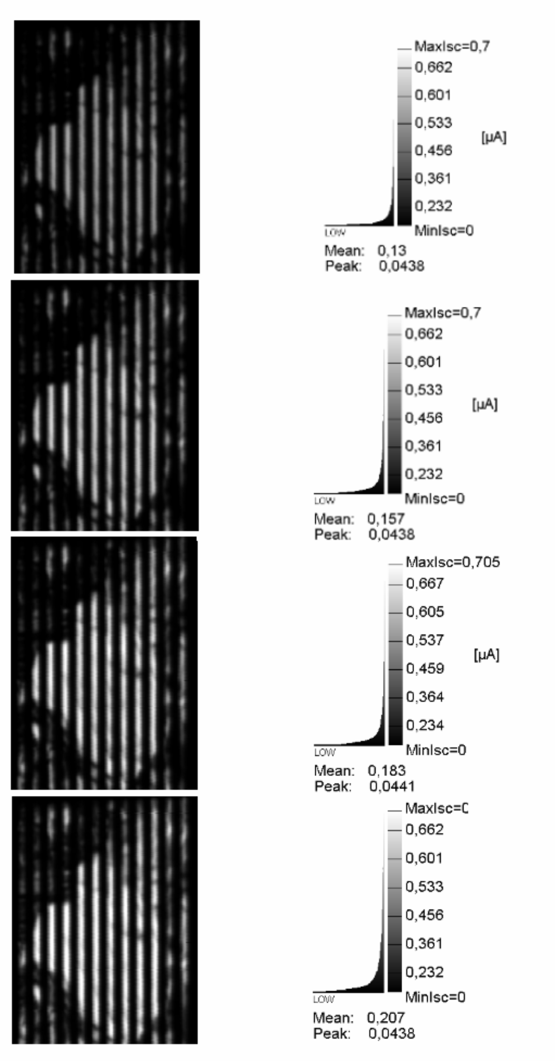

Figure 4: LBIC measurements of test structure. The patterned emitter structure on the rear shows increased collection probability. Variations along one emitter gridline can be caused by varying carrier lifetime or inhomogeneities in emitter formation during printing and firing.

Fig 4 shows the LBIC measurements of one test structure at wavelengths of 635nm, 833nm, 910nm and 980nm. Lighter regions represent areas of higher collection probability.

The measurements also reveal variations in the collection probability along several emitter fingers. Whether this is caused by local inhomogeneities in the emitter or varying carrier lifetime of different crystals in mc-Si is still under investigation.

3.4 Thermographic measurements

Thermographic imaging revealed only localised shunting of the cell. Although the shunt resistance of the test structures were still too low to achieve good fill factors, we are optimistic that by optimising the screen printing process, paste selection and firing conditions we can significantly improve the values that have been reached in this first attempt.

4 CONCLUSION

We have developed a cell process that allows the fabrication of IBC cells with a low thermal load thus being suitable for mc-Si wafers.

We have produced test structures on n-doped mc-Si to investigate the formation of local emitter structures by screen printing and firing of aluminium paste. These investigations aim at the development of a screen printed IBC solar cell done without a gas phase boron diffusion.

While the test structures clearly exhibited rectifying behaviour, shunt values were still below 1000Ωcm². To investigate and improve the inhomogeneity of local emitter structures further experiments are ongoing.

5 ACKNOWLEDGEMENTS

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