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Simplified edge isolation of buried contact solar cells

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Abstract

The aim of this work is to implement simple edge isolation techniques in buried contact solar cell (BCSC) process by preserving the active cell area. Here we present results of two simplified edge isolation techniques for BCSC and they are compared with the standard process incorporating mechanical edge isolation using a dicing saw. The first technique is chemical wet etching of the solar cell's rear side in an inline system recently developed by University of Konstanz and Rena. The second technique is edge removal carried out in a fluoride/oxide radicals environment of a Asyntis plasma etcher. While the shunt resistance R_{sh} obtained with wet etching is between 1500 and 7000 Ωcm^2 , the standard process shows R_{sh} values ranging from 2100–6300 Ωcm^2 . The R_{sh} after plasma processing is between 1000 and 3600 Ωcm^2 . These cell results show that both wet and plasma etching achieve results close to mechanical edge isolation.

However, a slight reduction of short circuit current is observed for the cells undergone standard as well as plasma processing. This is due to the presence of floating volume shunts formed at the rear n–p⁺ junction, which are not removed by either the standard or plasma process. These shunts do not influence the *IV*-curve of the solar cells and are nearly invisible with conventional thermography, as they are not connected to the front side emitter grid.

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Hence, light-modulated lock-in thermography measurements were carried out to analyse these shunts.

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1. Introduction

A typical crystalline silicon solar cell process on p-type material consists of saw damage etch, emitter diffusion, antireflection coating on the front side, front and rear side metallisation and a process step which electrically isolates p- and n-type regions of the solar cell. During a n-type emitter diffusion from the gas phase on p-type substrates the emitter is typically formed on the entire surface of the wafer. When re-defining the rear p-contacts, most techniques cannot avoid an ohmic behaviour of the newly introduced p/n-junction. The ohmic behaviour is due to shunts located at the border line between the heavily doped n-type emitter and newly introduced p/p⁺⁺ type region. In principle, there are two ways to circumvent this problem.

Solution A: Isolation of front and rear side emitter (edge isolation)

This can be realised by mechanical, laser cutting or plasma etching. If the shunts are formed between the rear side emitter (residue emitter) and metallised rear side, they are not connected to the front side contact and hence do not affect the *IV* characteristics.

Solution B: Avoid residue emitter on the rear side or remove it before defining the p-contact.

It can be realised by masked diffusion or etching of the rear side emitter. The result will be the same or even better than solution A, therefore we will call this edge isolation, too.

A variety of edge isolation techniques is available for industrial production of screen printed silicon solar cells [1,2].

Basic methods for edge isolation according to solution A are mechanical or laser cutting. These are the most common techniques used for removing the shunted edges of buried contact solar cells (BCSCs). Mechanical edge isolation using a dicing saw is carried out with diamond dicing blades of typical thickness of 0.1 μm . Usually 1 to 2 mm silicon from the edges are cut off. This method electrically isolates the heavily doped front side emitter to the rear side metallisation. This kind of edge isolation leads to a reduction in active cell area by 3–6% for $125 \times 125 \text{ mm}^2$ cells and hence a corresponding decrease in short circuit current (I_{sc}) of the manufactured solar modules. The mechanical edge isolation obviously produces waste silicon which cannot be recycled. The silicon waste produced by edge isolation of 500 wafers sized $125 \times 125 \text{ mm}^2$ of thickness 0.3 mm is 174.75 g.

In this work newly developed, industrially feasible and lossless alternatives, wet edge isolation and plasma edge isolation are presented. To show the benefits,

a BCSC process using basic and alternative edge isolation technologies was carried out and the results are compared.

1.1. Alternative edge isolation technologies

Apart from mechanical or laser cutting, plasma etching is one of the most familiar technologies used in the industry for edge isolation of screen printed solar cells. In this technique, the wafers are stacked together and loaded into a vacuum chamber for etching in a fluoride/oxide plasma environment; 2–5 μm of silicon are removed from the edges to electrically separate the front/rear emitter. The coin stacking method ensures high throughput and low cost per wafer. However, careful handling of the wafers is necessary to avoid wafer damage.

Another industrially applicable technology, which has been introduced recently is the removal of the rearside emitter in an automated inline etching system developed by Universität Konstanz and Rena [4]. The wafers are transported through an acidic etching solution in a way that only the rear side comes in contact with the chemical bath. As the wafers do not need any stacking, handling becomes much easier and the risk of wafer damage is reduced.

Klein et al. developed an edge shunt removal method for silicon solar cells using an etching paste applied only at the edges. The etching action is carried out at temperatures between 70 and 150 $^{\circ}\text{C}$ and takes between 30 and 240 s [3]. However, solar cell results were not presented in this work.

2. Experimental

2.1. BCSC processing

In this work two alternative BCSC processes were carried out and the results were compared with the standard process to investigate the advantages of wet-chemical, dry-plasma edge isolation of BCSCs.

Block-cast multicrystalline silicon wafers of size $125 \times 125 \text{ mm}^2$ from ‘Baysix’ (p-type boron doped, thickness 330 μm and bulk resistivity $\approx 1.5 \Omega\text{cm}$) have been used in this investigation. The cell fabrication starts with the defect etch in alkaline solution and acidic cleaning followed by a light POCl_3 emitter diffusion of sheet resistance 100 Ω/sq . Silicon nitride (SiN_x) antireflective coating on the front side of the wafer is carried out in the next step using low pressure chemical vapour deposition (LPCVD) process. A special clamping on the wafers was applied in order to prevent too much deposition of SiN_x on the rear side. For BCSCs the SiN_x acts as a front surface passivation, antireflection coating, diffusion barrier and plating mask: SiN_x covered areas will not be doped by POCl_3 and cannot be metallised by electroless plating. After SiN_x deposition, contact grooves sized 50 μm are formed on the front side by mechanical cutting. A selective emitter of sheet resistance 10 Ω/sq is diffused inside the grooves. Full aluminium (Al) back surface field (BSF) is formed on the rear side by screen printing Al and a belt furnace alloying process. In order to

ensure good bulk passivation and metallisation, the rear side aluminium is removed again in hydrochloric acid. A bulk hydrogen passivation is carried out using a microwave induced remote hydrogen plasma (MIRHP) source. In the next step aluminium is evaporated on the rear side. The evaporated Al on the rear side has two advantages, firstly it acts as a rear side diffuse reflector and secondly it increases the adhesion of electroless plated copper. The final step is the electroless metallisation of nickel and copper followed by mechanical edge isolation. The above-mentioned BCSC sequence is termed as Process A. More detailed description of BCSC process step is described in literature [5] (Fig. 1).

The chemical etching experiment is denoted as Process B. In the chemical etching experiment the edge isolation is done chemically by removing the rear side emitter after the light emitter diffusion. The etching is carried out in a recently developed inline system described in the next section. The SiN_x coating thereafter preserves proper edge isolation, though the rear side of the wafer receives an emitter again when doing the strong groove diffusion. The reason is that both strong emitter diffusion and Al BSF formation are masked by marginal SiN_x on the rear side. Marginal shunts by spike-shaped penetration of Al into n-type silicon are avoided.

The plasma etching experiment is called Process C. The plasma etching step is applied after the light emitter diffusion. Once again, the SiN_x coating after this step preserves the edge isolation during the groove diffusion, as marginal SiN_x on the rear side defines a masked p-type region of a few millimeters lateral extension.

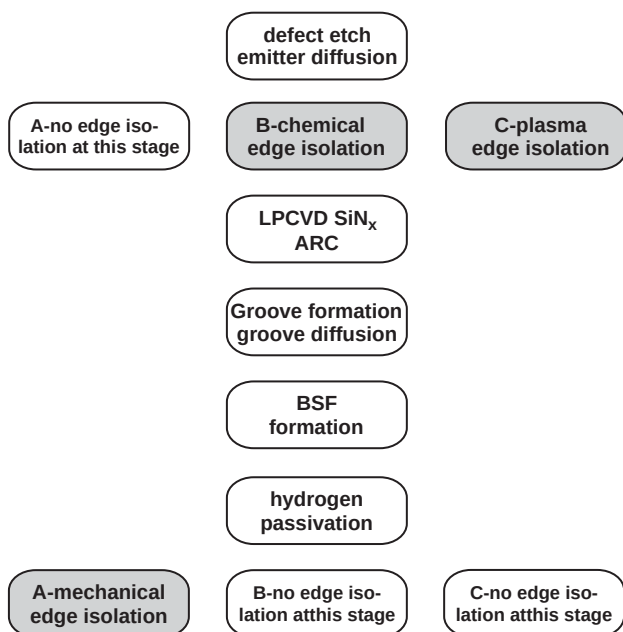


Fig. 1. Details of three different BCSC process sequences followed in this work.

It should be noted that in Process A, Process B and Process C all process steps are the same except the edge isolation technique.

2.2. Simplified edge isolation of BCSC (acidic and plasma edge isolation techniques)

As both plasma and wet edge isolation methods are less complicated as compared to mechanical edge isolation, we will call those techniques ‘simplified edge isolation’ from here on.

For the acidic wet edge isolation technique together with the company Rena, an inline etch system has been developed for isotropic etching and texturing of silicon wafers. The system can be used for saw damage etching, acidic isotexturing and single-sided etching of wafers. The etching solution contains HF, HNO₃ and H₂O and no organic additive like CH₃COOH is present. The inline system consists of an array of rollers on which the wafers are transported. For the rear side emitter removal, the wafers travel through an etching bath which is filled up to a certain level to achieve that only one side of the wafers is in contact with the etching solution. The etching solution is kept below room temperature which ensures less thermal evaporation and almost no emission of acidic vapours during the process. The etching parameters (etching depth and speed) can be varied depending on the wafer transport velocity, etching bath concentration and temperature. As this technique removes only about 5 µm from the rear side, there is no loss in active cell area. The waste silicon mass produced when processing 500 wafers sized 125 × 125 mm² is 91 g. This technique is highly industrially feasible with a throughput of 1500 wafers per hour. More than 30,000 wafers have been processed so far in this system while writing this manuscript. The rear side etching replaces the edge isolation that is industrially done with plasma etching or laser cutting. In addition, an emitter free backside of the cell is useful or even necessary for advanced cell concepts [4].

The second part of our investigation concentrates on plasma etching of BCSC. In the plasma edge isolation process, the wafers are stacked together and loaded into a remote plasma etcher from Asyntis for processing. The etching radicals fluorine/oxygen are generated from a remote plasma source of 2.4 GHz frequency. The generated radicals etch the silicon surface up to 5 µm. The waste silicon mass produced when processing 500 wafers sized 125 × 125 mm² is less than 9 g. In order to ensure uniform edge isolation, the etching is carried out for 120 s in two sequences. This method avoids the handling of dangerous chemicals and cost per wafer is quite low as a large number of wafers is processed in one step. The waste gases produced by plasma etching however are toxic and have to be filtered/washed before disposal into atmosphere. The plasma etching experiment is denoted as Process C. It should be noted that the plasma edge isolation disconnects the front side emitter from the rear side as does the mechanical edge isolation. The rear side emitter is not removed by plasma processes, instead it is overcompensated by the screen printing paste during the formation of the p⁺ BSF. The presence of emitter residue near the edges causes the formation of ‘floating volume shunts’ (see Fig. 3) and is discussed in detail in Section 2.4.

2.3. Comparison of standard and simplified edge isolation techniques

To compare the effectivity of the different edge isolation methods cells from the plasma etching Process C and chemical etching processes Process B are compared with the cells from the conventional process with mechanical edge isolation using the dicing saw (standard Process A).

The cell parameters of the best cell from each process are listed in Table 1. The best cells were selected in order to see the potential of each edge isolation process. The cell parameters achieved with Process C and Process B are quite comparable with the results from the standard process. The highest value of short circuit current density was obtained in the Process B. This is due to the complete removal of the rear side light emitter, which reduces rear side volume shunts, improves thermal stability and rear side surface passivation. However the V_{oc} values in Process B and Process C are slightly lower as compared to the cell from Process A, this could be due to the relatively low R_{sh} values obtained for these cells. Hence, a higher R_{sh} value would increase the maximum possible V_{oc} of the alternative processes. The shunt resistance values reached with Process B and Process C are still in an acceptable range (more than $10^3 \Omega \text{ cm}^2$ was taken as good enough according to [1]). This shows that either wet or plasma etching for edge isolation of BCSC after light emitter diffusion can replace the standard mechanical edge isolation. The total power output of the cells from Process B and Process C is higher than W_p reached by Process A due to the perseverance of the full wafer area.

Fig. 2 represents the range of V_{oc} and R_{sh} values obtained from each process. The results show that acidic and plasma etching processes have cell parameters comparable to the standard process. Again from Fig. 2, it should be noted that the plasma process shows some weakness in both V_{oc} and R_{sh} , this could be due to plasma induced damage introduced during the edge isolation process. The cells from the wet chemical edge isolation Process B are slightly better than the other two groups. The next paragraph will discuss the benefits from Process B in detail.

In general the wet etching and plasma etching process can replace the mechanical edge isolation giving comparable cell results, but preserving the active cell area. In our experiment, this increases the total power output of an individual cell by up to

Table 1

The solar cell parameters of best cells (highest efficiency) from various processes

Process	Area (cm^2)	FF (%)	J_{sc} (mA/ cm^2)	V_{oc} (mV)	Eta (%)	R_{sh} ($\Omega \text{ cm}^2$)	Power (W_p)
Process A (Standard)	144	78	32.7	622	15.9	6379	2.28
Process B (Wet etching)	156.25	77.5	33.2	619	15.9	2739	2.49
Process C (Plasma)	156.25	77.9	32.5	617	15.7	1386	2.44

The cells prepared using the standard BCSC process is represented by Process A. It can be seen that the acidic edge etching Process B and plasma edge isolation Process C are comparable with the mechanical edge isolation in standard process.

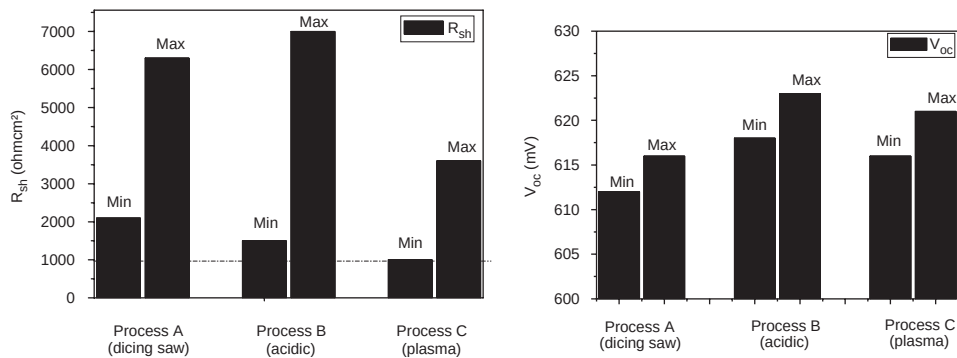


Fig. 2. The minimum and maximum values of R_{sh} in each process (left). The dotted line represents the threshold R_{sh} value required for satisfactory performance of solar cells. The right diagram shows the variation of V_{oc} .

9%. When connecting solar cells from Process B or C to a module, the preserved active cell area will increase module performance, which can be 3.6% in industrial production.

2.4. The rear side

As already mentioned in the introduction, mechanical and plasma edge isolation isolates rear-side shunts by cutting off the electrical connection around the cell edge. However the shunts are still present and active. As they have no contact to the front grid, they will not affect the IV characteristics. But the isolated rear side shunts, which can also be called floating shunts, will reduce the short circuit current of the solar cell. Light-generated electrons in the p-type region can diffuse either into the emitter on top or into the residue of the emitter on the rear side (see bottom left of Fig. 3). The electrons entering the residue emitter will travel a short-circuited path to the p^+ region and do not contribute to the external current. This reduces the J_{sc} value without affecting the shape of the IV -curve. The Process C avoids this problem, by complete removal of the rear side light emitter and SiN_x masked diffusion and overcompensation thereafter.

An investigation of the formation of the rear side shunts was done using light modulated thermography analysis. Light modulated thermography is different from conventional thermography, as the signal source is modulated light. This enables to detect shunts which do not have a direct ohmic link to the solar cell's contacts. The details of the light modulated lock-in thermography measurement are available in [6,7].

Fig. 4 (right) shows the thermograph of a cell from Process C. Most of the shunts are located near the rear side edges (not exactly at the edges). This is the region where the backside emitter comes in contact with the p^+ layer. Number and strength of these shunts increase when 'unwanted' silicon nitride is removed from the rear side.

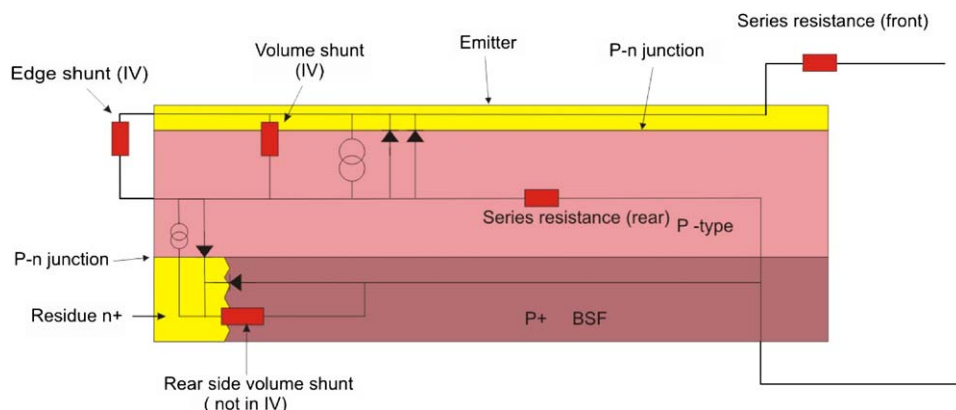


Fig. 3. Sketch to explain the formation of rear side floating shunts. Though the rear side emitter is isolated from the front side, it can still collect photogenerated charge carriers, which are directly fed to the rear side volume shunt. Hence the short circuit current of the solar cell is reduced without affecting the shape of the *IV*-curve.

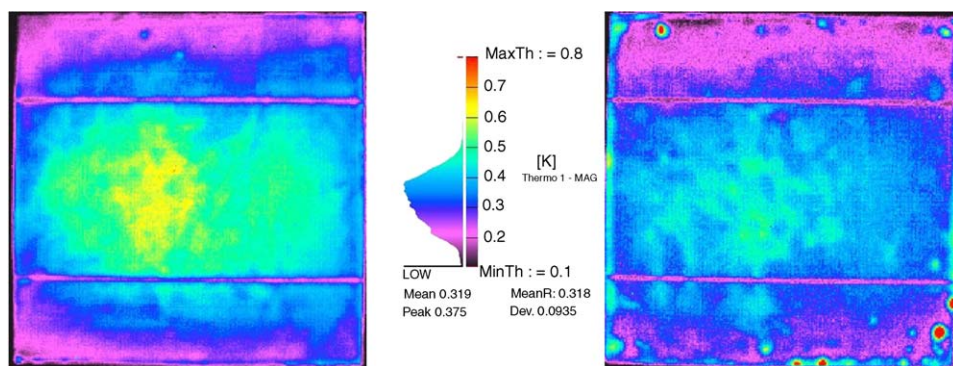


Fig. 4. Thermography map of cells from Process B (left) and Process C (right). The formation of rear side shunts near the edges can be seen from several red spots in the right image. The shunts are at the interface between rear side p^+ over doped region and residue of the emitter.

The removal of the light emitter (Process B) has further advantages: Together with the emitter, the top layer of the wafer is removed which contains a high concentration of contaminants collected by phosphorus gettering. The removal of these contaminants makes the wafer more tolerant to high temperature steps thereafter (LPCVD SiN_x deposition). Additionally, the reduced n-doping on the rear side enables higher p^+ doping and a more powerful BSF. This effect can be seen in comparative light beam induced current (LBIC) images, see Fig. 5.

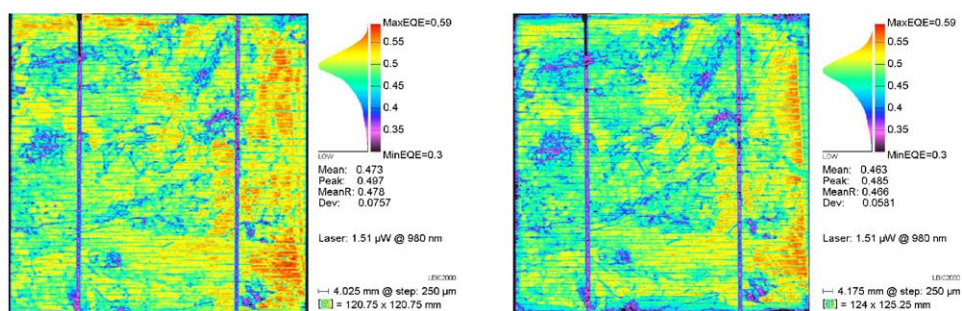


Fig. 5. LBIC images of solar cells from Process B (left) and Process C (right). The EQE topography at a wavelength of 980 nm (penetration depth 105 μ m) shows improvement for those cells whose backside emitter was removed by acidic etching. Regions of EQE improvement in right diagram is indicated by arrows.

At long wavelengths (980 nm), the external quantum efficiency (EQE) of the left cell (Process B) is slightly higher than the EQE of the right cell (Process C). Especially the marginal regions are improved by Process B. This is where the back side light emitter is not sufficiently overcompensated by Process C. Thus, the main advantage of removing the backside light emitter is, in addition to edge isolation, the improvement of BSF that increases long wavelength performance of the solar cell.

3. Conclusions

Simplified edge isolation processes for buried contact solar cells (BCSCs) using acidic and plasma etching were investigated. Both simplified edge isolation process, plasma etching or wet etching, avoid cutting off wafer edges and reduction in active cell area. Both process are industrially feasible. These processes can effectively replace the conventional mechanical or laser edge isolation of BCSC. The formation of volume shunts on the rear side was analysed using light modulated lock-in thermography measurements. BCSCs with conventional or plasma edge isolation showed a slight reduction of J_{sc} by shunts at the rear side emitter– p^+ interface. These shunts are electrically disconnected by conventional or plasma edge isolation, whereas acidic rear side etching can effectively avoid them. The latter holds also for screen-printed industrial type solar cells. Plasma edge isolation is already a standard industrial technique and may easily be adapted to BCSC processing. The acidic rear side etching is being transferred to industry for screen printed solar cell processing and will allow a slight increase in J_{sc} due to an improvement of the BSF. Both simplified edge isolation technologies for BCSC do not decrease active cell area. Thus, BCSC module performance may be increased by 3.6% using the new technologies.

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