A NOVEL APPROACH FOR SINGLE SIDE WET CHEMICAL POLISHING OF CRYSTALLINE SILICON SOLAR CELLS

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ABSTRACT: Single side etching processes, e.g. parasitic emitter etch and single side etching, are steps used in the fabrication of high efficiency solar cell concepts. For cost reduction the combination of process steps is preferable. Because chemical treatments produce reactive gases that are able to damage structures like the front side emitter, single side polishing needs to be done before the emitter diffusion. Due to this fact and ineffective exhausting systems, the combination of the emitter etch and the single side polishing step have not been achieved yet. Another factor influencing the etching is the shading of the etched surface due to the transport system or gas bubbles sticking between the wafer surface and the etching solution. With a newly developed single side etching tool the shading and the emitter damage has been reduced due to a novel transport system, a fluid flow concept and a high-performance exhaust system. Damage to the front side of the wafer due to reactive gasses produced during the etch process was investigated and the performance of the new exhaust system was tested. With etching mixtures containing different amounts of HF, HNO_3 and H_2SO_4 when combined with the improved exhaust system, it was possible to limit the emitter damage while raising the etching rate. The fluid flow system in combination with the new transport system led to a homogeneous surface without shading effects. In addition the mechanism of fluid wraparound to the front side of the wafer was investigated.

Keywords: Single side etching, Chemical polishing, PERC, Cost reduction

1 INTRODUCTION

For high efficiency solar cell concepts there is a need for separate treatments to the front and rear side of a silicon wafer [1]. A smooth polished rear surface is desirable for passivated cell concepts (e.g. PERC) as the flat surface decreases the surface recombination velocity and leads to an increase in light trapping [2]. In the current state of the art cells are texturized on both sides resulting in a rather rough surface which is disadvantageous for the rear side [3]. Therefore an inline single-side polishing step is introduced directly after texturisation. Following this, the emitter is constructed using a double-sided diffusion process. To avoid a short circuit between the front and the rear side of the solar cell, the emitter on the rear side is removed in a further wet chemical process step. So in total there are two single side wet chemical processes, one before and one after the diffusion process. In terms of cost reduction there is the intention to merge both processes into one step [4] (Figure 1).

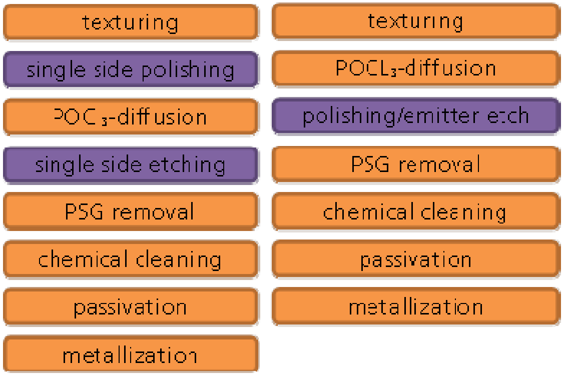

Figure 1: Process scheme for the PERC solar cell concept with the standard process (left) and combined wet chemical process (right). The orange highlighted steps are two side processes and the purple highlighted are single sided process steps.

The simplified sequence used produces a solar cell process with one process step less in comparison to the standard process.

The current state of the art for single side etching is a systems based on rollers. The wafers are transported horizontally through or over an etch bath with a chemical solution mainly consisting of HNO_3 and HF. There are two possibilities for contact to be made between the wafer and the etch solution (Figure 2) [4]. (a) The bath level is higher than the rollers and a meniscus will develop or (b) the bath level is lower than the rollers and only a part of the rollers have contact to the etch mixture. Thus the rollers transport the mixture via grooves to the wafer surface. The main disadvantage of these roller based systems is the continuous contact between the mechanical parts of the transport system and the wafer surface. Due to this permanent contact there are masking effects preventing a homogenously etched surface and abrasion between the wafer and the rollers. Also the abrasion caused by the rollers precludes the possibility of cleaning the wafer with such a transport system. In addition there are masking effects due to an undefined chemical flow. Another disadvantage is the inadequate exhaust allowing the reactive gases to flow over the front side. This makes these tools inappropriate for polishing a wafer with an emitter on the front side because polishing requires relatively aggressive etch mixtures resulting in a higher concentration of reactive gases.

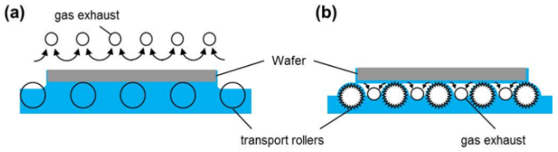

Figure 2: Transport by rollers. Because of the permanent contact between rollers and wafer as well as rollers and etch mixture there is a possibility of abrasion and contamination. The wafers are not fixed that's why they can drift out of the line. The exhaust systems are not able to protect the front side of the wafer from attacks of the gaseous reaction products because they are too far away (a) or in the wrong position (b). In (a) the contact between wafer and etch mixture happens via a meniscus because of a high bath level. An exhaust is at the borders of the transport line above the wafer level. In (b) the liquid is transported to the wafer surface by grooves in the rollers. The gas exhaust is between the rollers [2].

Due to the exhaust system in the state-of-the-art equipment it is not possible to combine the two single side processes, i.e. polishing and emitter etch, in one step.

In this paper we investigate factors influencing both the front and rear wafer surfaces and the key features of a newly developed inline wet chemical processing concept. A new transport system will reduce abrasion, shadowing and front side emitter damage due to reactive gases. The system is engineered for proven wet chemical processes but the focus is mainly on newer and advanced inline single-side processes like chemical polishing.

2 FACTORS INFLUENCING THE WAFER SURFACE

There are different factors influencing the front and rear surface of single side etched wafers (Figure 3).

The front side has to be protected from two main sources of emitter damage. One is the fluid that wraps around onto the front side destroying the local emitter and the surfaces texture. The other issue is the emitter damage due to waste gases reacting with the whole front side. The wraparound and the reactive gases can be controlled by modifying the etching mixture and the amount of material removed from the rear side.

On the rear side a uniform surface must be achieved. There are two mechanisms that affect this. First there is shadowing of some areas due to both the transport system as well as liquid and gaseous reactions products that aren't removed quickly enough. Second the etching mixture determines whether the material removal is homogenous or inhomogeneous and thus if there are etching structures or not [5].

3 SINGLE SIDE ETCHING TOOL

The single side etching tool presented here is the SINGULUS STANGL LINEA II (Figure 4). It has a modular design and is fully automated. It is designed and constructed to prevent previously mentioned destructive influences on the front and rear surface of a wafer.

The first basin is filled with an acidic etching mixture and is used for single side polishing or the etching back of the rear side emitter. The second basin contains KOH and it is a two side process for stain removal.

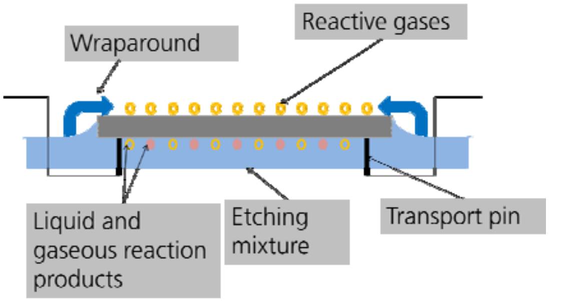

Figure 3: On the front and rear side are different factors affecting the etching result. On the front side the emitter and texturized surface has to be protected and on the rear side there can be inhomogeneous etching due to shadowing of the reactions products and transport system or an inappropriate etching mixture.

The last basin is filled with HF and HCl to clean the wafers and to remove the PSG from the front side of the wafer. The last basin provides the option of cleaning the wafer with other cleaning mixtures, e.g. containing additional ozone.

Other major advantages such as the exhaust system and the fluid flow concept will be explained in the following sections.

Figure 4: LINEA II is a fully automated wet chemical inline machine designed for the mass production of solar cells. The modular design of the process stations makes it possible to adapt the tool setup individually to particular cell concepts. Besides the proven wet chemical process steps like texturing, PSG removal and cleaning, the machine is also suitable for advanced inline processes like rear-side chemical polishing for PERC cells and chemical edge isolation.

3.1 Transport System

One of the key features of the "spider chain" wafer transport system is that it minimizes the contact area with the wafer and thus reduces shadowing of the etched surface (Figure 5). The wafer lies on 8 pins going through the etching mixture. In addition wafers travel in physically separate lanes, and there are stopping pins prohibiting the wafer from floating forwards or backwards in its lane during processing. Thus each wafer lies in its own slot reducing the chance of wafer jams. A continuous chain goes through the whole machine linking each processing module.

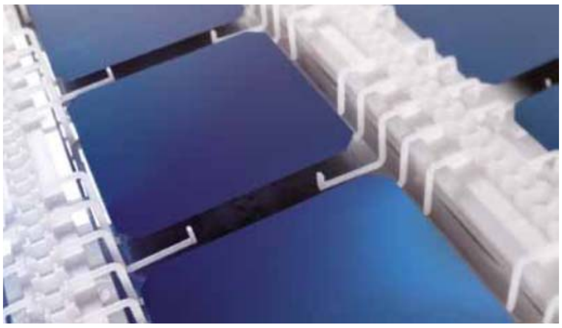

Figure 5: Innovative transport chain with eight pins. There is no contact between the mechanical parts and the etch mixture or the wafer but for eight small legs. Due to the stopping pins seen between the wafers, the wafer can't float out of its position. The exhaust and overflow ducts lie between the chain and the wafer edge.

3.2 Exhaust System

The first basin has an exhaust system that is present on both sides of each lane (Figure 6). This exhaust system was developed to remove waste gases more effectively, close to their source at the wafers edge. Additionally, air is blown in from the top of the chamber and is directed through slits in a cap in the middle of the wafer. This results in a constant flow of clean air from the middle to the edge of the wafer creating a push pull system. These two mechanisms work together to prevent any unwanted reactions between the emitter and the reactive gases that are coming from the solution.

3.3 Fluid Flow Concept

A fluid flow concept was designed to ensure the continuous removal of the gaseous and liquid reaction products below the wafer (Figure 6). This results in homogeneous wafer surface properties. The etchant is circulated through plates with specially shaped slits to the surface of the wafer to be etched. Due to shape of the slits gas bubbles and other reaction products are directed from the centre to the edges of the wafer in a uniform manner. Thus shadowing effects are reduced.

In addition, it is possible to adjust the level between the wafer and liquid surface, i.e. the meniscus height that possibly reduces wraparound of the liquid on to the top surface.

4 EXPERIMENTAL SETUP

The experiments were performed using p-type mono- and multicrystalline silicon wafers with a thickness of 180 to 200 µm. The monocrystalline materialc was on <100> oriented Cz-silicon wafers with random pyramids and a weighted reflection of approximately 12%. The multicrystalline material was textured with a standard acidic isotexture process with a weighted reflection of approximately 28%.

Both, mono and multicrystalline material had an emitter on both sides.

In order to protect the emitter on the front side from the reactive gases, the gas phase during etching has to be characterized. This was realized by researching the gas phase with FTIR using the matrix-isolation technique and gas sensors measuring the gas concentration. In beakers gas phases were simulated and the emitter damage investigated.

In order to improve the exhaust system and better protect the front side emitter, some experiments using temporary inlet extension ducts [I don't know how descriptive you want to be here] were performed on the LINEA II.

On a smaller test tool with a high-resolution camera the mechanism of the wrap around was examined firstly with water and then with an etching mixture containing HF and HNO_3.

With different shaped plates as described in section 3.3 the removal of the reaction products was investigated on a smaller test tool and on the LINEA II.

The surfaces have been characterized by etching rate, confocal microscopy, weighted reflection and 4-point probe measurements to determine the emitter sheet resistance.

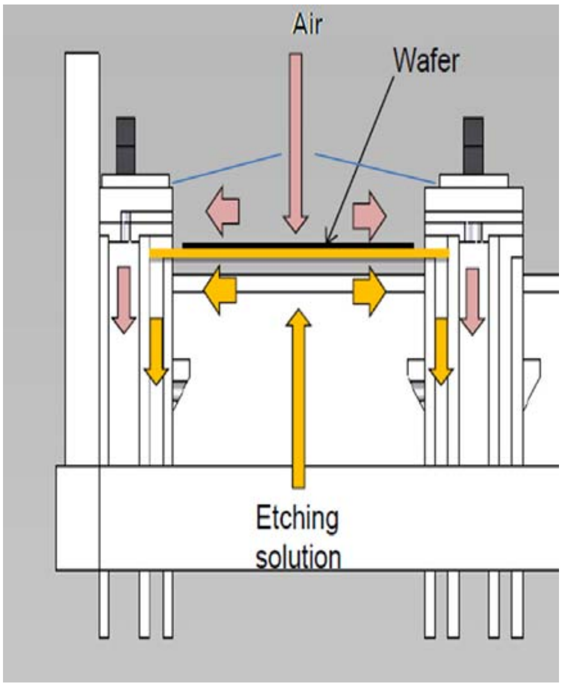

Figure 6: The etching solution that contacts the rear side of the wafer is directed to the wafer surface creating a high pressure region that pushes the reaction products from the wafer surface, the shape of the high pressure region reduces the shading of the wafers and accelerates the process. The reaction solution then flows through drains on the sides of each lane while the gases surfacing at the edge of the wafer are drawn off by the exhaust system as described in section 3.2.

5 RESULTS AND DISCUSSION

All results discuss the factors influencing the quality of the wafer front and rear surface. The first results presented concern the front side. Finally a factor affecting the rear side of the wafer is discussed.

5.1 Gas phase

In Figure 7 an FTIR measurement of a gas phase is shown. The measured gas phase was taken directly out of the polishing process chamber. On the FTIR spectrum H_2O, HF, HNO_3, CO_2 and NO_2 were found in significant concentrations [6, 7]. With this information only HF and NO_2 come into consideration for the etch attack. The small CO_2 peak on the right is the solid CO_2 on the cold window of the matrix isolation chamber.

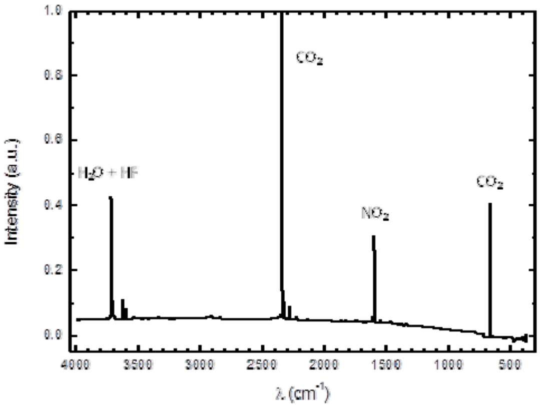

Figure 7: FTIR spectrum of the acidic gas phase during an acidic single side polish process. The responsible components for gas phase etching are probably HF and NO_2.

A synthesized gas phase was established. With another FTIR measurement the synthesized gas phase was confirmed to be similar to the original sample. In figure 8 etch rates depending of the gaseous components and concentrations are shown. The etching rate was calculated by measuring the difference in emitter sheet resistance and comparing it to the emitter profile. Wafers were exposed to different concentrations of HF and NO_2 and the etch rate was measured. It was found that for gaseous etching of the emitter both components have to be present. The maximum etch rate occurs at a ratio of 4: 3 (NO_2: HF), which is in contrast to the expected maximum etch rate which should have been at a ratio of 1: 2 (NO_2: HF).

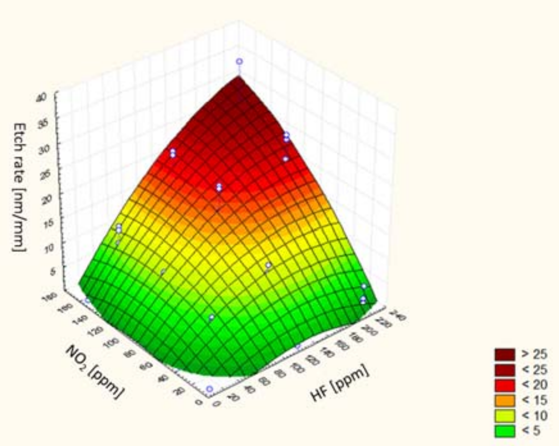

Figure 8: Etch rate of crystalline silicon versus the concentrations in *ppm* of the gaseous etching components HF and NO_2. For emitter etching to occur, both components have to be present. The removal of one component will stop the emitter etching on the front side.

5.2 Exhaust System of SINGULUS STANGL LINEA II

To further improve the exhaust system experiments were performed to test various designs for the air injection. Extended inlet ducts were placed in the slits of the cap directing the air closer to the wafer. Using an incense stick it was asserted, that the air flows more smoothly over surface and then straight to the exhaust ducts. Without the inlet ducts the air is partly not reaching the wafer surface and is flowing with more turbulence to the exhaust system.

In order to confirm the effectiveness of the improved air flow system, emitter damage with and without the inlet ducts and varying transport velocities was tested.

Figure 9 shows that adding the inlet ducts reduces the impact of changes in transport velocity. Even at low speeds the damage with the inlet ducts is the same as at high speed without them. A high transport velocity with the inlet ducts further reduces damage, but not as dramatically as the case without them.

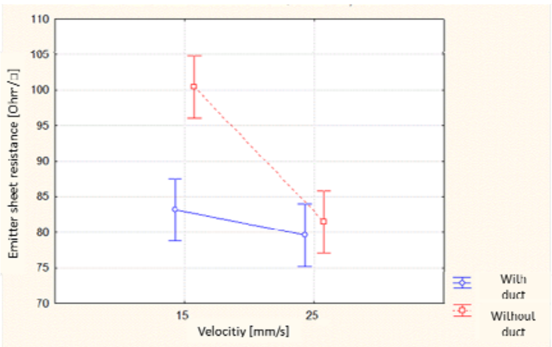

Figure 9: Emitter damage with and without inlet ducts at different transport velocities. Increasing emitter sheet resistance is equivalent with emitter damage.

5.3 Wraparound

While researching the wraparound it was observed that independent of the surface, whether hydrophilic or hydrophobic, the meniscus contacts the lower edge of the wafer (Figure 10).

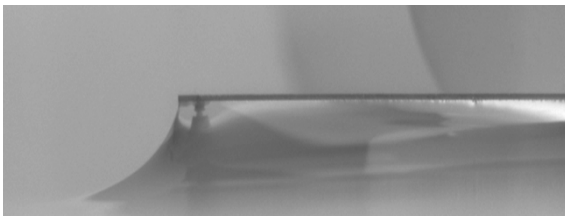

Figure 10: Hydrophilic wafer contacting with water. The meniscus contacts the wafer on the lower edge of the wafer.

Contacting a wafer with an HNO_3-HF etching mixture causes a meniscus to develop at the lower edge of the wafer. But at the moment the reaction starts, gas bubbles arise and burst when they come out under the wafer. The bursting bubbles splash the wafer edge with etching solution. Due to the cohesion the meniscus rises. Furthermore, as the meniscus rises, the bursting bubbles splash even higher causing the meniscus to rise all the way up the edge to the front side of the wafer.

5.4 Homogenous Etching

The homogeneity of the wafer surfaces with and without the removal of the gas bubbles was investigated. Without the continuous removal during the etching process round inhomogeneous structures were observed (Figure 12 left). These structures are caused by the gas bubbles sticking to the wafer surface during the etching process. The surface is nearly homogenous for wafers where the gas bubbles were continuously removed from the surface by the process described in chapter 3.3 (Figure 12 right).

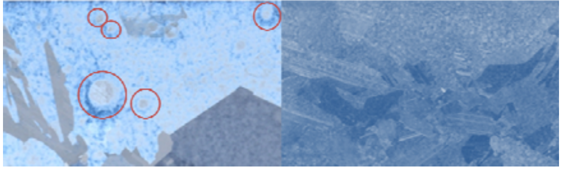

Figure 11: Left: Inhomogeneous wafer with high amount of shading resulting from gas bubbles (red circled); Right: Homogeneous wafer resulting from the continuous removal of reactive products by advanced fluid flow.

In Figure 13 a microscope image from part of a wafer showing shaded and non-shaded regions. Different etch patterns can clearly be seen. Consequently the gas bubbles lead to an inhomogeneous etching structure and have to be removed.

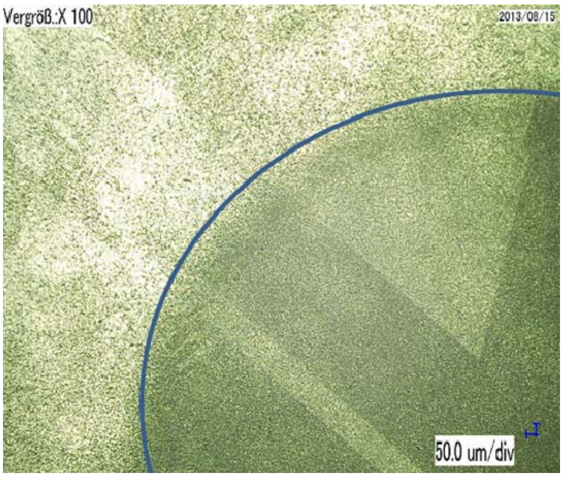

Figure 12: Inhomogeneous structure because of a shadowing by gas bubbles during the etching process. In the left part an area without shading and in the right part an area with shading due to a gas bubble is shown (blue circled).

6 CONCLUSION

The exhaust and fast transport system of the novel single side etching tool protects the emitter by establishing a continuous flow of fresh air from the middle to the edges of the wafer and by placing an exhaust at the edges of the wafer where the reactive gases emerge. By upgrading the etching mixture and the exhaust the quality and efficiency of the tool can be further improved due to less emitter damage and higher etching rates.

The wrap around due to bursting gas bubbles and the shadowing by reaction products can be prevented with the presented fluid flow concept where the reactive products are continuously removed from the etching surface.

Finally, we can say that the novel single side etching tool settles all claims for single side processes, particularly for advanced processes like polishing. Through the further optimization of both the mechanical parts, e.g. the exhaust system, and the chemical part we will be able to present more results for the chemical edge isolation or polishing than on other single side etching tools. Additionally the combination of emitter etches and polishing in one step is very promising for advanced cell concepts like PERC.

7 ACKNOWLEDGEMENTS

The author would like to thank the whole PVTEC production team and the SINGULUS STANGL SOLAR team.

8 REFERENCES

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