SURFACE TEXTURING FOR SILICON SOLAR CELL APPLICATION USING ICP-PECVD PLASMA TECHNIQUE

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ABSTRACT: This work is focused on plasma-induced texturing using a single chamber inductively coupled plasma – plasma-enhanced chemical vapour deposition (ICP-PECVD) lab-tool. Plasma treatment using pure NF_3 under low pressure conditions leads to high etch rates (1.2–1.4 µm/min) enabling fast surface texturing. 6 min plasma treatment on wafers with saw damage decreases the effective reflectivity R_{eff} from 31% to 13.7% without anti-reflection coating (ARC), which is lower than the value for a common alkaline surface texture. For planar (KOH pre-treated) samples R_{eff} can be reduced from 38% to 17.8% after 4 min plasma treatment. Lifetime measurements reveal a post-process lifetime of 250 µs without any further damage removal etching (DRE). This refers to a low density of plasma-induced defects. Furthermore, it is demonstrated that plasma textured surfaces enable excellent contact formation for screen-printing of Ag/Al pastes on boron emitters leading to low specific contact resistances below 5 mΩcm^2 even for low set peak firing temperatures (T_{Set} < 800°C). These values are much lower than values realized with a common isotropic wet acidic etch and slightly lower than values realized with a common alkaline surface texture, leading to reduced power losses due to lowered series resistance. In addition, the specific contact resistance on $POCl_3$ emitters by screen-printing of commercial available Ag pastes is determined to be below 1 mΩcm^2, nearly independent of the set peak firing temperature.
Keywords: PECVD, plasma texturing, NF_3, boron, contact resistance

1 INTRODUCTION

An important process step in solar cell production is the texturing of the wafer surface, which reduces surface reflection and enhances light-trapping in order to improve the coupling of incoming light into the solar cell. Thus the conversion efficiency and generated electrical energy output of solar cells can be increased.

Commonly a mask-less isotropic wet acidic etch is used for texturing of multi-crystalline Si substrates [1]. With this method the surface reflection can only be reduced to moderate values [2]. Furthermore, common isotropic wet acidic texturing can only be conducted on wafers with saw damage and results in texturing of both wafer sides. However, there are different Si wafers with a saw-damage less surface as, e. g., epitaxial thin-films or ribbon-grown wafers. Furthermore, depending on the solar cell technology, it can be beneficial to use single side texturing.

Therefore, promising alternative methods like reactive ion etching (RIE) are under investigation by many research groups [3-9]. This enables single side texturing of Si substrates, nearly independent of the surface morphology, leading to very low surface reflectivity.

However, low reflectivity is not the only requirement for increasing solar cell efficiency. It is known that RIE can create surface defects [10-12]. This may lead to strong surface recombination resulting in a drop of V_{OC} and therewith efficiency losses. It is known that plasma-induced damage can be removed by damage removal etching (DRE) in a HNO_3/HF mixture [5,6,13]. Though, the surface reflectivity is increased by DRE.

This work is focused on plasma-induced texturing using a single chamber inductively coupled plasma – plasma-enhanced chemical vapour deposition (ICP-PECVD) lab-tool using pure NF_3 plasma. We investigate the influence of etching time on the surface reflectivity for surfaces with/without saw damage. The impact of plasma induced surface defects is investigated on lifetime samples without DRE.

Furthermore, especially when using Al containing Ag pastes for contact formation via screen-printing, the surface morphology is important [14]. Therefore, we analyze the contact formation with screen-printing of Ag/Al pastes on boron emitters from BBr_3 diffusion for plasma textured surfaces

2 EXPERIMENTAL

For the present work an ICP-PECVD plasma lab tool was used. As precursor gas we used NF_3 instead of SF_6 or CF_4 to avoid formation of sulfurous or carbonaceous chemical compounds, which are known for their detrimental influence on surface recombination velocity [15]. The dry texturing process due to reactive fluorine radicals was conducted under low pressure conditions using pure NF_3.

We investigated the behavior of plasma etching on substrates with and without saw damage. Therefore, half of the wafers were pre-etched in hot KOH solution to remove the saw damage completely (removal ≈ 10 µm per side) before plasma treatment. Reflectivity of plasma treated samples was measured with a spectrophotometer.

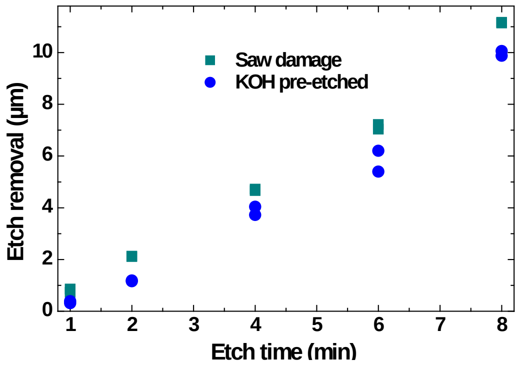

Figure 1: Plasma etch removal as a function of etch time on saw damage and KOH pre-treated surfaces.

The influence of plasma induced surface defects was investigated on 2 Ωcm p-type float zone (FZ) lifetime samples, which were surface passivated by 25 nm thin atomic layer deposited(ALD)-Al_2O_3 layer on both sides.

To investigate the contact formation on plasma textured surfaces using screen-printing of commercial available Ag/Al pastes, test structures using a transfer length method (TLM) grid structure were fabricated. We used boron emitters from BBr_3 diffusion with a sheet resistance R_{sh} = 50 Ω/sq. The contact formation was realized in an infrared (IR) belt furnace for peak firing temperatures in the range of 780 - 870°C (set point).

3 RESULTS

3.1 Etch rate and optics

The plasma etch removal for the wafers with saw damage is slightly higher compared to the KOH pre-treated wafers as shown in Fig. 1. An etching time of 8 min ensures sufficient removal of the complete saw damage. The etch rates could be calculated to 1.4 µm/min for the wafers with saw damage and to 1.25 µm/min for the KOH pre-treated wafers. The high etch rates enable a fast texturing process.

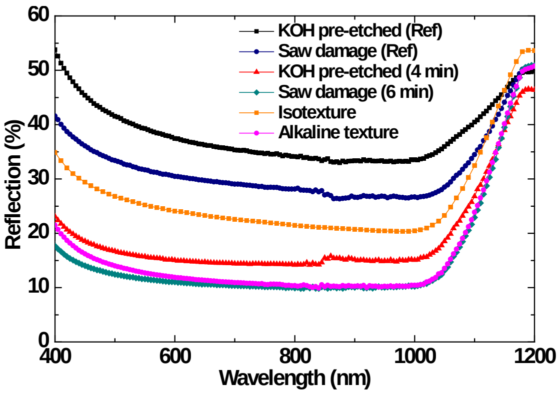

Figure 2: Reflectivity of plasma treated and reference samples without ARC as a function of wavelength.

The lowest reflectivity for the KOH pre-treated wafers was achieved after 4 min plasma treatment, whereas for the wafers with saw damage the lowest reflectivity was achieved after 6 min plasma treatment (see Fig. 2). For comparison, the reflectivity of a KOH etched wafer and a wafer with saw damage before plasma treatment are also shown in Fig. 2, as well as the reflectivity of a common isotropic wet acidic etch and a common alkaline surface texture. It has to be noticed that the reflectivity of the 6 min plasma treated wafers with saw damage is slightly lower than the value for a common alkaline surface texture.

Table I: Overview of minimal reflectivity R_{min} and effective reflectivity R_{eff} without ARC. The effective reflectivity values are weighted with the AM1.5 global spectrum.

Surface	R_{min} (%)	R_{eff} (%)
KOH etched	33.2	38.1
Saw damage	26.4	31.3
KOH etched (4 min plasma)	14.2	17.8
Saw damage (6 min plasma)	9.8	13.7

Tab. I shows an overview of the minimal reflectivity R_{min} and effective reflectivity R_{eff} for the wafers which are shown in Fig. 2. The effective reflectivity values are weighted with the AM1.5 global spectrum in the range of 350 – 1200 nm.

6 min plasma treatment on wafers with saw damage decreases the effective reflectivity R_{eff} from 31% to 13.7% without anti-reflection coating (ARC). For the KOH pre-treated samples R_{eff} can be reduced from 38% to 17.8% after 4 min plasma treatment.

3.2 Surface recombination

However, low reflectivity is not the only requirement for increasing solar cell efficiency. It is known that plasma texturing can create surface defects [10-12]. This may lead to strong surface recombination resulting in a drop of V_{OC} and therewith efficiency losses. It is also known that plasma induced damage can be removed by damage removal etching (DRE) in a HNO_3/HF mixture [5,6,13]. Though, the surface reflectivity is increased by DRE. To avoid formation of surface defects, we use an ICP-PECVD plasma lab tool with pure NF_3 as precursor. The post-process surface recombination was analyzed on 2 Ωcm p-type FZ-Si reference samples, which were surface passivated by 25 nm thin ALD-Al_2O_3 layer on both sides. Lifetime measurements reveal a post-process lifetime of 250 µs without any further DRE. This refers to a relatively low density of plasma-induced defects.

3.3 Contact formation

Especially when using Al containing Ag pastes for contact formation via screen printing on boron emitters, the surface morphology is important [14]. Fig. 3 illustrates the specific contact resistance ρ_c as a function of peak firing temperature in an IR belt furnace for a commercially available Ag/Al paste.

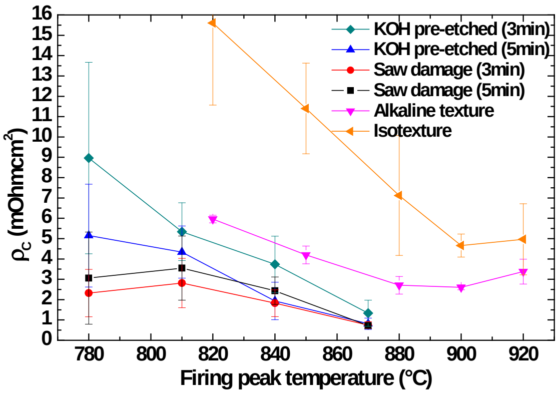

Figure 3: Specific contact resistance on a 50 Ω/sq BBr_3 boron emitter as a function of peak firing temperature in an IR belt furnace for a commercially available Ag/Al paste. The values were determined via TLM measurements.

The values were determined via TLM on c-Si wafers with a 50 Ω/sq BBr_3 boron emitter, which was passivated with 70 nm SiN_x. The SiN_x layers were deposited with the same ICP-PECVD lab tool used for plasma texturing. The results show that plasma textured surfaces enable excellent contact formation on boron emitters leading to low specific contact resistance below 5 mΩcm^2 even for low set peak firing temperatures (T_{Set} < 800°C). These values are much lower than values realized with a common isotropic wet acidic etch and slightly lower than values realized with a common alkaline surface texture. Lower contact resistance leads to reduced power losses due to lowered series resistance.

The specific contact resistance on 50 Ω/sq $POCl_3$ emitters by screen-printing of commercially available Ag pastes was determined to be below 1 mΩcm^2, nearly independent of the set peak firing temperature in the investigated temperature range of 780 - 870°C.

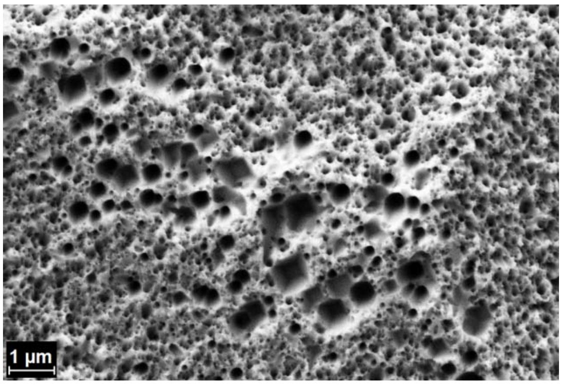

Figure 4: SEM image after 4 min plasma treatment on KOH pre-treated sample.

Fig. 4 shows the scanning electron microscopy (SEM) image of a KOH pre-treated sample after 4 min plasma texturing.

Due to technical problems during cell processing, the benefit of plasma texture could not yet be demonstrated on cell level. This will be done by comparison of p-type standard solar cells (Al BSF) with dry plasma texture and with common isotropic wet acidic texture.

4 SUMMARY

An alternative method for surface texturing using an ICP-PECVD lab tool has been demonstrated in this work. Plasma treatment using pure NF_3 under low pressure conditions leads to high etch rates (1.2–1.4 µm/min) enabling fast surface texturing. Effective reflectivity could be reduced from 31% to 13.7% for wafers with saw damage without ARC, which is lower than the value for a common alkaline surface texture. For KOH pre-treated samples R_{eff} could be reduced from 38% to 17.8%.

Lifetime measurements revealed a post-process lifetime of 250 µs without any further damage removal etching (DRE). This refers to a low density of plasma-induced defects.

Furthermore, it could be demonstrated that plasma textured surfaces enable excellent contact formation for screen-printed Ag/Al pastes on 50 Ω/sq BBr_3 boron emitters leading to low specific contact resistance < 5 mΩcm^2 even for low set peak firing temperatures ($T_{Set} < 800$°C). In addition, the specific contact resistance on 50 Ω/sq $POCl_3$ emitters by screen-printing of commercially available Ag pastes was determined to be below 1 mΩcm^2.

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