EASY & SIMPLE SILICON SOLAR CELL CONCEPT FOR CONCENTRATED SUNLIGHT

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ABSTRACT: The overall aim to lower the cost and realize a high efficiency photovoltaic system can be achieved by concentrator systems since, compared to non-concentrating systems, the solar cells are replaced by more cost-effective optical devices. The EASY & SIMPLE (Especially Advanced Structuring with high Yield & Selective emitter IMPLEmentation) silicon solar cell concept is an approach combining straight forward solar cell processing with medium to high light concentration. The EASY & SIMPLE cell concept is based on mechanical V-grooving of the front surface and a subsequent definition of the contact area along the ridges. The front contacts can be defined by mechanical means, using a conventional dicing saw or by a self-aligning SiN deposition, both processes avoid the use of photolithography. The V-grooved surface serves as a means for relaxing the requirements for tracking if adequately installed. Additionally, the V-grooved front surface opens the opportunity to apply the SAFE (Shallow Angle Finger Evaporation) metallisation scheme [5]. As an alternative to this technique, an electroless plating process depositing nickel and copper as has been applied in the same way as to the similar LOPE (LOcal Point contact and shallow angle Evaporation) solar cell concept [5]. In this paper, we introduce the cell concept and present cell results under concentrations of between 1 and 67 suns. Some design considerations for the cell front side dependent on texture angle are also discussed.

Keywords: - 1: concentrator cell- 2: silicon – 3: mechanical texturisation

1. INTRODUCTION

There are two main approaches for concentrator systems, either the complexity of the system is kept low [1] or a higher concentration of light is used with more sophisticated optics and solar cells. A wide variety of silicon solar cells for use under concentrated sunlight have been developed, e.g. wet chemically V-grooved cells [2], chip size point contact cells [3] and laser groove buried grid (LGBG) cells [1] and the rear contact cell RLCC [4] The point contact silicon solar cell is optimised for concentration as high as 250 suns ($25W/cm^2$) with accordingly complex solar cell processes and optics, the LGBG solar cells for operation at 1 sun are used with very few changes in cell structure and put under low concentration of 2 to 5 times [1].

In developing new concentrator cell designs, one has to pay special attention to how and where to carry the current, because of the high current densities. The grid finger spacing should be adequately narrow and the finger cross section rather wide. Thus many concentrator cell concepts have an unmetallised front side with both contact polarities located on the non-illuminated rear side [3,4]. In the case of small and medium concentration, one can afford to contact the front side emitter with very small contact fingers which get the large cross section by being buried into the cell bulk [1]. The EASY & SIMPLE cell concept is designed for a medium concentration of about 50 suns. The emitter contacts are on the illuminated front side but since they are located on vertical flanks of an asymmetric V-groove, they give only a very small rise in short circuit current losses due to shading. In contrast to the V-grooved cell introduced by Borden et al. [2] the front side texture applied to the EASY & SIMPLE cells leads to a smaller optical width of the contact fingers of a factor of 3.5 for the wet chemically etched structure assuming a finger width of 50 µm and a finger thickness of 5 µm. Thus the EASY & SIMPLE cell concept combines the advantages of a V-grooved front surface with buried grid fingers.

Figure 1 shows a schematic drawing of an EASY & SIMPLE cell. The asymmetric V-texturisation is done mechanically using a conventional dicing saw equipped with bevelled dicing blades. The definition of the emitter contact region is done mechanically similar as in the case of the LOPE (local point contact and shallow angle evaporation) cell [5], but instead of generating point contact areas the contact areas are line-shaped running parallel to the V-grooves.

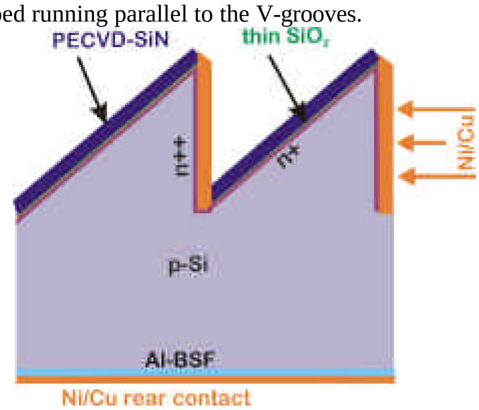

Figure 1: Schematic drawing of the EASY & SIMPLE solar cell. The line-shaped contact area is defined mechanically or by directional PECVD.

The metallisation can be done either by metal evaporation under a shallow angle, i.e. applying the SAFE (shallow angle finger evaporation) technique [5] or by electroless plating of Ni and Cu. Both methods are self- aligning. The contact finger spacing can be chosen freely as whole-numbered multiple of the distance between two neighbouring grooves. The cutting depth and the groove angle of the flat flank determine the maximum finger width and minimum finger distance.

In this paper we present different solar cell processes, aiming at a process sequence with the most self aligning steps.

2. SOLAR CELL PROCESSING

The front surface texturisation, which is the first processing step, defines the emitter contact finger width and spacing.

Mechanical asymmetric V-texturisation

Thermal oxidation: 130 nm

Light $POCl_3$-diffusion: 90 Ω/sq

Thermal oxidation: 20 nm

PECVD-SiN: 110 nm

Directional PECVD-SiN only onto 30° flank

Mechanical opening of dielectric layer on vertical flanks using a conventional dicing saw

Contact area already self-defined

Heavy $POCl_3$-diffusion: 7 Ω/sq

Al-BSF formation using evaporated Al

Electroless Ni/Cu plating

Pn-junction isolation by using the dicing saw

Figure 2: Processing sequences for the EASY & SIMPLE cells discussed here. Steps written in bold letters lead to a significant process simplification, not done yet.

The mechanical V-groove surface texturisation of a 250 µm thick float zone wafer is done using a conventional dicing machine equipped with an asymmetrically bevelled saw blade (85°/30° measured against the wafer surface). The cutting depth is around 70 µm. The saw damage of 4 µm is removed in an acidic solution (HNO_3, CH_3COOH, HF). After an RCA-cleaning the wafer undergoes a thermal oxidation for masking the subsequent shallow emitter diffusion. A second thin thermal oxide serves as surface passivation. A 110nm thick PECVD- (plasma enhanced chemical vapour deposition) SiN layer is applied as an antireflection coating and diffusion mask for the subsequent heavy diffusion into the contact regions.

There are two possible ways to define the contact areas: either by a highly selectively deposited SiN layer or by opening a more homogeneously deposited SiN by mechanical means. The first method is based on the selectivity of the PECVD-SiN process in a parallel plate reactor, which leads to a lower deposition rate on vertical compared to horizontal planes. Thus the vertical flank shows a far thinner SiN layer than the flatter. Thus the SiN on the vertical flank can be removed with HF or other appropriate solutions while the flat flank is still covered by a thick SiN layer. The second method, removing the SiN from the vertical flank utilizing the dicing saw equipped with a 15 µm thick saw blade means an additional processing step compared to the first method.

Having defined the emitter contact region, the back surface field formation and the heavy emitter diffusion can be done simultaneously in a co-diffusion process. In detail this includes an RCA cleaning followed by Al evaporation onto the rear side and $POCl_3$-diffusion in a tube furnace. The back surface field can be in defined regions only or full area. First studies looking at the selectivity of SiN deposition regarding vertical and horizontal planes show that a thickness of 110 nm on the horizontal flank leads to roughly 75 nm on the vertical flank. In a next study the composition of the SiN on vertical and horizontal planes will be investigated to eventually use this information for selectively etching the SiN on the vertical flank. The EASY & SIMPLE cells introduced here have been fabricated applying the mechanical method and not using a Al-codiffusion but separate steps.

3. CELL DESIGN CONSIDERATIONS

Since the EASY & SIMPLE cells developed here will be implemented in a concentrator system they will be encapsulated. Thus the surface texture should allow minimum reflectance with encapsulant. This means that for minimum surface enlargement a quite flat structure can be chosen. The structure should also be asymmetrical to enhance the number of chances each light ray has to enter the solar cell. Fischer calculated 2.7 chances per ray and only a surface enlargement of a factor of 1.27 [6] for an asymmetric structure of 90°/25°. The realisation of this structure was done with a saw blade cutting an 85°/30° structure. The depth of the cuts and the distance between two cuts (index) determine the contact grid structure. This is an optimisation problem. On the one hand, the contribution of the emitter to the sheet resistance should be minimised. One the other hand, assuming a fixed texture angle, reducing the path length in the emitter also reduces the finger width. From a technological point of view, a structure less than 40 µm deep cannot be realised properly because of deviations in wafer thickness and cutting depth.

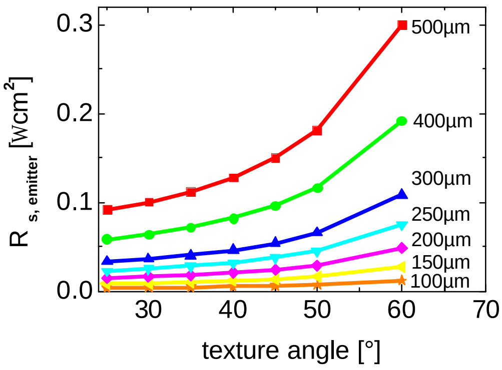

Figure 3: Contribution of the emitter on the series resistance versus texture angle for various finger spacings.

Figure 3 illustrates the dependence of the emitter contribution to the series resistance on the texture angle for various contact finger spacings. Larger texture angles mean charge carries in the emitter must travel larger distances before collection. Only contact spacings of less than 200 µm are affordable for concentrations up to 100 suns assuming the series resistance has to be 1/suns the value at 1 sun because the linear increase of J_{SC}.

In the case the contacts running perpendicular to the grooves, $R_{s,emitter}$ is reduced by the surface enlargement factor. Figure 4 demonstrates the smaller series resistance contribution for such front side design. With this design a self-aligning contact area definition can not be realised, rather the dielectric layer must be opened by mechanical means e.g. by laser ablation or using a dicing saw [7].

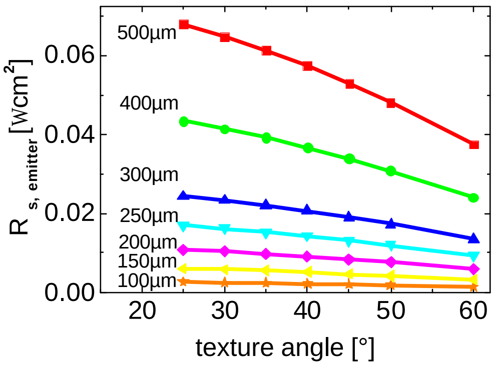

Figure 4: Contribution of the emitter to the series resistance versus texture angle for various finger spacings in the case the contact fingers running perpendicular to the texture.

The contact resistance and the resistance in the finger decreases with increasing groove angle while the contact spacing is fixed due to wider contact fingers. The absolute value of R_C must be considered, particularly in the case of Ni as a contact metal because of its high contact resistivity - about 20 Ωcm^2 [8]. The contact thickness was assumed to be 10 µm.

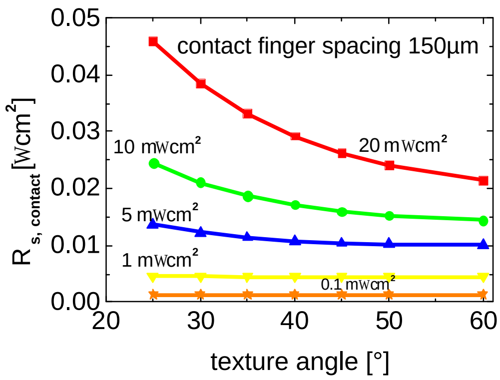

Figure 5: The contact resistance for different contact resistivities versus the texture angle. The texture defines the finger width.

An estimate of the fill factor FF is given by [9]

$$FF = FF_0\,(1-R_S J_{SC}/V_{OC})$$

where $FF_0 = 0.84$, $J_{SC} = 38.7\ mA/cm^2$ and $V_{OC} = 652mV$ after [6]. The fill factor loss at 1 sun versus the texture angle for different contact spacings is shown in Figure 6. The smaller the contact finger spacing the smaller the FF-loss. The dependence on the texture angle differs for the contact spacing between 100 and 500 µm. In case of the 100 µm spacing the increase in $R_{S,\ emitter}$ is so small compared to the decrease in $R_{S,\ contact}$ and $R_{S,\ finger}$ that the FF is approximately constant throughout the range of texture angles considered here. For finger distances above 400 µm the emitter contribution dominates the total series resistance and therefore the FF decreases significantly with larger texture angles.

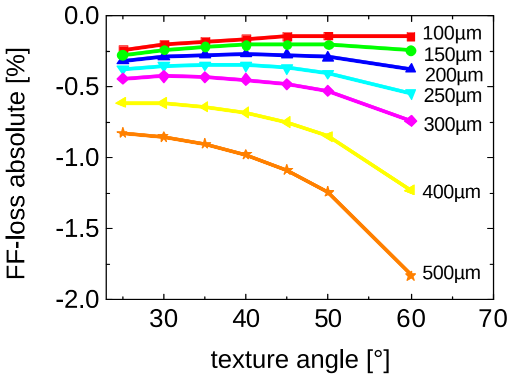

Figure 6: The main contribution to the series resistance of the EASY & SIMPLE cells are considered in the FF estimate. The FF-loss absolute is defined as the difference between the ideal FF of 84 % and the calculated one.

For a concentrator cell, the series resistance of the cell should be only a fraction $suns^{-1}$ from the value at one sun due to the linear increase in J_{SC} with concentration. Therefore the series resistance should be less than 0.005 Ωcm^2 for up to 100 suns. This is only possible if a maximum texture angle of 30° is assumed combined with a contact resistance ρ_C of maximum 0.1 mΩcm^2. The resistance contribution from the grid fingers can be neglected for all texture angles. Thus the main challenge for plated EASY & SIMPLE cells is the reduction of the high contact resistance of Ni on Si.

4. RESULTS AND DISCUSSION

The first EASY & SIMPLE cells have been successfully realised applying the second sawing step for contact area definition. In order to simplify the process no local BSF or local rear contact was formed but a full BSF as mentioned in Fig. 2. The low efficiencies are at least partly explained by insufficient surface passivation of front and rear side, unpassivated pn-junction at the cell edges and a high metallisation ratio on the emitter of 36 % plus busbars. This high metal fraction reduces the V_{OC} to a calculated value of about 652 mV. Except for the high front side metallisation ratio the losses are not inherent to the cell concept and therefore not discussed here any further. Figure 7 show the cell efficiency versus concentration. The maximum cell efficiency is achieved at 15 suns. The rise in efficiency is strongly correlated to the FF rise which in turn reflects the decreasing influence of the diode currents particularly from the second diode (space charge region). For higher light intensities the increased series resistance totally dominates the FF and thus the efficiency. The short circuit current increases linearly up to the highest light intensities of 67 suns. Since the texture was chosen to minimise the series resistance the contact resistance ρ_C is likely to be one of the main reasons for the FF losses besides J_{02}. ρ_C for an unsintered Ni-contact is as high as 20mΩcm^2 [8] and this amounts to a total series resistance of 0.05 Ωcm^2 which is one order of magnitude higher than desired. For further cell optimisation first of all the series resistance has to be reduced.

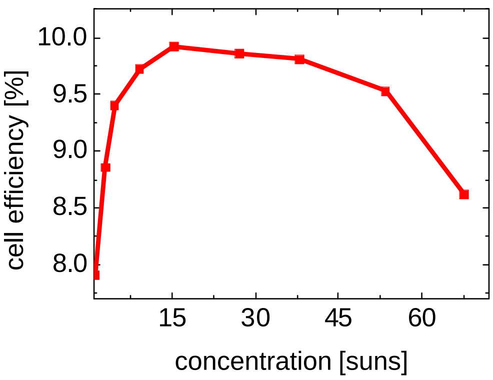

Figure 7: Cell efficiency versus light intensity of the first EASY & SIMPLE cells with plated contacts. Maximum efficiency is achieved at 15 suns.

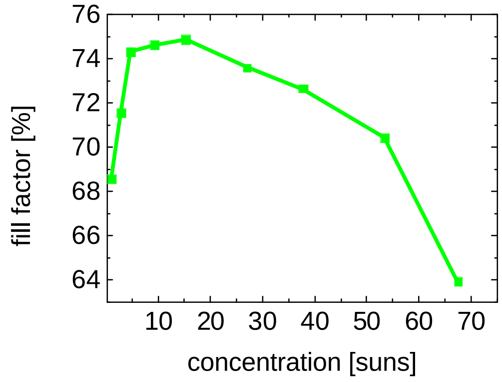

Figure 8: Fill factor of an EASY & SIMPLE cell versus light intensity. The high series resistance losses decrease the FF with increasing concentration significantly.

5. CONCLUSION

The EASY & SIMPLE cell concept has been introduced and successfully realised. Grid design optimisations dependent on the texture angle have been undertaken showing an excellent correspondence between optical and electrical requirements. In both cases a texture angle of around 30° is optimum. The cell efficiency at higher intensities is strongly dominated by series resistances. Therefore further investigation should focus on minimising the contact resistance. In addition, the directed PECVD-SiN has to be optimised for selective deposition on vertical and horizontal planes. Since that will allow the second sawing step to be avoided, this therefore has the potential to simplify the processing sequence significantly.

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