PASSIVATING EFFECT OF A-SI/C-SI HETEROJUNCTION EMITTERS FORMED ON ISOTEXTURED SURFACES

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ABSTRACT: We investigate the passivating effect of a-Si/c-Si heterojunction (HJ) emitters formed on isotropically textured (isotextured) surfaces developed for multicrystalline silicon (mc-Si). We use quasi steady state photo conductance (QSSPC) measurement and I-V characteristics of the HJ cell structure. The QSSPC approach was shown to be effective to find out which type of isotexture is feasible for the HJ emitter. QSSPC results also demonstrated the HJ emitter sufficiently covers the isotextured surface in spite of the scale differences. I-V characteristics for the HJ cell structure from mc-Si substrate presented Jsc of 33.6 mA/cm² and Voc of 0.600V, which is comparable to a conventional mc-Si cell. The applicability of isotexture for HJ emitter was therefore affirmed.
Keywords: Heterojunction, Texturisaion, Multi-Crystalline

1 INTRODUCTION

At present, the a-Si/c-Si heterojunction (HJ) emitter is industrialized only with single crystal silicon (sc-Si) [1,2] but not with multicrystalline silicon (mc-Si), in spite of its promising features of higher Voc and a low temperature process [1-7]. To realize its industrialization for mc-Si, the front surface must be textured to enhance anti-reflection and the HJ emitter should be optimized on the textured surface. Conventionally, anisotropic texturing using alkaline solution is used for mc-Si as well as for sc-Si, but in mc-Si it causes steps at the grain boundaries as high as several microns [8], which makes it difficult to cover the surface with the thin film HJ emitter with the thickness of 10 ~ 50 nm [4-6]. Recently, isotropic texturing with acidic solution (also called, isotexture) is commonly used as the method to form texture on mc-Si solar cell [9,10]. Although the size of its roughness is normally 0.5 ~ 5 µm, much larger than the thickness of the thin film HJ emitter, steps at the grain boundaries are much smaller than for alkaline texture.

The purpose of this study is to investigate whether the isotextured surface is applicable for a thin film HJ emitter, and demonstrate which type of isotexture is most feasible for this.

In the process of testing several combinations of thin film and isotexture, evaluating them in I-V characteristics with actual HJ cell structures is favorable. But in practice, this is not so easy because there are several additional uncertainties in a cell process. Some researchers already suggested that the effective lifetime (τ_{eff}) measurement with the HJ emitter is an effective way to evaluate the passivating effect of the HJ emitter [1,2,4,7], because it enables to evaluate just the illuminated status of the HJ structure without the influence like series resistance to the outside circuit.

In this study, the HJ is investigated with the τ_{eff} and the implied Voc measured by quasi steady-state photo conductance method (QSSPC) [11]. HJ cell structures are also fabricated and the I-V characteristics are compared with the results of QSSPC.

2 EXPERIMENTAL

Figure 1 shows the sample structures with HJ of p-type a-Si and n-type c-Si; Fig.1 (a) for the passivating effect of the HJ emitter on the isotextured surface with τ_{eff} and implied Voc measured by QSSPC; Fig.1 (b) for I-V characteristics of the HJ cell structure.

For both samples, n-type mc-Si or sc-Si float zone (FZ) wafers with a thickness of 220 ~ 250 µm and a resistivity of 1 ~ 3 Ω·cm were used. The thin film for the HJ emitter consists of p-type a-Si and intrinsic a-Si with the thickness of 10 ~ 30 nm deposited by rf-PECVD [12]. An indium tin oxide (ITO) film is deposited by sputtering on the HJ emitter. ITO is also known to function as anti-reflection coating for silicon because its refractive index is about 2.0.

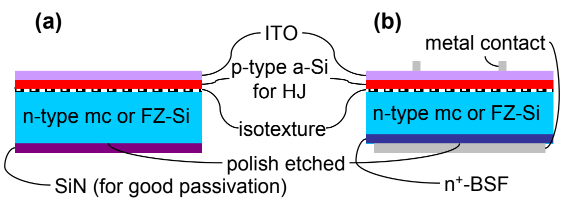

Figure 1: Sample structures for evaluation. (a) QSSPC. (b) I-V characteristics of the HJ cell.

To evaluate the passivating effect of the HJ emitter formed on the isotextured surface, avoiding other uncertain factors is important. A unique structure where the effect of the HJ emitter is focused on is provided as shown in Fig. 1 (a). In this structure, only the front side is isotextured. The rear surface is polish-etched and a silicon nitride (SiN) film which has ability to passivate crystalline silicon surfaces well [13] is deposited on it.

I-V characteristics measurement is not possible for this structure because it does not have a metal contact on the rear side, but τ_{eff} measurement is possible. In this case, τ_{eff} can be expressed as [7]

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{1}{\tau_s}, \qquad (1)$$

where τ_b is the bulk lifetime and τ_s is the surface lifetime. τ_s can be also expressed as

$$\frac{1}{\tau_s} = \frac{1}{\tau_{HJ}} + \frac{1}{\tau_{SiN}}, \qquad (2)$$

where τ_{HJ} is the surface lifetime of the HJ side and τ_{SiN} is the surface lifetime of the SiN side. When preparing several varieties of the HJ emitter and isotexture, τ_b and τ_{SiN} can be kept constant and the comparison of τ_{eff} only represents the change of τ_{HJ}.

This structure has an additional advantage over investigation of a double HJ structure, in which uncertainties with respect to cleanliness of deposition of a HJ on the second side and the level of symmetry of the test device are avoided.

To evaluate I-V characteristics with the structure shown in Fig. 1 (b), metal contacts on both front and rear side are necessary. Silver is evaporated on the front side with a comb-like pattern and on the rear side with a whole area.

An ohmic contact between ITO and silver is low enough on the front side. On the rear side, a heavily doped n^+-type layer is formed to obtain an ohmic contact between silver and silicon. The n^+-layer is formed by phosphorus diffusion in prior to the HJ emitter formation. This process is also expected to improve the bulk quality of mc-Si by phosphorus gettering.

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3 RESULTS AND DISCUSSION

3.1 QSSPC

Figure 2 shows the effective lifetime (τ_{eff}) at a minority carrier density of $10^{15}/cm^3$ and the implied Voc measured by QSSPC. Three types of isotexture (A, B, C) are investigated, as well as the polish-etched surface as reference. A reference sample is also provided for each type of surface with surface passivating SiN [13] on the front instead of the HJ emitter. The mc-Si wafers are all from neighboring positions of the ingot to allow good comparison, and the HJ emitters on the same type of wafer (FZ or mc-Si) are deposited at the same time.

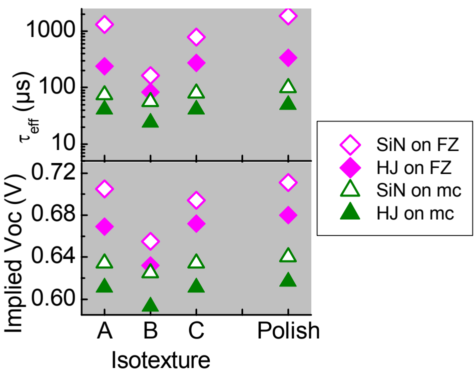

Figure 2: τ_{eff} and implied Voc measured by QSSPC.

In the case that SiN is deposited on the front as well as the rear, τ_{eff} for the polish-etched wafers can be expressed from equations (1) and (2) as

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{2}{\tau_{SiN\_on\text{-}polish}}, \qquad (3)$$

where $\tau_{SiN\_on\text{-}polish}$ is the surface lifetime of the SiN side on polish-etched surface, and almost represent τ_b of the wafer material because $\tau_{SiN\_on\text{-}polish}$ is large enough [13]. They are 1800 µs for FZ and 100 µs for mc-Si. τ_{eff} for Isotexture A and C are of the same order as for the polish-etched for both FZ and mc-Si, which means the surfaces of Isotexture A and C can be as well-passivated as when polish-etched.

In the case that HJ emitters are deposited, a similar tendency can be observed. The HJ emitters on Isotexture A and C give a lifetime as high as on a polish-etched surface. This means the coverage of the surface by HJ emitter is sufficient in spite of the scale difference. As a consequence, Isotexture A and C are shown to be feasible in combination with the HJ emitter for both FZ and mc-Si.

3.2 Reflectance

Spectral reflectance was measured for the structure of Fig.1 (a) to see the anti-reflection possibilities for the isotextured surface. Figure 3 shows the spectral reflectance curves for HJ/ITO stacks on Isotexture A, C, and polish-etched. The reflectance for the optimal thickness of SiN on standard isotexture, as used on the conventional mc-Si solar cells [9] is also shown for reference.

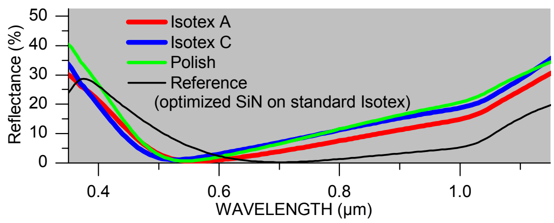

Figure 3: Spectral reflectance of HJ/ITO stacks formed on isotextured and polish-etched surfaces, with a curve of a conventional mc-Si cell (ECN baseline) for reference.

To obtain better anti-reflection performance, the reflectance should have a minimum at 0.6 ~ 0.7 µm. In that sense, the ITO films for Isotexture A, C and polish-etched were too thin, and their anti-reflection performance can be improved by optimizing the thickness.

In this comparison of Isotexture A, C, and polish-etched, Isotexture A gives lowest reflectance in the range of wavelength above 0.6 µm. In the same range, the slopes for Isotexture A and C is more gentle than that of polishing-etched, which presents the isotextured surfaces contribute to lower reflectance in the range of long wavelength.

3.3 I-V characteristics

I-V characteristics under AM1.5G illumination were measured on HJ cells with an area of 0.69 cm², with the layout shown in Fig. 1 (b). Also in this case, the mc-Si wafers are all from neighboring positions in the ingot and the HJ emitters on the same type of wafer (FZ or mc-Si) were deposited at the same time.

Figure 4 shows the efficiency, Voc, Jsc, and FF of the cells with Isotexture A, C, and polish-etched on both FZ and mc-Si wafers. Because of some uncertain factors in the ITO and the metallization processes, the value of FF is sometimes not sufficient, especially for the cells with Isotexture C on mc-Si wafer, as visible in the figure. Nevertheless, it is still possible to compare the values of

Voc and Jsc among the tested samples, and in that way judge the feasibility of combining isotexture with the HJ emitters.

Jsc of the cells with the textured surfaces are about 3 to 5% larger than that with the polish-etched surface (except Isotexture C on mc-Si), which demonstrates that the textured surface reduces reflection on the front surface and contributes to the increase of the photo-generated current. The absolute value of Jsc is as large as 33.6 mA/cm² for the mc-Si cells, which is comparable to that of conventional homo-junction mc-Si cells. As described in section 3.2, optimization of the ITO thickness may lead to further increase of Jsc.

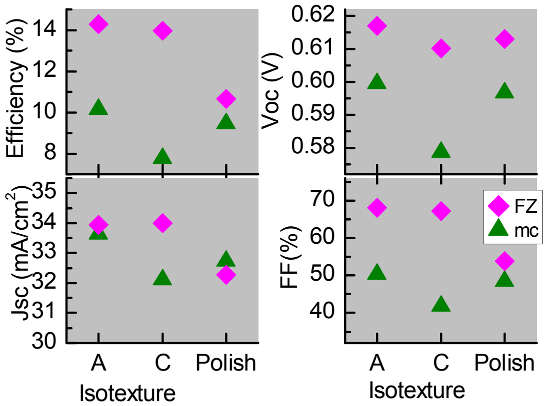

Figure 4: I-V characteristics under AM1.5G illumination for the HJ cell with isotexture, compared to polish-etched.

On the other hand, the Voc of the cells with the textured surfaces is maintained at the same level as, or is even higher than, as the Voc of the polish-etched cells, which suggests that the increase of the interface area caused by isotexture does not cause a reduction of Voc.

The absolute value of Voc exceeds 0.60 V in spite of the poor surface passivation on the rear due to full coverage with the metal contact. If a better surface passivating film like SiN is deposited on the rear, a higher Voc would be expected.

3.4 Implied and actual Voc

The actual Voc values shown in Fig.4 can be compared with the implied Voc values shown in Fig.2. The differences between the implied and actual Voc are 0.05 ~ 0.07 V for the FZ wafers and 0.01 ~ 0.03 V for the mc-Si wafers. Several reasons can account for the difference between the implied and actual Voc, and most of them should be common for FZ and mc-Si. But apparently, an uncommon factor can be observed dominantly in the results.

The major difference of the process between the samples of Fig.1 (a) and (b) is the phosphorus diffusion for the n^+-BSF which was applied to (b) but not to (a). A phosphorus diffusion process is known to have a gettering effect for impurities [14] and to improve the quality of mc-Si for both p- and n-type wafers [15]. The quality of FZ wafers is high as-received and there is probably almost no room left to be improved by the gettering process. The samples of Fig.1 (b) experience the phosphorus diffusion process and the quality of mc-Si wafer may be improved while that of FZ may not.

This interpretation suggests that the HJ cells based on mc-Si wafers need the phosphorus diffusion process to obtain a high efficiency. Although the industrialized HJ cell using sc-Si also employs a HJ BSF layer [1,2], a phosphorus-diffused BSF layer might be a better choice for a HJ cell based on mc-Si. Such a structure would require a SiN layer for good surface passivation, and hydrogen passivation effect of SiN [15] will thus also contribute to the quality improvement of mc-Si. It does not need ITO on the rear because of the sufficiently low sheet resistance and even fire-through contact normally used in a conventional homo-junction cell process can be applicable.

4 CONCLUSIONS

We investigated the passivating effect of a-Si/c-Si HJ emitters formed on isotextured surfaces developed for mc-Si. A unique structure which reduces several uncertainties in the evaluation of the passivating effect of the HJ emitter was proposed, and the approach measuring the structure with QSSPC was shown to be effective to find out which type of isotexture is feasible for the HJ emitter. QSSPC results also demonstrated that the HJ emitter sufficiently covers the isotextured surface in spite of the differences in scale between isotexture roughness and HJ layer thickness. I-V characteristics for HJ cells on mc-Si substrates with isotextured surface presented a Jsc of 33.6 mA/cm² and Voc of 0.600V. Those values are comparable to those of conventional mc-Si cells and still leave room to be improved with better rear surface passivation, better optimized ITO, etc.

The applicability of isotexture for HJ emitters was therefore affirmed. Furthermore, our results suggest the necessity of a phosphorus-diffused BSF for the HJ cells based on mc-Si wafers.

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