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# Back-contact back-junction silicon solar cells under UV illumination

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ABSTRACT

The performance of n-type Si back-contact back-junction (BC-BJ) solar cells under illumination with high energy ultraviolet (UV) photons was investigated. The impact of the phosphorus doped front surface field (FSF) layer on the stability of the front surface passivation under UV illumination was investigated. Lifetime samples and solar cells without the front surface field showed a significant performance reduction when exposed to ultraviolet light. The surface saturation current density ($J_{0e}$) increased from 48 to 446 fA/cm$^2$ after the UV exposure. At the same time the efficiency of the BC-BJ solar cells without the FSF diffusion reduced from 19.8% to 14.3%. In contrast to the lifetime samples and solar cells without the FSF diffusion, the tested $n^+nn^+$ structures and the BC-BJ solar cells with applied FSF diffusion profiles were significantly more stable under UV exposure, i.e. $J_{0e}$ increased only by a factor of 25% and the efficiency of these cells decreased only 0.3%$_{abs}$ by the UV illumination. Finally it was shown that the performance of the UV-degraded solar cells without FSF could be improved during a forming gas anneal (FGA). Due to application of FGA the efficiency almost fully recovered from 14.3% to 19.6%.



## 1. Introduction

Back-contact back-junction (BC-BJ) silicon solar cells represent an attractive high-efficiency cell structure.

In mass production, BC-BJ solar cells achieve average efficiencies of 22.4% as presented by De Ceuster et al. [1]. For comparison, standard silicon solar cells currently have efficiency in the range of 16–18%. Recently a new record efficiency of 23.4% for a large area (149 cm$^2$) BC-BJ solar cell was announced by Swanson [2].

Due to the fact that the collecting p–n junction is placed on the rear surface of BC-BJ solar cells, and that most of the photogeneration takes place close to the front side, the requirements on the front surface passivation quality are very high. Thus, a low front surface recombination rate is one of the critical factors influencing the efficiency of the back-junction solar cells.

The front surface passivation scheme needs not only to be of very high quality. It is also essential that the applied front surface passivation scheme is stable under solar cell operating conditions. Especially the stability of the surface passivation under the high energy ultraviolet (UV) part of the solar spectrum is of main importance in order to maintain high device performance during the long-term field operation of the photovoltaic modules.

In our previous work [3] the front surface passivation scheme using a phosphorus doped front surface field (FSF) and a stack system of a thermal oxide and a PECVD silicon nitride for the BC-BJ solar cells was developed and studied. Also other positive effects of the FSF on the performance of the BC-BJ solar cells were investigated, such as improvement of the low-illumination performance [4] and improvement of the lateral transport of the majority carriers [5].

In the present work the influence of the exposure of the front surfaces of the BC-BJ solar cells to UV light is investigated. Additionally the influence of the FSF diffusion on the UV stability of lifetime samples and on the performance of the BC-BJ solar cells is presented.

## 2. Influence of the UV light on the front surface passivation of BC-BJ solar cells

The impact of the UV illumination of the oxide passivated silicon surfaces was investigated by many authors in the microelectronic field [6,7]. In the field of the silicon solar cells the work of Gruenbaum was pioneering. Already in 1988 Gruenbaum et al. [8,9] reported that the efficiency of some of the point-contact concentrator solar cells, developed at the Stanford University by Sinton et al. [10], decreased after exposure to concentrated sunlight. The decrease in solar cell performance was caused by an increase in the front surface recombination velocity. The studies of Gruenbaum et al. showed that the ultraviolet component of the incident light spectrum caused damage on the front surface.

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Gruenbaum et al. [11] performed the UV exposure and photoinjection experiments. It was discovered that the UV light of energy greater than 3.1 eV causes an increase in the surface recombination velocity ($S_{0,front}$) and increases interface state densities of the surfaces passivated with oxide. The energy of 3.1 eV corresponds to light with wavelength shorter than 400 nm. In the terrestrial solar spectrum there is a significant amount of photons with such energy [12]. The absorption of the UV photons with wavelength shorter than 400 nm could inject electrons from the conduction band in silicon into the conduction band of silicon oxide. This photoinjection would then create defects at the Si/$SiO_2$ interface.

However, Gruenbaum et al. [13] and Ruby and Schubert [14] showed that not all solar cell structures are prone to degradation under UV light. The formation of the diffused phosphorus region on the front side creates a high field region. This field reduces the concentration of the minority charge carriers close to the recombination centres at the front silicon surface. Even if $S_{0,front}$ increases substantially, the effective surface recombination velocity ($S_{eff}$) may increase minimally, leading to just a small reduction in efficiency of the solar cell.

## 3. Experimental

Symmetrical lifetime test structures, as well as high-efficiency BC-BJ solar cells were processed and analyzed in order to investigate the impact of the high energy UV photons on front surface saturation current density ($J_{0e}$) and on the solar cell performance.

### 3.1. Lifetime structures for determination of the surface saturation current density

Symmetrical $n^+nn^+$ test structures for the minority carrier lifetime measurements were processed on n-type FZ–Si wafers with a thickness of 250 μm and specific resistivity of 1 Ω cm. Due to very high bulk lifetime of the minority carriers in the applied n-type FZ–Si wafers, the effective minority carrier lifetime is almost entirely limited by the surface recombination. In this way an accurate determination of the surface recombination is possible. The lifetime structures shown in Fig. 1 were processed on textured wafers (random pyramids texture).

For selected samples, directly after the texturization process, both surfaces were additionally passivated by the application of the phosphorus doped front surface field. FSF doping profiles were formed by diffusion from a liquid $POCl_3$ source in a tube furnace. Two different FSF doping profiles investigated in this study are shown in Fig. 2. Both profiles were formed at the same diffusion temperature. After diffusion the phosphorus glass was fully etched back in a buffered HF solution. The deep diffused ("FSF-deep" in Fig. 2) profile was formed by an additional high temperature drive-in oxidation process at the temperature of 1050 °C. The high oxidation temperature caused redistribution of the phosphorus atoms and transition from the error-function dopant profile (profile: FSF-shallow) to Gaussian profile (profile: FSF-deep). The silicon oxide layer was then etched back in HF solution. Sheet resistance (shown in Fig. 2) of the investigated front surface field phosphorus profiles was calculated by integrating the dopant profiles using the mobility model of Masetti et al. [15]. Next, all samples were passivated with a thin (10 nm) thermal $SiO_2$ layer and an antireflection-$SiN_x$ coating (thickness of 60 nm). Finally, the samples were annealed in a forming gas atmosphere at a temperature of 425 °C for 15 min.

### 3.2. Back-contact back-junction Si solar cells

The schematic cross-section of the BC–BJ solar cell analyzed in this work is shown in Fig. 3. The cells were also fabricated from n-type FZ–Si wafers with the resistivity of 1 Ω cm and a thickness of around 160 μm.

The front cell side has the same structure as both surfaces of the lifetime structures. Thus, the front side of the BC–BJ solar cells is textured with random pyramids. For selected samples, the front surface was additionally passivated with phosphorus $n^+$ front surface field diffusion. The same phosphorus diffusion profiles (FSF-deep and FSF-shallow) as discussed in Section 3.1 were applied to the solar cells. The front surface was then passivated

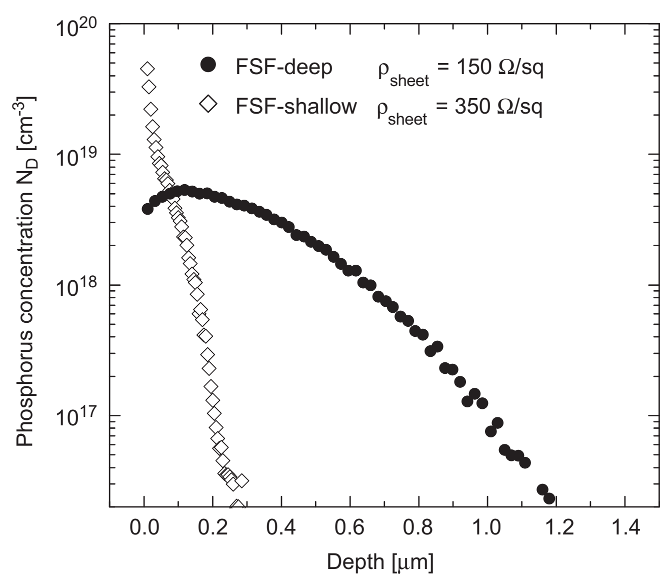


**Fig. 2.** Secondary ion mass spectroscopy (SIMS) profiles of the studied phosphorus dopant profiles measured after all high temperature processing steps. Sheet resistance of both diffusion profiles is shown in the graph.

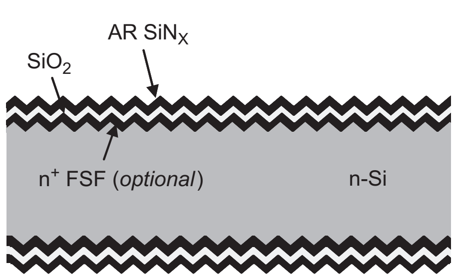


**Fig. 1.** Textured symmetrical structures used for the lifetime measurements and for the determination of the surface recombination current density.

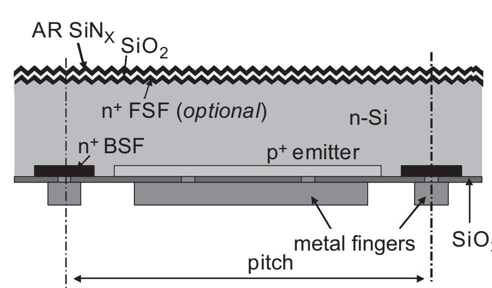


**Fig. 3.** Schematic cross-section of the n-type high-efficiency back-contact back-junction silicon solar cell investigated in this work. Note that sketch is not to scale.