

## TWO-DIMENSIONAL ANALYSIS OF THE BACK-SIDE CONTACTS OF THIN SILICON SOLAR CELLS

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**ABSTRACT:** In this work, results of two-dimensional simulation of two back surface passivation schemes of silicon solar cell are presented. The surface passivation properties of the different rear surface designs are determined using the multi-purpose device simulator MINIMOS-NT. We assume similar device geometries with two local aluminum contacts on the front and back side and surface passivation of the rear side with two dielectric layers: dielectric with a positive surface fixed charge (for example  $\text{SiN}_x$ ) as well as a dielectric with negative fixed charge,  $(\text{Al}_2\text{O}_3)_x(\text{TiO}_2)_{1-x}$ . Due to the negative charge a region of strong accumulation is formed in the p-type Si substrate, inducing a change in the surface potential. Respectively a surface electric field builds up, which leads to a decrease of the surface recombination velocity of minority carriers as in the case of back surface field (BSF) effect with a  $p^+$  region. The device simulations are performed to gain a better understanding of the effect of fixed charge on the electrical properties of the silicon rear side. The distribution of minority carrier concentration and current density for electrons and holes are disparate. The analysis shows that using a dielectric with negative fixed charge offers substantial advantage for rear side passivation of p-Si solar cells.

**Keywords:** simulation, back contact, back-surface-field

### 1 INTRODUCTION

In order to increase the cost effectiveness of silicon solar cells, low-cost prime materials such as silicon wafers with reduced thickness are used. The reduction may lead to losses due to the complete transmission of longer wavelength light through the wafer (possibly modified by the reflection at the back surface) and also due to the increase of the surface recombination at the back side. However, the rear electrical contact has the largest impact on the solar cell behavior. An Ohmic back contact on the full rear surface reduces the photocurrent and increases the dark current by acting as surface with high recombination velocity. A blocking rear contact featuring back surface field (BSF) enhances the photocurrent and lowers the dark current by preventing recombination at the back surface. This effect (the build up of BSF) is obtained by diffusion or alloying a highly doped  $p^+$  region on the back side of the p-Si solar cell [1]. The potential energy barrier between the  $p^+/p$  regions tends to "confine" minority carriers in the lightly doped region, away from the Ohmic contact and its infinite surface recombination velocity. The typical back surface scheme for Si solar cell production is the full area back surface field formed by aluminum alloying. However, for thin Si wafers (below 200  $\mu\text{m}$ ) the back conventional processing steps are not suitable. The full screen printed Al back contact causes a warping of the wafer induced by thermal expansion coefficients of the Al/Si interface [2,3]. On the other hand, for thin wafers the effective back surface reflection is significant. Due of these reasons, the local contacts become an object intensive studies [4-6]. Different passivation schemes with dielectric films as  $\text{SiN}_x$  or  $\text{SiO}_2$  are investigated.

The application of  $(\text{Al}_2\text{O}_3)_x(\text{TiO}_2)_{1-x}$  thin films with negative fixed charges at the dielectric/silicon interface was recently introduced in [7-9]. Due to the negative charge a region of strong accumulation is formed in the

p-type Si substrate, inducing a change in the surface potential. Respectively a surface electric field builds up, which leads to a decrease of the surface recombination velocity of minority carriers similar to the back surface field (BSF) effect with  $p^+$  region.

In this work we present results of two-dimensional simulation of two types of solar cell structures. While the first uses the established  $\text{SiN}_x/n^+-\text{Si}/p\text{-Si}/\text{SiN}_x$  setup, the second is a  $\text{SiN}_x/n^+-\text{Si}/p\text{-Si}/(\text{Al}_2\text{O}_3)_x(\text{TiO}_2)_{1-x}$  device. The device simulations are performed to gain a better understanding of the effect of fixed charge on the back-side local contact.

### 2 SETUP

The influence of the polarity of the fixed charges at the interface dielectric/p-type Si is studied by means of two-dimensional numerical simulation performed with the multi-purpose device simulator MINIMOS-NT [10]. It incorporates advanced physical models and robust numerical methods for the two-dimensional simulation of semiconductor devices. A general view of the simulated solar cell structure is shown in Fig. 1 and the layer properties are summarized in Table I.

It should be noted that the thickness of the wafer is 150  $\mu\text{m}$ . The simulation setup uses the drift-diffusion carrier transport model. Shockley-Read-Hall and Auger recombination (generation), doping-dependent carrier mobilities, and optical generation are accounted for. Trap densities of  $10^{13} \text{ cm}^{-3}$  and trap capture cross sections of  $10^{-19} \text{ m}^2$  for both electrons and holes are assumed. The non-zero surface recombination velocities are 2000 cm/s for both carrier types. An exposure to monochromatic light at wavelength of 800 nm and intensity of 100  $\text{mW/cm}^2$  is simulated. The surface reflection of the front side is roughly 10 %.

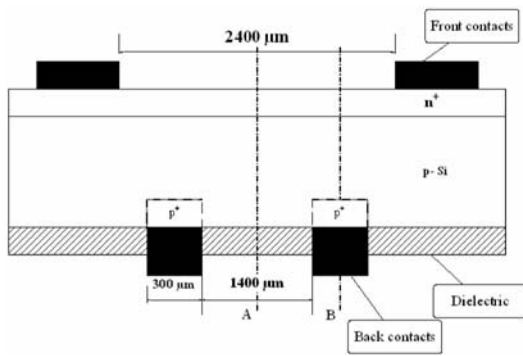


Fig. 1. Cross section of the simulated solar cell structure.

Table I. Parameters of the simulated solar cells.

Parameter	Value
<b>p base</b>	
- Doping concentration $N_A$	$1 \times 10^{16}$ at.cm <sup>-3</sup>
- Thickness	150 μm
<b>n+ emitter</b>	
- Doping concentration $N_D$	$5 \times 10^{19}$ at.cm <sup>-3</sup>
- Thickness	0.8 μm
<b>Local BSF under contact</b>	
- Doping concentration $N_A$	$1 \times 10^{19}$ at.cm <sup>-3</sup>
- Thickness	1 μm
Spacing between the front contacts	2400 μm
Spacing between back contacts	1400 μm
Surface recombination at the front and back sides	2000 cm/s

Two types of solar cells were simulated differing only in the back surface passivation scheme. The process flow of the solar cells is shown in Fig. 2.

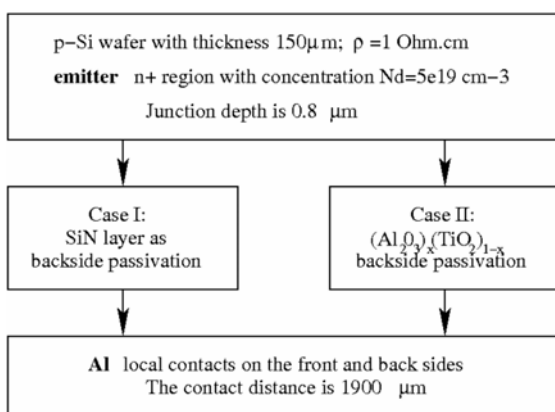


Fig. 2. Process flow of the analyzed solar cells with different back-side surface passivations.

### 3 SIMULATION RESULTS

Two cases for the fixed charges on the interface dielectric/p-Si are studied: negative charge density of  $8 \times 10^{11}$  cm<sup>-2</sup>, and positive charge density of  $3 \times 10^{11}$  cm<sup>-2</sup>.

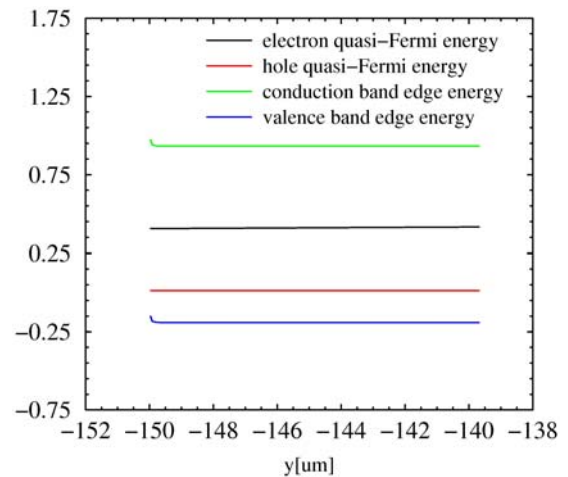


Fig. 3a. Energy band diagram of dielectric/p-Si interface with negative fixed charges (cross section AA in Fig. 1).

Figs. 3a, 3b, and 3c show the band energy diagram near the dielectric/p-Si interface. For negative fixed charges at the silicon interface (Fig. 3a), there is an accumulation of the majority carriers (holes) on the band bending of the conduction band, which forms a barrier for the electrons. This effect is similar to the case with BSF (Fig. 3c).

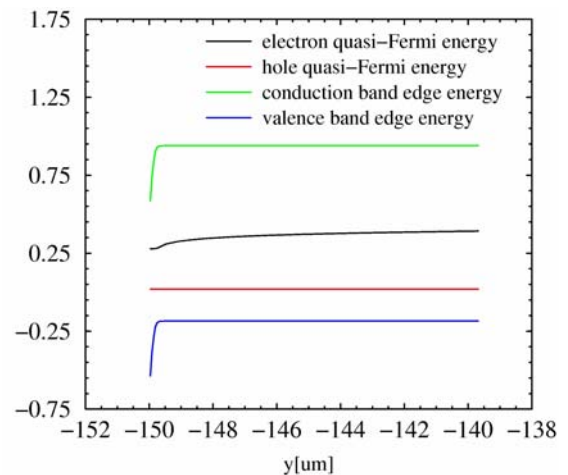
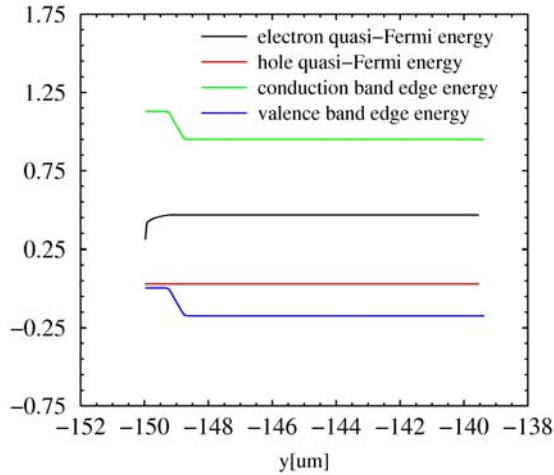


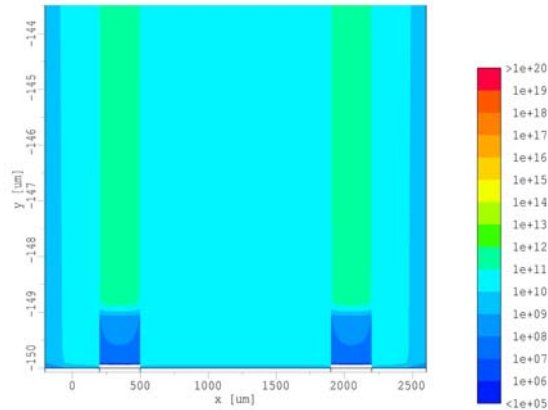
Fig. 3b. Energy band diagram of dielectric/p-Si interface with positive fixed charges.

The SiN<sub>x</sub> film contains a high amount of fixed positive charges (with charge density  $N_f = 3 \times 10^{11}$  cm<sup>-2</sup>) inducing a strong band bending resulting in an inversion layer (see Fig. 3b). Fig. 3c illustrates the energy band diagram for the cross section BB in Fig. 1. There is a local BSF under the Al back contacts.

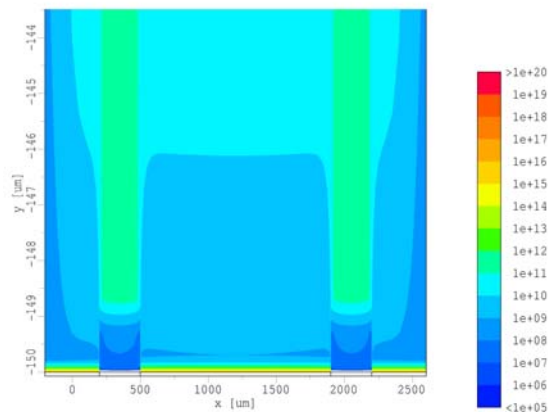
Figs. 4a and 4b show the distribution of the electron concentration. The concentration of the electrons at the back side is very high for the case of the positive fixed charges (Fig. 4b) compared to the concentration with negative fixed charges (Fig. 4a).



**Fig. 3c.** Energy band diagram of the local contacts (cross section BB in Fig. 1).



**Fig. 4a.** Electron concentration [ $\text{cm}^{-2}$ ] for negative fixed charges at the interface.



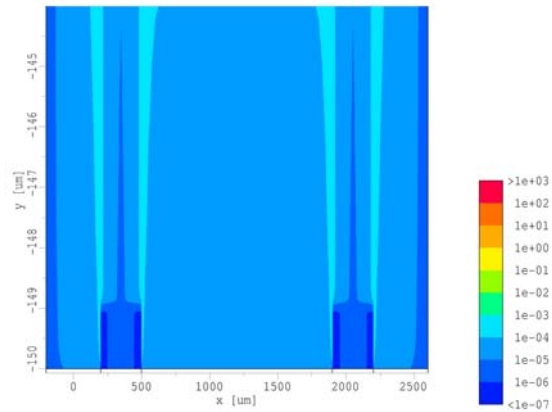
**Fig. 4b.** Electron concentration [ $\text{cm}^{-2}$ ] for positive fixed charges at the interface.

that case the minority carrier current density toward the back surface is given by

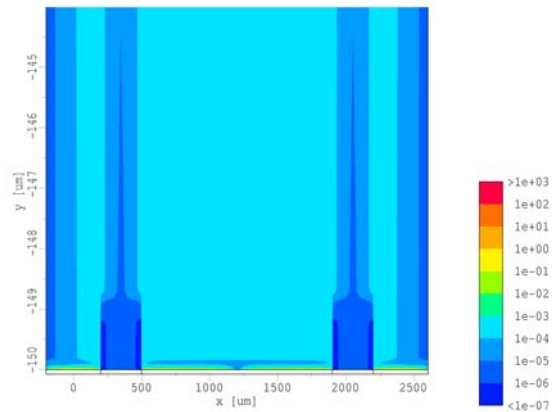
$$J_{\text{backsurface}} = q \cdot S_n (n_p - n_0)$$

for p-type material where  $n_p$  is the electron concentration near the surface,  $n_0$  is the electron concentration in equilibrium, and  $q$  is the elementary charge. Thus, for the same surface recombination velocity ( $S_n$ ) there is a much higher recombination of electrons in the presence of positive fixed charges at the dielectric/p-Si interface.

The two-dimensional simulation results of the electron current density near the back-side local contacts are shown in Figs. 5a and 5b. In the case of positive fixed charges, a higher electron current density near the rear surface is observed (Fig. 5b), which is in agreement with the results and assumptions reported in [5,11].



**Fig. 5a.** Electron current density [ $\text{A}\cdot\text{cm}^{-2}$ ] in the p-Si region of the back-side passivated surface with negative fixed charges at the interface.

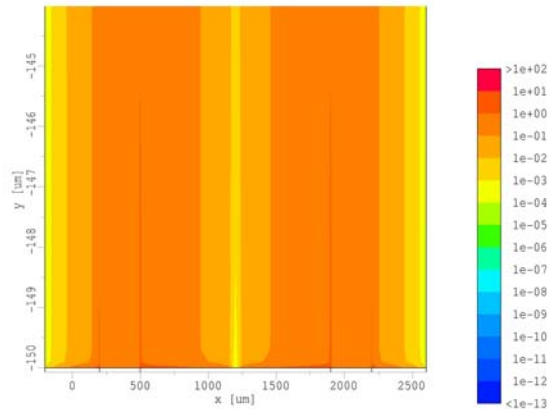


**Fig. 5b.** Electron current density [ $\text{A}\cdot\text{cm}^{-2}$ ] in the p-Si region of the back-side passivated surface with positive fixed charges at the interface.

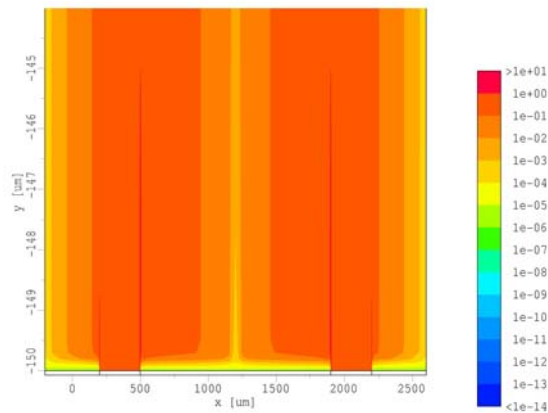
The rate at which electrons are lost at a surface is described by the surface recombination velocity  $S_n$ . In

The majority carrier current density simulation results show the opposite distribution. Figs. 6a and 6b

present the hole current density near the back-side local contacts. In the case of negative fixed charges, there is a higher value of the hole current density at the surface near the metal contacts and this can affect the contact resistance as well as the series resistance.



**Fig. 6a.** Hole current density [ $\text{A}\cdot\text{cm}^{-2}$ ] in the p-Si region of the back-side passivated surface with negative fixed charges at the interface.



**Fig. 6b.** Hole current density [ $\text{A}\cdot\text{cm}^{-2}$ ] in the p-Si region of the back-side passivated surface with positive fixed charges at the interface.

### 3 CONCLUSION

The two-dimensional numerical analysis has shown that using a dielectric with a negative fixed charge offers substantial advantages for passivation of p-Si solar cells. Negative fixed charge with density higher than  $1 \times 10^{11} \text{ cm}^{-2}$  induces a back surface field and as a result greatly decreases minority carrier concentration on the backside. The DC simulation at conditions close to a short circuit show that the electron current density near the back solar cell surface is negligibly small, while the distribution of the hole current density is suitable for low-ohmic backside contact. Improvement of the solar cell performance could be expected when dielectrics with negative fixed charge are used for rear side passivation.

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