Study of p-layer on the hydrogenated amorphous silicon HIT solar cells

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Abstract

In this article, we've studied the effect of p-layer doping density NA and surface band bending Esbb at the interface ITO/p-layer on the performance of heterojunction solar cell (ITO/p-a-Si:H/i-pm-Si:H/n-c-Si/Al). Despite the deterioration of p-layer material quality with doping density, the reduced bulk recombination was found to compensate for the increased loss in the p-layer. An increase of p-layer doping density NA and contact barrier height ϕ_{b0} (Variation of the surface band bending Esbb) leads to an increase of the efficiency of HIT (heterojunction with intrinsic thin layer) solar cells.

Keywords: HIT solar cells; Doping density; Surface band bending; Potential barrier height; J(V) characteristics; Simulation.

1. Introduction

Recently, heterojunction with intrinsic thin layer solar cell, were under intensive investigation since they are combing the low cost and low temperature process of hydrogenation amorphous silicon (a-Si:H) deposition coupled with the high stability of crystalline silicone (c-Si). An important scientific and technological progress on HIT has led to solar cells with efficiencies up to 27% [1,2]. Computing modeling of HIT structures has been carried out to understand carrier transport in these structures.

The parameters studied in this work include the p-layer doping density NA and contact barrier height ϕ_{b0}. The combination of these parameters determinates the built-in potential in p-i-n and HIT solar cell. Simulation of a range of experimental results on HIT cells developed by Sanyo group and available in the literature [3] has been undertaken to extract typical parameters that characterize state-of-the-art HIT cells on N-type crystalline silicon substrates. The principal parameters used in this study are summarized in table 1.

Experimentally if we interpose thin Palladium or Chrome film between Transparent Conductive Oxides TCO and p-doped a-Si:H interface, it is possible to change the work function without a decrease of optical transmission [4,5]. With a change of the work function of the TCO, it is this ϕ_{b0} that varies.

In order to simulate the effects of p-layer doping density NA and the height of the front contact barrier ϕ_{b0} in the structure HIT: ITO/p-a-Si:H/i-pm-Si:H/n-c-Si/Al, we have varied NA and ϕ_{b0} to study the dependence of the solar cell output. The back contact barrier height ϕ_{bL} is assumed to give neutral (no band bending) contact to the n^+ back layer. We chose the pm-Si:H as an intrinsic thin layer because of its excellent electric properties [6].

Table 1 : Principal input parameters

Parameters	p-a-Si :H	i-pm-Si :H	n-cSi
d(A°)	110	30	300 x10^4
χ(eV)	3.90	3.95	4.22
Eμ (eV)	1.90	1.96	1.12
E_{ac} (eV)	0.27	0.92	0.06
ND, NATOT (cm^{-3})	1.0x10^{19}	1.0x10^{14}	3.0x10^{11}
NC, NV	1x10^{19}	2x10^{20}	5.0x10^{18}

2. Simulation model

We have used ASDMP simulation model (Amorphous Semiconductor Device Modeling Program) developed by the group of professor Parsathi Chatterjee [7]. Prof. Roca's group at École polytechnique de Paris, France, has demonstrated experimentally that ASDMP model mimics the performance of p-i-n and HIT solar [8].

ASDMP examines the behaviour of semiconductor device structures under steady state in one dimension by solving simultaneously Poisson's equation [Eq. (1)], the continuity equations for free electrons and free holes [Eq. (2)-(3)] using finite differences and the Newton-Raphson technique, and yields the J(V) characteristics and the quantum efficiency. These equations are:

$$\frac{d}{dx}\left(\varepsilon(x)\frac{d\psi(x)}{dx}\right)=\rho(x). \qquad (1)$$

$$0=\frac{1}{q}\frac{dJ_n(x)}{dx}+G_{opt}(x)-R_{net}(x). \qquad (2)$$

$$0 = \frac{1}{q}\frac{dJ_p(x)}{dx} + G_{opt}(x) - R_{net}(x). \qquad (3)$$

Where Ψ(x) is the potential energy of an electron at the vacuum level in electron volts, and ρ(x) is the space charge density in the semiconductor. J_n (x) and J_p (x) are the electron and hole current, respectively, and *q* is the charge of electron. The term G_{net} *(x)* represents the net optical generation of free electron-hole pairs per unit volume, while R_{net} (x) denotes the net recombination of free carriers per unit volume. The boundary conditions used for the Poisson's equation are:

$$\psi(0) = \phi_{b0} + \chi_0 - \phi_{bL} - \chi_L - V \qquad (4)$$

$$\psi(L) = 0 \qquad (5)$$

Where Ψ(0) [Ψ(L)] is the vacuum level at x=0 (L), ϕ_{b0} (ϕ_{bL}) the front (back) contact barrier height and χ_0 (χ_L) the electron affinity of the material at x=0 (L).

The generation term in the continuity equations has been calculated using a semiempirical model [9] that has been integrated into the modelling program.

3. Results and discussion

The structure used in this present work consists of a HIT structure ITO/p-a-Si:H/i-pm-Si:H/n-c-Si/Al (Figure 1).

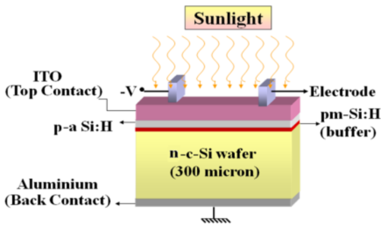


Figure 1. Schematic diagram of a HIT n-type c-Si substrates (ITO/p-a-Si:H/i-pm-Si:H/n-c-Si/Al) Solar Cell.

The principal parameters of each layer are summarized in table 1. In these cells, the contact barrier heights for a cell with the p-layer in contact with a ITO at x = 0 and the n-layer in contact with a metal at x = L, are given by:

$$\phi_{b0} = E_{\mu}(p) - E_{ac}(p) - Esbb \qquad (6)$$

$$\phi_{bL} = E_{ac}(n) \qquad (7)$$

Where E_{μ} (p) and E_{ac} (p) represent respectively the mobility band gap and the activation energy of the p-layer, and Esbb is the surface band banding due to the Schottky barrier at the ITO/p interface.

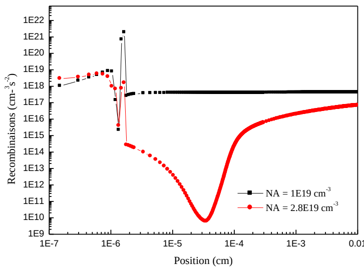


Figure 2. The recombination under AM 1.5 light as a function of position for NA = 10^{19} and 2.8 10^{19} cm^{-3}

Figure 2 shows the recombination under AM 1.5 light as a function of position for the p-layer doping density NA = 10^{19} and 2.8 10^{19} cm^{-3}. The reduced bulk recombination was found when we increase the NA. This reduction of the recombination is due to the decrease of the electric field seen in figure 3. This decrease of the electric field over the depletion region let the photogenerated holes able to pass to the front contact and the electrons to the back [10,11].

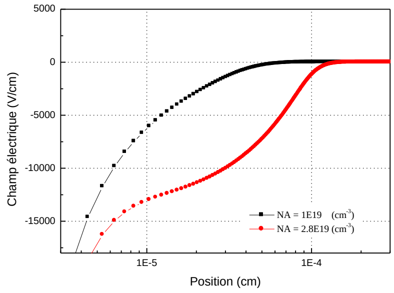
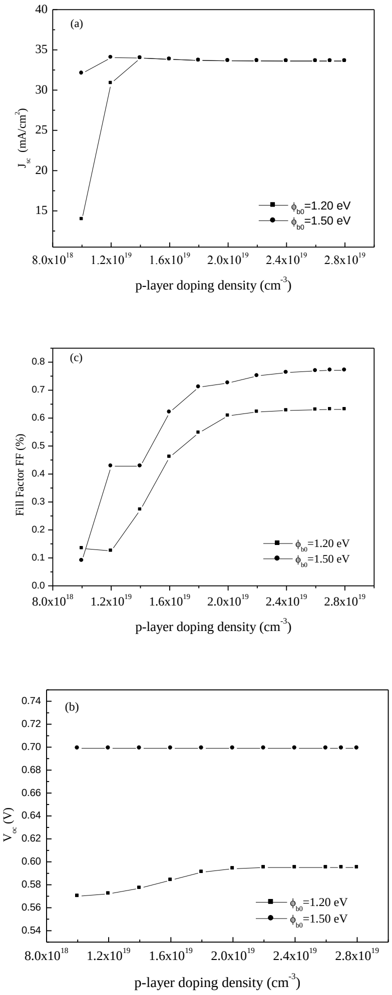


Figure 3. The electric field as a function of p-layer doping density NA = 10^{19} and 2.8 10^{19} cm^{-3}

The sensitivity of the short circuit current Jsc (a), the open circuit voltage Voc (b), the Fill Factor FF (c) and the cell efficiency η (d) to the p-layer doping density NA and front contact barrier height ϕ_{b0} is shown in figure 4. ϕ_{b0} is equal to 1.20 and 1.50 eV. NA is equal to 10^{19} and 2.8 10^{19} cm^{-3}.



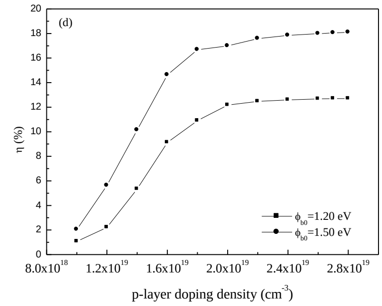


Figure 4. Plot of (a) J_{sc}, (b) V_{oc}, (c) FF and (d) η vs. p-layer doping density for ϕ_{b0}=1.20 eV and 1.50 eV.

Despite the deterioration of p-layer material quality with doping density, the solar cell output parameters are sensitive to NA. A large improvement of FF has been obtained because of the reduced bulk recombination seen in figure 2. Maximum sensitivity of all the solar cell output parameters became evident when we increase the front contact barrier height to ϕ_{b0} = 1.50 eV.

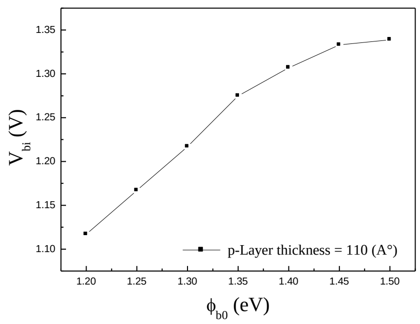


Figure 5. V_{bi} vs. ϕ_{b0} for cells with 11 nm of p-layer.

Figure 5 shows that the built-in potential V_{bi} depends to the front contact barrier height ϕ_{b0}. The increase of V_{bi} is the result of the change in the potential barrier which is reduced at the ITO/p-layer. We notice in figure 5 a decrease of the electric field when we increase the ϕ_{b0} value. This decrease let the holes able to pass from the p-layer to the contact.

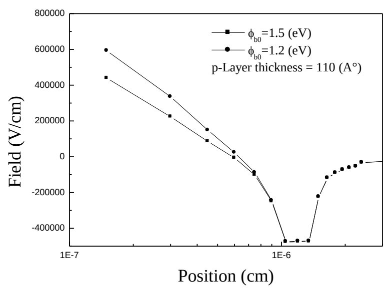


Figure 6. The electric field vs. position for cells with 11 nm of p-layer and ϕ_{b0}=1.50 eV and 1.20 eV.

Figure 6 indicates that a remarkable improvement on V_{oc} and FF has been achieved with the improvement of ϕ_{b0}. This augmentation is due to the reduction of the surface potential barrier. A reduction of this surface potential barrier leads to an augmentation of V_{bi} and consequently an increase of V_{oc}. The reduction of the field at the ITO/p-layer interface seen in figure 5 will support the passage of the holes towards ITO. A large improvement of FF has been obtained because of the reduced interface recombination as well as better ohmic contact between ITO and p-layer.

4. Conclusion

In conclusion, we have found that the cell performance depends strongly on the front contact barrier ϕb0 and the doping density NA. In spite of an increased loss in the p-doped a-Si:H when we increase the doping density a large improvement of FF has been obtained. The reduced bulk recombination was found to compensate for the increased loss in the p-layer.

An increase of front contact height barrier leads to an increase of the efficiency of solar cells. The explanation of an increased Voc is attribute to an enhancement of the Vbi and the improvement of FF is due to the decrease of the electric field between ITO and p-a-Si:H.

3. References

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