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Simulation studies on the effect of a buffer layer on the external parameters of hydrogenated amorphous silicon *p–i–n* solar cells

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Abstract. Device modeling of *p–i–n* junction amorphous silicon solar cells has been carried out using the amorphous semiconductor analysis (ASA) simulation programme. The aim of the study was to explain the role of a buffer layer in between the *p*- and *i*-layers of the *p–i–n* solar cell on the external parameters such as dark current density and open circuit voltage. Investigations based on the simulation of dark *I–V* characteristics revealed that as the buffer layer thickness increases the dark current for a given voltage decreases.

Keywords. Solar cell; thin film; buffer layer.

1. Introduction

Hydrogenated amorphous silicon (*a*-Si : H) is a widely studied material because of its tremendous potential in the fabrication of low cost solar cells for terrestrial applications (Kampus and Griffith 1981; Matsuda and Tanaka 1986; Matsuda *et al* 1990). The modeling of silicon solar cells is as important as the experimental work as it helps to optimize the device parameters and to understand the underlying physics of their operation. The main motivation for the work was to understand the increase in the open circuit voltage by introducing an appropriate buffer layer between *p* and *i* layers. Experimental studies on the effect of a buffer layer between the *p* and *i* layers were reported by several researchers (Yoshida *et al* 1988; Komaru *et al* 2001).

2. Modeling

In the *p–i–n* diode, the current density under dark condition, J_d, can be expressed as a function of voltage, V, by (Yoshida *et al* 1988)

$$J_d = J_o[\exp(qv/nkT) - 1]. \quad (1)$$

From this, the open circuit voltage can be written as (Yoshida *et al* 1988)

$$V_{oc} = nkT/q[\ln(J_{sc}/J_o) + 1]. \quad (2)$$

Since it is evident from the results of Yoshida *et al* (1988) that the J_d–V characteristics can be a measure to estimate the V_{oc}, we simulated J_d–V curves for different buffer layer thicknesses in an effort to understand the effect of buffer layer on the V_{oc}.

For this we made use of the amorphous semiconductor analysis (ASA) program. ASA is a one-dimensional device simulator, especially designed for the simulation of amorphous silicon devices like solar cells (Miro Zeman 1999).

The standard model of the density of state distribution in *a*-Si–H consists of a parabolic conduction band and a parabolic valence band, an exponentially decaying conduction band tail and an exponentially decaying valence band tail. For dangling bond states distribution, defect-pool model (Powell and Deane 1993) was used. Since solar cells work under illumination, a good optical design is necessary for achieving high efficiency. The optical generation rate, G_{opt}, is an important input parameter for electrical modeling. If it is assumed that every photon generates exactly one electron-hole pair, the generation rate profile is equal to absorption profile.

Lambert-Beer's absorption formula is a simple analytical technique used for calculating the absorption profile of photons in *a*-Si–H solar cells. According to this approach a photon flux density after passing a distance, x, in a film with an absorption coefficient, $\alpha(\lambda)$, is reduced by a factor, $\exp[-x\alpha(\lambda)]$. Only a single reflection at the rear surface is accounted for in this simulation. Multiple passes through the device are not simulated. The absorbed energy of incident and reflected light is summed without accounting for interference effects (Willeman 1998).

Figure 1 shows the structure of the solar cell used for the simulation. Light enters the solar cell through the glass

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Table 1. Parameters of the semiconducting layers.

Layer	Thickness (nm)	Mobility gap (eV)	Electron mobility ($m^2/v/s$)	Hole mobility ($m^2/v/s$)	*n* (vb tail mob edge) (cm^{-3} eV^{-1})	*n* (cb tail mob edge) (cm^{-3} eV^{-1})
p-layer	9	1·90	20 × 10 (–4)	5 × 10 (–4)	1 × 10 (28)	1 × 10 (27)
Buffer	0 to 450	1·95	8·5 × 10 (–4)	2 × 10 (–4)	1 × 10 (27)	1 × 10 (27)
i-layer	450 to 0	1·75	20 × 10 (–4)	5 × 10 (–4)	1 × 10 (27)	1 × 10 (27)
n-layer	20	1·75	20 × 10 (–4)	5 × 10 (–4)	1 × 10 (28)	1 × 10 (28)

Where '*n* (vb tail mob edge)' and '*n* (cb tail mob edge)' are the density of states at the valence band mobility edge and conduction band mobility edge, respectively.

GLASS – 1·5 mm
TCO – 665 nm
P-LAYER – 9 nm
BUFFER
I-LAYER (Total thickness of buffer and I-layer – 450 nm)
N-LAYER – 20 nm
METAL ELECTRODE

Figure 1. Structure of the solar cell used for the simulation.

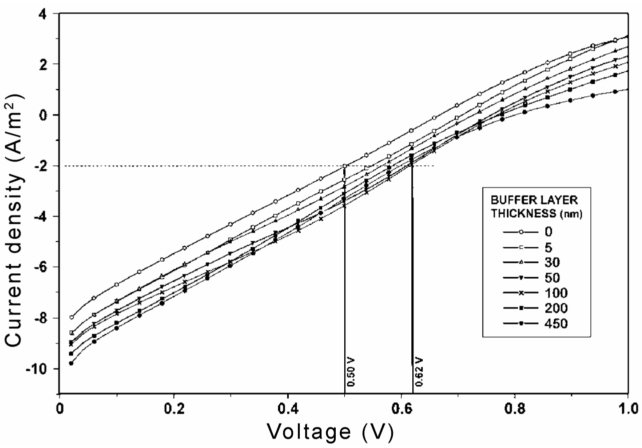

Figure 2. Effect of buffer layer on the simulated dark *I–V* characteristics of a *p–i–n a*-Si : H solar cell.

and transparent conductive oxide (TCO). In our simulations we used four semiconducting layers: *p*-type *a*-SiC : H layer, intrinsic *a*-SiC : H buffer layer, intrinsic *a*-Si : H layer and *n*-type *a*-Si : H layer. Thicknesses of *p*-type and *n*-type layers were 9 nm and 20 nm, respectively and kept constant throughout the simulation. The total thickness of the buffer layer (which is introduced between the *p*- and *i*-layers) and the *i*-layer was fixed at 450 nm.

The important parameters assigned to various layers of the solar cell are given in table 1. The simulation proceeded as follows: (a) During the first trial the thickness of the buffer layer was zero and the thickness of the *i*-layer was kept at 450 nm and (b) in the subsequent trials the buffer layer thickness was increased in six steps from 5 nm with a bandgap of 1·95 eV (*i*-layer thickness, 445 nm and bandgap, 1·75 eV) up to a maximum buffer thickness of 450 nm. This corresponds to *i*-layer thickness zero.

3. Results and discussion

Figure 2 shows the effect of the buffer layer on the simulated dark current–voltage characteristics of a *p–i–n a*-Si : H solar cell, with buffer layer thickness varying from 0 to 450 nm.

From this figure we find that the dark *I–V* curve shifts towards the right side (i.e. the dark current decreases for a given voltage), as the buffer thickness increases from 0 to 100 nm. Above 100 nm up to 450 nm, J_d does not change appreciably.

Figure 3 shows the variation of open circuit voltage (V_{oc}) with buffer layer thickness for the same cells. One can see that introduction of a buffer layer of thickness, 30 nm, increases the open circuit voltage by 0·06 V. V_{oc} is a maximum at a buffer thickness of 30 nm and above that it remains more or less a constant up to 450 nm.

The dominant mechanism behind the generation of J_d is thought to be the recombination at the *p–i* interface (Yoshida *et al* 1988). The presence of a buffer layer increases the electric field near the *p–i* interface. This leads to a higher collection of charge carriers at the interface (Petit *et al* 2007). Figure 2 shows that the major change in J_d occurs up to a buffer layer thickness of 30–50 nm and between 100 nm and 450 nm there is not much variation in the J_d–V curve.

From figures 2 and 3 we can infer that the effective thickness of the interface recombination region determining the recombination component of J_d is ~30–50 nm for the present solar cells. Also we find that the increase in V_{oc} is proportional to the shift in the J_d–V curve as experimentally shown by Yoshida *et al* (1988). It appears that a minimum thickness of 30 nm of buffer layer improves the performance of the solar cell.

Since there is 7% increase in the open circuit voltage by the introduction of a suitable buffer layer, then even with a 2–3% reduction in fill factor, the energy conversion efficiency of the cell will be increased by ~4–5%.

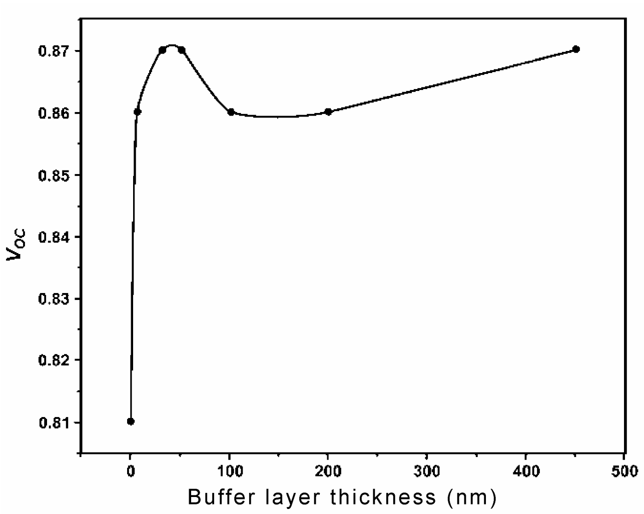

Figure 3. Variation of simulated open circuit voltage (V_{oc}) with buffer layer thickness for a *p–i–n a*-Si : H solar cell.

4. Conclusions

Simulation studies were carried out using amorphous semiconductor analysis program, on the effect of a buffer layer on the external parameters of hydrogenated amorphous silicon *p–i–n* solar cells and the following results were obtained:

(I) When a buffer layer was introduced between the *p*-layer and *i*-layer of the solar cell, the open circuit voltage, V_{oc}, increased.

(II) For the structure and parameters assigned to the solar cell as given in figure 1 and table 1, it was found that when the buffer layer thickness was increased from 0–450 nm the dark *I–V* curve shifted towards the right side (i.e. The dark current decreased for a given voltage).

(III) For the same solar cells the open circuit voltage, V_{oc}, increased by 0·06 V for a buffer layer thickness of 30 nm and remained more or less a constant up to 450 nm. This increases the energy conversion efficiency of the cell by ~ 4–5%.

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