Light-Induced Degradation in a-Si:H P-I-N Solar Cells

Herval Paes Jr. and Wolfgang Losch
PEMM/COPPE/Universidade Federal do Rio de Janeiro
Caixa Postal 68.505, 21945-970, Rio de Janeiro, Brazil

Received July 21, 1995

The effects of light-induced degradation in hydrogenated amorphous silicon (a-Si:H) on carrier transport properties in p-i-n structures have been investigated by dark current versus voltage ($I_d \times V$) curves and primary photocurrent charge collection for electrons and holes. The influence of i-layer thickness and illumination time has been systematically investigated. In case of white light-soaking experiments a strong dependence of cell degradation on i-layer thickness is observed. In degraded cells, superlinear current versus voltage characteristics ($I_{ph} \alpha V^m$) in the low voltage regime were observed. These results were analysed using a model which includes space charge effects. The analysis indicates that the deterioration of transport properties in the investigated p-i-n cells is mainly related to bulk and not to interface effects.

I. Introduction

A-Si:H p-i-n solar cells show a performance degradation under prolonged illumination. It is widely accepted that this effect is related to the creation of metastable defects[1]. In this field of research charge collection experiments performed on solar cell structures are a powerful tool of investigation since they permit a direct correlation between light-induced defects and changes in carrier transport.

A model for the interpretation of experimental results of charge collection including space charge effects in the solution of the transport equation system was suggested by Abel, Paes and Bauer[2]. In this paper we therefore apply simulated results from this model to experimental data, and address the question: is the degradation of a-Si:H p-i-n solar cells a pure bulk or an interface effect?

II. Sample preparation and experimental set-up

A-Si:H p-i-n solar cells with i-layer thickness ranging from 0.4 to 3.0 μm were deposited on glass/SnO_2 covered substrates by conventional PECVD of silane. The p and n doped layers were 100 and 400 Å thick respectively. In order to enable hole charge collection a NiCr semi-transparent film was used as metallic rear contact.

The initial conversion efficiency was around 5% for the solar cell with i-layer thickness $t_i = 0.4\mu$m. Typical values for the open circuit voltage (V_{OC}) and short circuit current density (J_{SC}) were 0.70 V and 12 mA/cm^2, respectively.

The solar cells were characterized by dark current (J_D) and primary electron (J_{EO}) or hole (J_{HO}) photocurrent densities versus applied voltage (V) curves. The ($J_{EO} \times V$) and ($J_{HO} \times V$) curves were obtained under sample illumination from either side with strongly absorbed light ($\lambda = 450 \pm 20$ nm) under reverse bias.

Light-soaking experiments with white light were done using an ELH lamp through an IR-cut filter. Standard condition for such degradation is defined by cell illumination through the p-layer, under open circuit at a light intensity (I) of 1 W/cm^2. Sample temperature during light-soaking was not precisely controlled but remained below 40°C.

III. Results and discussion

Dark current density versus voltage ($J_D \times V$) curves

The investigated diodes presented good rectification ratios excluding significant effects of charge injection from the contacts. Degradation by white light-soaking strongly affects $(J_D \times V)$ curve under forward and reverse bias, for details see reference [3].

Street and Hack[4] suggested a method to evaluate the density of states (DOS) changes due to metastable light induced defects, which consist on monitoring the variation on the reverse dark current density (J_{DR}) for a fixed voltage as a function of degradation time. Using this method, the DOS dependence on degradation time as a function of i-layer thickness was determined (see Fig. (1)). A strong dependence of the degradation on i-layer thickness was observed. In all cases the defect creation kinetics approximates to the common $t^{(1/3)}$ time dependence, according to the weak-bond to dangling-bond conversion model[5].

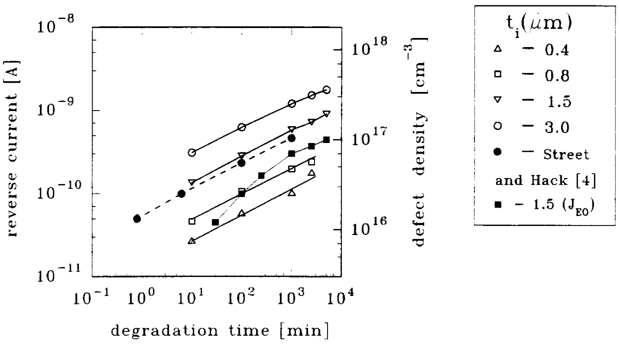

Figure 1. Dependence of reverse dark current (I_{DR}) at fixed electric field $(E = 2 \times 10^4$ V/cm) on degradation time as a function of i-layer thickness. White light-soaking performed on standard condition.

Influence of white light-soaking and i-layer thickness (t_i) on $(J_{PH} \times V)$ curves

The influence of white light-soaking on electron (J_{EO}) primary photocurrent current density versus applied voltage (V) curves is shown in fig.(2.a-d). In $(J_{EO} \times V)$ curves of the initial state, the electron photocurrent depends only weakly on applied voltage and thickness whereas after degradation strong influence of these parameters is observed. In the superlinear functional dependence region, $J_{PH} \propto V^m$, for a fixed voltage the collection efficiency decreases when degradation time increases and the change still depends strongly on i-layer thickness. This observation demonstrates photogenerated carrier/defect interaction during transport across the i-layer. At high voltages photocurrent saturation is observed, as expected since the photogeneration rate is limited. The changes on $(J_{PH} \times V)$ curves due to degradation tends to saturate with increasing degradation time.

No significant change of V_{OC} has been observed during light-soaking experiments contrary to the behavior of a-Si:H p-i-n solar cells with buffer layer on the p/i interface[6]. However, the short circuit current density decreases with degradation time. The degradation rate depends strongly on the solar cell bias condition and varies inversely proportional to the collection effficiency.

The changes of $(J_{EO} \times V)$ curves introduced by white light-soaking were analysed using the model proposed by Abel, Paes and Bauer[2]. The influence of parameters like carrier extended mobility (μ), recombination velocity in the photogeneration volume (v_s), density of states at Fermi level (G_{EFO}), intrinsic layer thickness (t_i) and temperature on simulated $(J_{PH} \times V)$ curves characteristics was investigated.

By fitting the simulated curves to experimental results (Fig. 2) the changes in bulk and interface properties due to light induced defects could be determined. The variation of the parameters G_{EFO} and v_s with i-layer thickness and degradation time is shown on Fig. 3. The recombination velocity (v_s) for p/i interface was approximately constant, such behavior could be expected due to the small variation observed on V_{OC}. However, G_{EFO} depends strongly on i-layer thickness and inducing time. This result indicates degradation of the bulk to be the dominant effect after white light-soaking in the investigated a-Si:H p-i-n solar cell. This is in agreement with results obtained experimentally by Herbst *et al* [7] using keV-electron irradiation to induce metastable defects. Block[8] also suggested a strong bulk effect contribution to the cell performance degradation using numerical modeling.

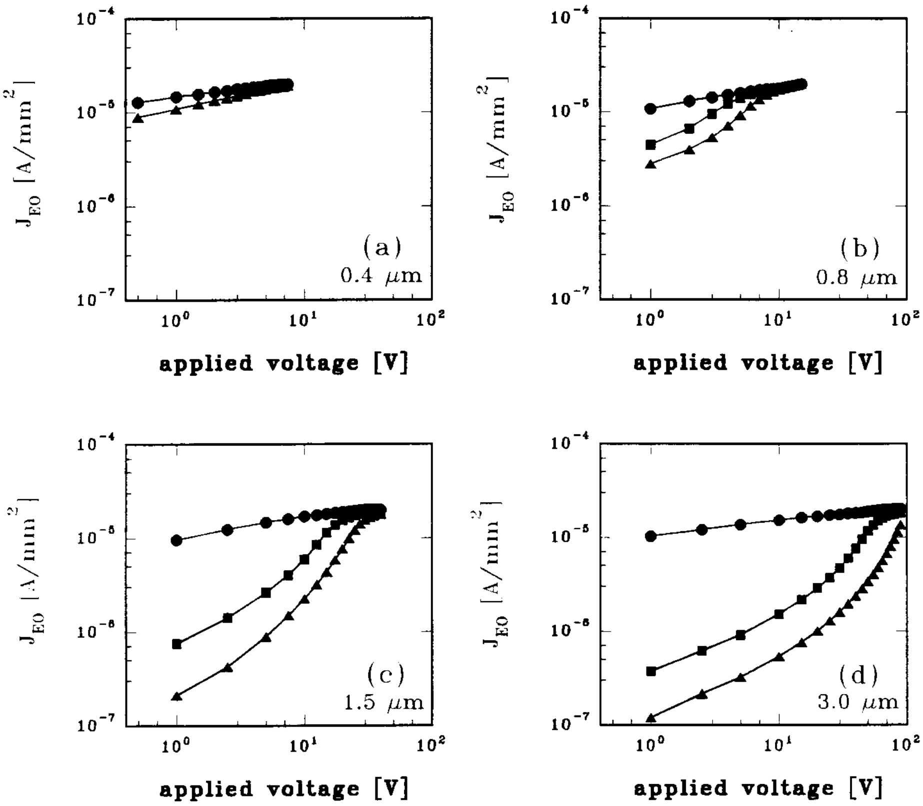

Figure 2. Variation of the electron photocurrent density (J_{EO}) with applied voltage (V), i-layer thickness (t_i) and light soaking time t=0 (●). 100 (■) and 1000 (▲) minutes.

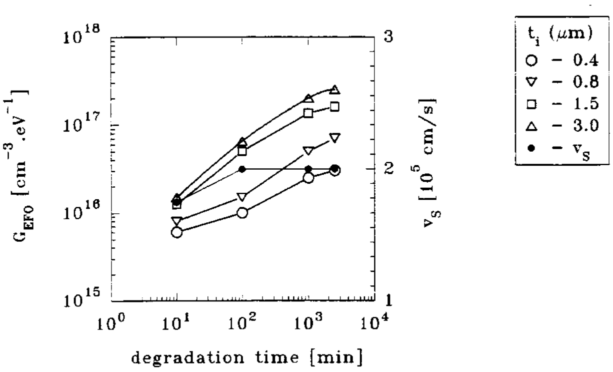

Figure 3. Variation of the parameters v_s (•) and G_{EFO} (empty symbols) with white light-soaking time determined using the model suggested by Abel, Paes and Bauer[2].

The dependence of the parameter G_{EFO} on degradation time determined from $(J_{EO} \times V)$ curves analysis can be compared with those from $(J_{DR} \times V)$ curves (see Fig. 1). Both methods evaluate the DOS change due metastable defects in the same order of magnitude.

IV. Conclusions

- white light soaking introduce changes on $(J_D \times V)$ and $(J_{PH} \times V)$ curves of a-Si:H p-i-n solar cells with magnitudes depending on i-layer thickness.

- analysis of $(J_{EO} \times V)$ curve changes due to light induced degradation indicate that deterioration of carrier transport properties in degraded cells is dominated by bulk effects. Such procedure permits to evaluate DOS change with degradation.

Acknowledgments

We acknowledge financial support from Brazilian (FINEP/CNPq) and German (DAAD/Volkswagen-Stiftung) institutions.

References

1. C. Fortmann et al., J. Appl. Physics, **64** 4219, (1988).
2. C. Abel, H. Paes and G. Bauer, Mat. Res. Society, Spring Meeting - 1991.
3. H. Paes, C. Achete and W. Losch, Mat. Res. Soc. Proc., **297**, 595 (1993).
4. R. Street and M. Hack, J. of Non-Crystalline Solids, **137/138**, 263 (1991).

5. M. Stutzmann, W. Jackson and C. Tsai, Phys. Review B **32**(1), 23 (1985).
6. W. Kopetzky and R. Schwarz, Appl. Phys. Letters **62**, 2959 (1993).
7. W. Herbst et al., 23^{rd} IEEE Photovoltaic Specialists Conference - May 1993.
8. M. Block, Journal of Non-Crystalline Solids, **164/166**, 701 (1993).