SIMULATING SUNS-V$_{OC}$ SILICON SOLAR CELL CHARACTERISTICS WITH A NEW QSS-MODEL

Andres Cuevas and Jason Tan
Department of Engineering
The Australian National University, Canberra, ACT 0200, Australia

ABSTRACT

Theoretical modeling of Suns-V$_{oc}$ characteristics of silicon solar cells in extreme conditions of surface recombination and illumination intensity predicts departures from the standard I-V characteristic curves. These departures result in ideality factors that can be either higher or lower than unity, depending on the conditions. Analytical proof of such non-idealities is also given in the paper, showing that they are due to the finite diffusivity of carriers towards the surfaces.

1. INTRODUCTION

The surfaces of silicon solar cells are usually highly doped, as in the n+pp+ cell structure, or coated with a dielectric, or they may have a heterojunction with a-Si:H. The common feature is that there is a high population of one type of carrier at the surface, which leads to a behavior of surface recombination that is best represented via a saturation current density, $J_{o(surf)}$. Measuring this parameter is, therefore, very important. At the wafer level, the method of choice is to plot the inverse effective lifetime as a function of carrier density and determine the slope of the resulting straight line [1]. In practice the wafer may not be in high injection, or the line may not be perfectly straight, and the method becomes ambiguous.

In some cases the Suns-Voc technique [2] is preferable, for example if the surfaces are not symmetrical, or the wafer has a low resistivity, or if the device is already finished. In this paper we focus on possible effects stemming from high surface recombination and the need for carriers to diffuse towards the surface in order to recombine. Modelling, using a newly developed QSS-Model [3], permits to explore the potentialities and limitations of the technique.

2. ANALYSIS OF SURFACE-LIMITED DEVICES

2.1 Modelling assumptions

To focus on surface recombination, we neglect bulk recombination and characterise the front and rear surfaces by means of the corresponding J_{ofront} and J_{oback}. To enhance the diffusion of carriers from the point of generation to that of recombination we focus on ultraviolet (500nm) or white illumination at high intensities. We use as an example a 250μm thick high resistivity wafer ($N_A=10^{14}cm^{-3}$). Photo-generation is expressed here as a current density, given by the photogenerated current at one sun illumination, J_{ph}, times the number of *suns*. A value of J_{ph}=43 mAcm^{-2} has been used at one sun.

2.2 Reference n=1 case: front surface recombination

When all recombination (and generation) occurs at the front surface there is no reason for photogenerated carriers to diffuse towards the rear, and the slope of the carrier density profile is zero, that is, $\Delta n_{(front)}=\Delta n_{(back)}$. Consequently the open-circuit voltage is:

$$V_{oc}=\frac{kT}{q}\ln\left(\frac{\Delta n_{front}^2}{n_i^2}\right)=\frac{kT}{q}\ln\left(\frac{suns\cdot J_{ph}}{J_{0\mathrm{front}}}\right) \qquad (1)$$

This expression represents the classic case of a constant ideality factor n=1.

2.3 Ideality factor n>1 case: asymmetrical (rear surface) recombination

When front and bulk recombination are negligible, all carriers must recombine at the rear surface:

$$J_{0\mathrm{back}}\frac{\Delta n_{back}^2}{n_i^2}=suns\cdot J_{ph} \qquad (2)$$

For UV/white light all carriers diffuse from the front to the rear side, and the open-circuit voltage is:

$$V_{oc}=\frac{kT}{q}\ln\left(\frac{suns\cdot J_{ph}}{J_{0\mathrm{back}}}+suns\cdot J_{ph}\frac{W}{qn_i D_a}\sqrt{\frac{suns\cdot J_{ph}}{J_{0\mathrm{back}}}}\right) \qquad (3)$$

The first term in this V_{oc} expression represents the classic n=1 ideality factor dependence, since in this case the total saturation current density is $J_0=J_{0back}$. The presence of a second term Eq. 3 implies that the ideality factor will be higher than one, because the voltage will be increasingly higher than in the ideal case as the photogenerated current increases.

A computer simulation of this case with a high $J_{0back}=10^{-11}$Acm^{-2} and UV-rich xenon flash illumination is shown in Fig. 1. The departure from ideality is noticeable in the *Suns-*V_{oc} plot, especially at high illumination levels. For comparison, an ideality one line has been plotted using a total $J_0=10^{-11}$Acm^{-2}. Fig. 2 indicates that the effect produces local ideality factors above unity, up to almost 1.2 at illumination levels approaching 100 suns. The drop at higher illuminations is due to the onset of Auger recombination.

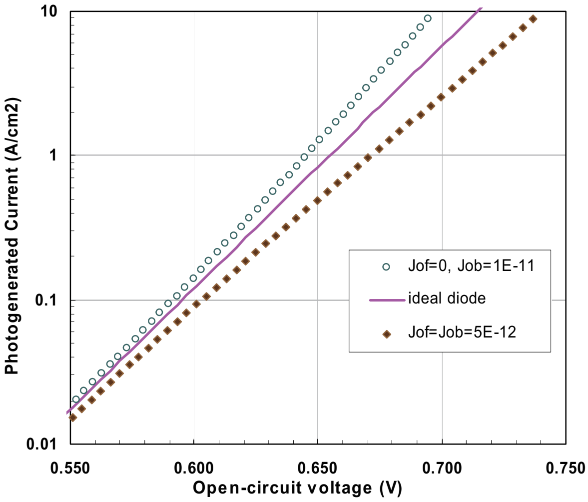

Fig. 1 Modelled *Suns-*V_{oc} curves for silicon solar cells having a base resistivity of 130Ωcm and either $J_{0front}=0$, $J_{0back}=10^{-11}$Acm^{-2} (upper curve), or $J_{0front}=J_{0back}=5\text{x}10^{-12}$Acm^{-2} (lower curve).

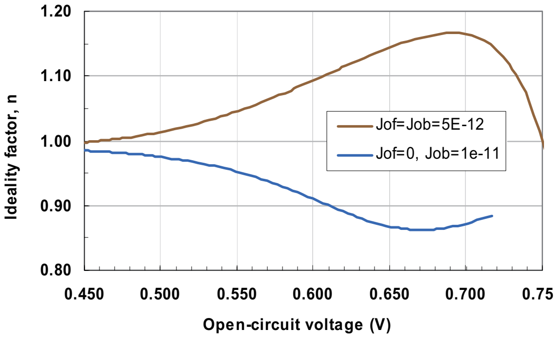

Fig. 2 Ideality factors corresponding to the *Suns-*V_{oc} curves in Fig. 1.

2.4 Ideality factor n<1 case: UV illumination, symmetrical surface recombination

Even if the recombination velocities at the front and rear surfaces are identical, that is, $J_{0front}=J_{0back}$, the share of total recombination taken up by each surface can be significantly different when photogeneration takes place near one of them. As the light intensity increases, the share of the front surface becomes increasingly higher, to make up for a decreasing percentage of back surface recombination, due to diffusivity limitations.

The open-circuit voltage is approximately given by:

$$V_{oc}=\frac{kT}{q}\ln\left(\frac{\Delta n_{front}^2}{n_i^2}\right)+$$
$$+\frac{kT}{q}\ln\left(1-\frac{W}{qD_a}\left(suns\cdot J_{ph}-J_{0\mathrm{front}}\frac{\Delta n_{front}^2}{n_i^2}\right)\right) \qquad (4)$$

The first term in this V_{oc} expression is identical to the reference case. The presence of a second term, always negative, implies that the voltage will be increasingly *lower* than in the ideal case, that is, the ideality factor will be less than one.

A computer simulation of this case is also shown in Fig. 1, for which a high $J_{0front}=J_{0back}=5\text{x}10^{-12}$Acm^{-2} has been assumed, together with UV (500nm) illumination. The departure from ideality is noticeable in the *Suns-*V_{oc} plot, especially at high illumination levels. Fig. 2 indicates that the effect of diffusivity limitation now produces local ideality factors slightly below unity, down to 0.85 at illumination levels approaching 100 suns. A simple check using a very high diffusion coefficient in the simulation gave an ideality factor one, thus confirming the physical origin for n<1. Different values for surface recombination and wafer thickness than those used in the simulations presented here lead to different values of the ideality factor.

3. CONCLUSIONS

Theoretical modeling predicts unexpected Suns-V_{oc} characteristics for extreme cases. These departures from the standard behaviour are due to the fact that the finite diffusivity of carriers can restrain surface recombination, which results in a non-linear relationship between $ln(J_{ph})$ and V_{oc}. This can produce ideality factors either greater of lower than one, depending on the weight of total recombination occurring at each surface. The phenomenon can be proven through simple analytical derivations. Nevertheless, these extreme conditions are not common, and the effect can be masked by other effects such as non-ideal contacts or bulk recombination.

REFERENCES

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