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ABSTRACT – The paper presents an investigation into the impact of most common defects in silicon solar cells that degrades the total conversion efficiency. These defects will be modelled using SCAPS software and a comparison will be introduced to show the real impact on the device performance. Extensive simulations will be performed based on the I-V characteristics of the designed solar cell. This type of studies provides a deep physical insight into the influence of defects and impurities and how they reduce the solar cell performance.

Keywords: Solar cells; Renewable energy; Defects.

1. Introduction

Solar cells is gaining a significant amount of interest by researchers as one of the most valuable sources of renewable energy. However, many types of defects present during the manufacturing process, which may be caused by pasting spot, scratches, dirty cells and other possible reasons [1]. All these defects play a major role in the degradation of the device efficiency. In order to describe the properties of photovoltaic solar cells, it is helpful to consider absorption, radiation, generation and transport of charge carriers in the semiconductor and the factors that affect the device performance. Among the many types of defects that have significant impact on the crystalline silicon for photovoltaic applications are the vacancy, substitution impurity (point defects and is mainly seen in single crystalline cells), dislocations, grain boundaries, planner defects, line defects … etc. [2]. Dislocations are irregularity defects within the structure of crystal that change the arrangement of atoms. The degree of dislocation depends on the number of atoms moved or slipped on each side of the crystalline order. Dislocations identified by the boundary between the irregularity regions produced by slipped atoms. The device performance influenced by dislocations depends heavily on three parameters: the defect density, area fraction of the solar cell that contains defect clusters, and the line density of mid-gap re-combination centers along each dislocation. As mentioned before, when the dislocations increase, the V_{oc} is decreased, i.e. the efficiency of silicon solar cell will be significantly affected and vice versa. A better performance can be achieved with free dislocation defect [3][4].

The crystal deformation generated by dislocation can cause metal segregation from surface at high concentration or forming precipitates at grain boundaries. Grain boundaries is a small-angle boundaries that are detrimental in silicon solar cells, it can be appeared as arrays of dislocations. The grain boundary defect affect the performance of solar cell depending on N_{GB}. N_{GB} is related to density of dangling bonds and the density of metal impurities migrated to the grain boundary. As the grain size decreasing , the open voltage of a solar cell (V_{oc}) increases and all of these parameters affect the performance of a solar cell [5]. The arrangement of these dislocations and the way they move can be controlled by the heat treatment and the alloy content [6]. Another form of crystal disorder is the vacancy, which contribute directly or indirectly as radiation defects. Vacancy defects are electrically active centers that produce trap states at the band gap energy of silicon [7]. In vacancy defect (oxygen defect), if the concentration of oxygen is high at a portion of the ingot, the ring defects can form. Vacancy defects reduce silicon solar cell efficiencies by up to 20% relative or 4% absolute when the solar cell is made from this defective material. In the electronics industry, a vacancy defect problems have been resolved by taking a loss of material without cutting and using narrow margins [8].

Various types of impurities such as Iron, Nickle, and Copper are found in silicon and the impact of these impurities depends on concentration, type and distribution as well as the electronic state within the lattice [9]. Generally, the impurities in silicon cause a decrease in carrier lifetime, which

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determines minority carrier currents in semiconductor devices and then reduce the efficiency in solar cells depending on the concentration of impurities. During most of the steps of the production process, impurities are introduced and removed, the main elements such as (iron, cobalt, titanium) and dopant elements such as (boron, phosphor). Impurities cause defect energy levels within the gap in silicon, which increase recombination of charge carriers which highly affects the material properties [10].

In this paper, we will present a comprehensive study on the potential influence of these defects by modelling their impact in terms of the capture cross section of the defect, energy level within the bandgap and the added series resistance represented by the defect.

2. Modelling of silicon solar cell

A simple silicon solar cell is built in SCAPS software with a 600×250 µm p-type substrate ($p = 2 \times 10^{16}$ cm^{-3}), a 0.15µm n-type emitter layer ($n = 6\times10^{19}$ cm^{-3}) and a top 0.075µm ARC-layer. The cell is illuminated under the AM1.5 Global model at normal incidence. Figure 1 illustrates the designed silicon solar cell showing its dimensions and the doping concentration of each layer.

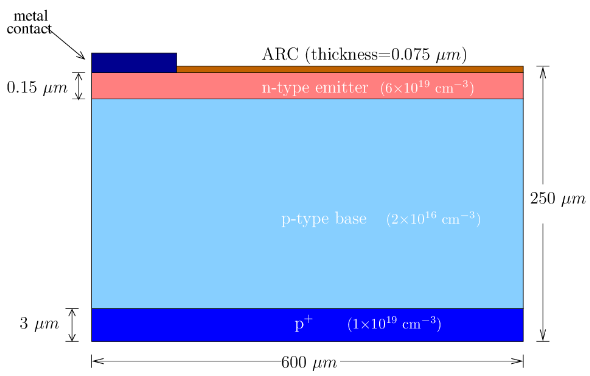

Figure 1: The simulated solar cell.

3. Simulation results and discussion

The first studied parameter is the electron and hole capture cross section, where the value was varied from 10^{-11} cm^2 to 10^{-15} cm^2 The capture cross section of impurities and defect depends mainly on the impurity type and concentration and the degree of disorder in the semiconductor lattice. The results showed that larger cross section areas have a significant impact on the device performance as shown in Figure 2.

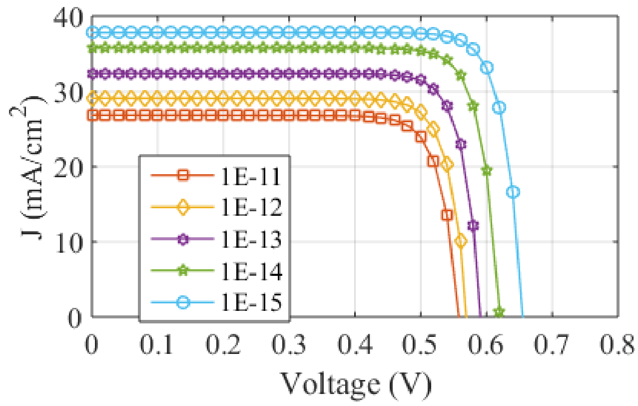

Figure 2: The impact of of changing the capture cross section of the defect.

In contrast, the state produced within bandgap of the semiconductor and its energy level was considered. Thus, the location of the defect electrical state level was varied from 0.2 eV to 1 eV referenced with respect to valence band. Results showed that mid-band trap states have the major impact on the device performance as shown in Figure 3, whereas the levels close to either the conduction band or the valence band had less impact.

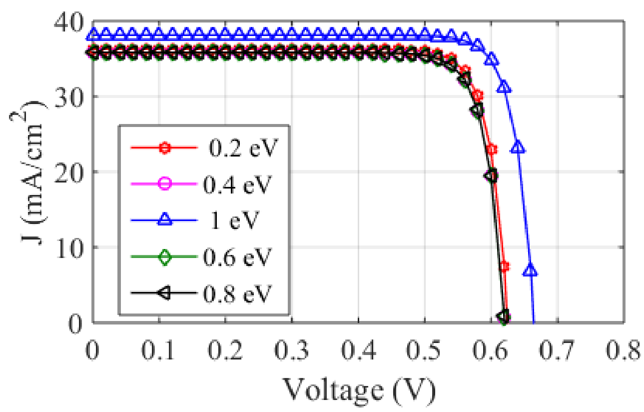

Figure 3: Reference of energy level effect.

As it is already mentioned in the introduction of this paper that some types of defects have direct impact on the band gap energy of the material such as grain boundaries. The open circuit voltage is connected directly to the band gap energy, and hence, decreasing the band gap energy leads to a decreased open circuit voltage, which in turn degrade the solar cell performance significantly. The band gap energy for silicon was decreased from 1.12 eV to 1.00 eV as shown in

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Figure 4 and its impact is clearly seen on the overall performance of the cell.

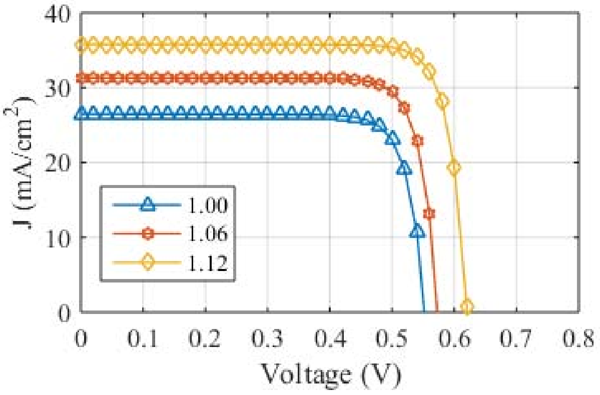

Figure 4: Impact of band gap energy.

All the results presented so far in this paper have dealt with the internal defect that could degrade the solar cell performance and their impact on the electrical characteristics of silicon solar cells. In the following, some external factor that also affect the solar cell performance will be introduced. These factors include the dust and dirt that may present on the glass surface of the solar panel, which significantly reduce the light transmission throughout the solar cell. In addition, placing the solar panel in a high temperature location with any cooling techniques will also contribute into the degradation in the solar cell performance. Figure 5 shows the impact of the light transmission through the cell surface, which clearly prove that the irradiation play a significant role in reducing the short circuit current, whereas its impact is trivial on the open circuit voltage. Moreover, Figure 6 illustrates the effect of raising the panel temperature on the overall performance of the cell. Unlike the light transmission impact, the temperature has a direct impact on the open circuit voltage while it has no obvious effect on the short circuit voltage.

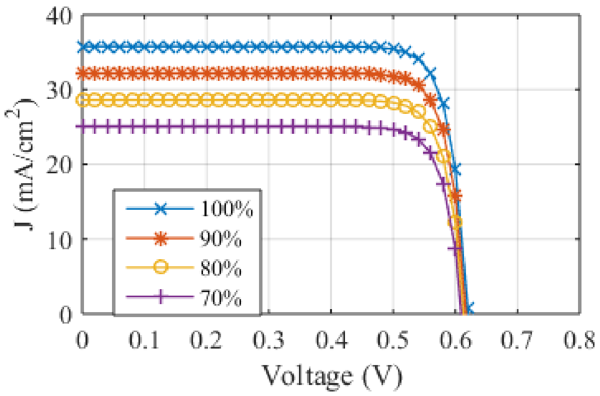

Figure 5: Light transmission effect on the solar cell performance..

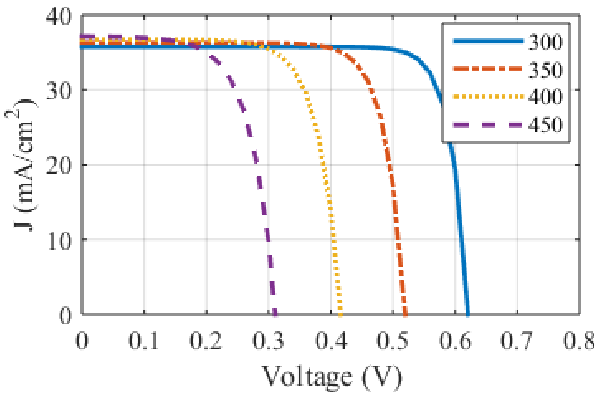

Figure 6: Temperature impact. Temperature represented in Kelvin.

4. Conclusion

In this paper, several types of defects were investigated and their impact on silicon solar cells was evaluated based on realistic simulations using SCAPS software. Internal defects related to silicon material such as dislocations, grain boundaries and impurities was introduced and their possible impact on the open circuit voltage and short circuit current was presented. In addition, other external factors that contribute towards degrading the solar cell performance such as transmission and temperature were studied.

REFERENCES

[1] Bulnes, F. G., Usamentiaga, R., Garcia, D. F., and Molleda, J., " An efficient method for defect detection during the manufacturing of web materials", *Journal of Intelligent Manufacturing*, 27(2), 431-445, 2016.

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[2] Al-Ani, Oras A., Ahmed M A Sabaawi, J. P. Goss, N. E. B. Cowern, P. R. Briddon, and M. J. Rayson. "Investigation into Efficiency-Limiting Defects in mc-Si Solar Cells." In *Solid State Phenomena*, vol. 242, pp. 96-101. Trans Tech Publications, 2016.

[3] Kovvali, Aditya, et al. "About the relevance of defect features in as-cut multicrystalline silicon wafers on solar cell performance." AIP Conference Proceedings. Vol. 1999. No. 1. AIP Publishing LLC, 2018.

[4] Needleman, David Berney, et al. "Dislocation-limited performance of advanced solar cells determined by TCAD modeling." Solar Energy Materials and Solar Cells 158 (2016): 29-36.

[5] Berney Needleman, David. "Performance limits of silicon solar cells due to structural defects." PhD diss., Massachusetts Institute of Technology, 2016.

[6] Hull, D.; Bacon, D. J. (2001). *Introduction to dislocations* (4th ed.), Butterworth-Heinemann.

[7] Erin Elizabeth Looney, "Oxygen Defect Engineering for Silicon Solar Cell Applications: Process Design and Modeling", *MSc Dissertation*, MIT, 2017.

[8] Looney, Erin Elizabeth. "Oxygen defect engineering for silicon solar cell applications: process design and modeling." PhD diss., Massachusetts Institute of Technology, 2017.

[9] Al-Ani, Oras A., J. P. Goss, Meaad Al-Hadidi, P. R. Briddon, M. J. Rayson, and N. E. B. Cowern. "Voids in silicon as a sink for interstitial iron: a density functional study." *Journal of Crystal Growth* 468 (2017): 101-103

[10] Coletti, Gianluca. "Impurities in silicon and their impact on solar cell performance." PhD diss., Utrecht University, 2011.

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