MULTIPHYSICS ANALYSIS OF PHOTOVOLTAIC SOLAR CELLS

SDVSS Varma Siruvuri[1], Pattabhi Budarapu[1]*

[1]*Scool of Mechanical Sciences, Indian Institute of Technoloby Bhubaneswar, 752050 Bhubaneswar,*
** Presenting Author email: pattabhi@iitbbs.ac.in*

Abstract

The physics of power generation on photovoltaic solar cells is complex, involving multiple fields. In this study, the performance characteristics of Silicon based solar cells are investigated considering mechanical, therma, electrical and chemical fields through a finite element (FE) analysis. A fully coupled thermo-mechanical-electrostatic-chemical relations for a deformable semiconductor are planned to be developed by combining the thermodynamically consistent formulation of the interaction between electric field and polarizable matter with the carrier charge transportation. A functional form of free energy considering the energies due to all the above-mentioned fields will be defined, through which the constitutive relations can be derived. As a result, the influence of the densities of electrons and holes can be coupled to the mechanical equilibrium. Therefore, the FE analysis can be finally extended to estimate the I-V characteristics of a p-n junction. Furthermore, each node of such three dimensional finite element is estimated possesses 14 degrees of freedom, leading to a total of 112 degrees of freedom per element.

1. Introduction

The durability of photovoltaic devices is mainly affected by the cracking in brittle Silicon due to thermo-mechanical loading, leading to electrically inactive solar cell areas and consequent power-losses. Inspite of the new and efficient manufacturing techniques to reduce the number of cells/modules rejected by quality control, it is impossible to avoid the occurrence of micro-cracking. The existing qualification standards IEC 61215 require passing of severe laboratory tests in an artificial climate chamber. However, micro-cracking is not used as a quantitative indicator for the quality assessment of PV modules. Micro-cracking can lead to large electrically disconnected cell areas, with up to 21% of power-loss. Based on the laboratory tests on single panels and field data, micro-cracked cells are observed to have a non-constant current voltage characteristics in time and an undesirable increase of the operating temperature. Therefore, it is required to perform structural analysis of the whole PV module in order to simulate the fracture at the cell level. The study of durability of PV modules requires the characterization of the effect of micro-cracking induced by mechanical loads and thermal excursions on the electric response of the solar panel. Furthermore, moisture diffusion along the epoxy layer induces the chemical degradation of the electric contacts, which is significantly augmented in case of imperfect sealing. Also, debonding of the backsheet due to either imperfect cohesion or aggressive environmental conditions like combined temperature cycles, moisture, and mechanical loads. To our best knowledge a three dimensional monolithic finite element formulation to solve the coupled multiphysics semiconductor equations in the presence of cracks is not yet attempted. Therefore, an innovative extended multiphysics model to extract the I-V characteristics of Silicon cells in the presence of cracks, is proposed here.

2. Results

Semiconductor devices can be modeled by a set of nonlinear coupled partial differential equations describing the dynamics of electrons and holes, the evolution of their temperature, the conservation of the total energy, as well as the evolution of the electric potential based on the dynamic movement of charges. The traditional fixed charge work well for bulk-like systems. However, they are generally less robust in environments that require the charge redistribution in response to changing system conditions like free surfaces. Therefore, in this proposal, the dynamic charge scheme has been adopted for modeling Silicon. Based on the Boltzmann equations, the complete hydrodynamic semiconductor transport equations are given below [1,2]

$$\nabla \cdot \mathbf{E} = \frac{\epsilon}{\theta}\left(c_h - c_e + N_D - N_A\right)$$

$$\frac{\partial c_e}{\partial t} + \nabla \cdot (c_e \mathbf{v}_e) = \left[\frac{\partial c_e}{\partial t}\right]_{col}$$

$$\frac{\partial c_h}{\partial t} + \nabla \cdot (c_h \mathbf{v}_h) = \left[\frac{\partial c_h}{\partial t}\right]_{col}$$

$$\frac{\partial \mathbf{p}_e}{\partial t} + \mathbf{v}_e(\nabla \cdot \mathbf{p}_e) + (\mathbf{p}_e \cdot \nabla)\mathbf{v}_e = -\varepsilon c_e \mathbf{E} - \nabla(c_e k_b T_e) + \left[\frac{\partial \mathbf{p}_e}{\partial t}\right]_{col}$$

$$\frac{\partial \mathbf{p}_h}{\partial t} + \mathbf{v}_h(\nabla \cdot \mathbf{p}_h) + (\mathbf{p}_h \cdot \nabla)\mathbf{v}_h = \varepsilon c_h \mathbf{E} - \nabla(c_h k_b T_e) + \left[\frac{\partial \mathbf{p}_h}{\partial t}\right]_{col}$$

$$\frac{\partial w_e}{\partial t} + \nabla \cdot (\mathbf{v}_e w_e) = -\varepsilon c_e(\mathbf{v}_e \cdot \mathbf{E}) - \nabla \cdot (\mathbf{v}_e c_e k_b T_e) - \nabla \cdot \mathbf{q}_e + \left[\frac{\partial w_e}{\partial t}\right]_{col}$$

$$\frac{\partial w_h}{\partial t} + \nabla \cdot (\mathbf{v}_h w_h) = \varepsilon c_h(\mathbf{v}_h \cdot \mathbf{E}) - \nabla \cdot (\mathbf{v}_h c_h k_b T_h) - \nabla \cdot \mathbf{q}_h + \left[\frac{\partial w_h}{\partial t}\right]_{col}$$

The governing equations in the weakform can be derived from the above strong form relations. An iso-parametric three-dimensional finite element discretization of the continuum, based on a brick element with 8 nodes is considered. Therefore, each node of the finite element possesses 14 degrees of freedom, ndf=14; which leads to a total of 112 degrees of freedom (dof) per element, as mentioned in Fig. 1(a). A discontinuity in mechanical, thermal, and electric fields of a Silicon cell can be observed when a crack crosses the cell and the fingers grid, see Fig. 1(b). Cracks in the solar cells are filled up with a semipermeable dielectric medium such as air. Due to the low permeability of air, the crack surfaces can be assumed to be insulated, which leads to an electrical impermeability in the computations

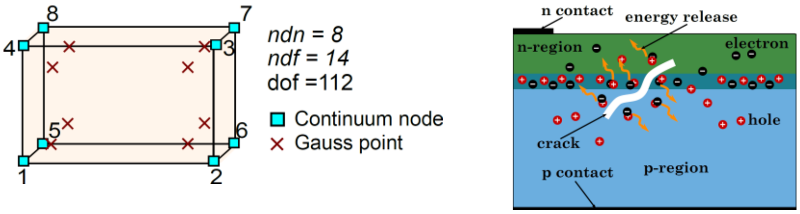

Fig. 1. (a) Multiphysics brick element. (b) Modeling of a crack in p-n junction.

Therefore, the crack introduces an additional resistance along the current path, which influences the I-V characteristics. The magnitude of the resistance is directly proportional to the crack opening displacement, which is observed as grey areas in an EL image of a cracked cell. Furthermore, crack surfaces will not permit the charges to pass through, acting as recombination centers leading to increase in local temperature around the crack as shown in the schematic Fig. 1(b). As a result, the net power output of the PV module decreases.

3. Conclusions

A three dimensional multiphysics method to analyse the performance of Silicon based photovoltaic solar cells is presented. Implemntation aspects and performance will be discussed during the oral presentation.

Acknowledgements

The authors are thankful to IIT Bhubaneswar for sponsoring this project through SEED Grant SP097.

[1] N. R. Aluru, A. Raefsky, P. M. Pinsky, K. H. Law, R. J. G. Goossens, and R. W. Dutton Computer Methods in Applied Mechanics and Engineering, vol. 107, pp. 269–298, 1993.
[2] N. R. Aluru, K. H. Law, A. Raefsky, P. M. Pinsky, and R. W. Dutton Computer Methods in Applied Mechanics and Engineering, vol. 125, pp. 187–220, 1995