54. IWK
Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

Startseite / Index:
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TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

SIMULATION OF SILICON THIN-FILM SOLAR CELL STRUCTURE

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ABSTRACT

In this paper simulations of solar cell structures are presented. For bulk silicon solar cells was used the PSpice software for analysis and simulation of electronic circuits. The strong influence of parasitic resistances is shown. Software ASA was applied for simulation of thin film silicon solar cell, focused to TCO layers.

Index Terms – Thin film/bulk solar cell, computer simulation, PSpice software, ASA software, TCO thin films.

1. INTRODUCTION

Computer simulations have proved to be an indispensable tool for obtaining a better understanding of solar photovoltaic cells (PVC) performance and for determining trends for optimizing material parameters and solar cell structures. We focused on the simulations of both the parasitic effect in real bulk PVCs and progressive thin film (TF) solar PVCs, based on amorphous silicon and transparent conductive layers of ZnO, ZnO:Al.

2. ELECTRIC PROPERTIES OF PVC

The most important electric parameters, which are used to characterize the quality of PVC, are defined: the short-circuit current I_{SC} (the current through the solar cell when the voltage across the solar cell is zero), the open-circuit voltage V_{OC} (the maximum voltage available from a solar cell, at zero current), the fill factor *FF* (indicating how far the product $I_{SC}V_{OC}$ is from the power delivered by the PVC) and the conversion efficiency (η).

The conversion efficiency is defined as the ratio of the photovoltaically generated electric output of the cell to the radiation power falling on it P_{in}:

$$\eta = \frac{I_m V_m}{P_{in}} = FF\frac{I_{SC}V_{OC}}{E\times A} = FF\frac{J_{SC}V_{OC}}{E}, \qquad (1)$$

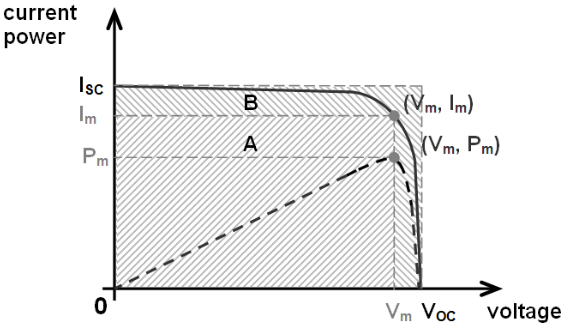


Figure 1 C-V and P-V (dash line) characteristics of illuminated solar cell

where *FF* is the fill factor of PVC $I_mV_m/I_{SC}V_{OC}$ (or *areaA/areaB* in Fig.1), *E* is value of irradiance and J_{SC} is the short-circuit current density I_{SC}/A. The values of V_m and I_m are the co-ordinates for maximal power point (he designates the optimal operating point of PVC), and can be estimated from the open circuit voltage and short circuit current: $V_m \sim (0.75\text{-}0.9)\times V_{OC}$, $I_m \sim (0.85\text{-}0.95)\times I_{SC}$ [1]. Efficiency is measured under standard test conditions (temperature of PVC 25°C, irradiance 1000 Wm^{-2}, air mass 1.5).

3. COMPUTER SIMULATION OF THE SOLAR CELL STRUCTURES

3.1. Bulk PVC structure

At the beginning we started with the basic simulation of simple 1st generation PVC (i.e. p-n junction represented as bulk silicon diode of large-area), following equivalent circuit diagram (Fig.2), by PSpice software [2] for analysis of electronic circuits and their simulations.

By means of the two diode model we achieved the better description of PVC. Diode D_1 representing the carrier injection current I_{INJ} and diode D_2 the recombination current I_R. The values of saturation current densities and ideality factors for this diodes are different: J_{s1} = 1e-12 Acm^{-2}, J_{s2} = 1e-8 Acm^{-2}, m_1 = 1 (ideal diode), m_2 = 2. We define the size of PVC

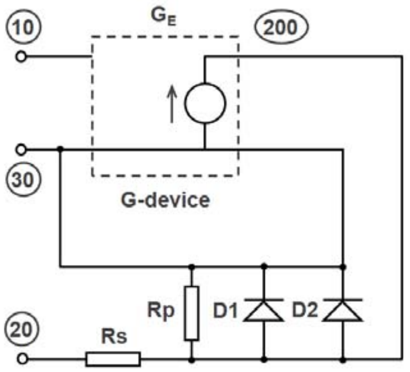


Figure 2 Equivalent circuit of real bulk PVC modelled in PSpice

area A = 100 cm^2. The other components are of resistive nature, a parallel (or shunt) resistance R_P and the series resistance R_S.

For obtaining high efficiency of PVC, the parallel parasitic resistance R_P (described loss currents at the edges of the solar cell and surface inhomogeneities) should be as high as possible and the series resistance R_S (the resistance through the wafer, the resistance of the back surface contact and the contact grid on the front surface) as a low as possible, ideally it's a deal: $R_S = 0$, $R_P \rightarrow \infty$. The values of parasitic resistances depend on PVC size, consequently also from area.

In PSpice is the value of the short circuit current I_{SC} assigned to a voltage-controlled current source (G-device, Fig.2) and is given by:

$$G_E = \frac{J_{SC} A}{1000} E \,. \qquad (2)$$

We considered that the value of short-circuit current density J_{SC} is given at standart test conditions.

3.2. Thin film PVC structure

Progressive solar PVC, 2nd and 3rd generation with higher efficiency of 20÷40%, are formed in thin film structures, predominantly based on amorphous silicon (a-Si:H, p-i-n junction) as the absorber material and transparent conducting oxide (TCO) semiconductors for transparent electrodes, e.g. single junction p-i-n a-Si PVC structure “glass/TCO/a-Si:H (p-i-n)/TCO/Ag or Al (reflective back contact)” or tandem solar cell structure “glass/TCO/a-Si:H (p-i-n)/μc-Si:H (p-i-n)/ TCO/Ag or Al (reflective back contact)” [3]. For the simulation of the thin film PVC we have used the ASA program, developed at Delft University of Technology [4], which is designed for the simulation of multilayered heterojunction device structures.

We focused for “superstrate“ configuration of thin-film solar PVC: Glass/ZnO:Al/a-Si:H (p-i-n)/ZnO/Al (reflective back contact). Schematic structure of a single junction a-Si:H PVC is shown in Fig.3. The active device consists of three layers: a p type a-Si:H layer, an intrinsic a-Si:H layer and an n type a-Si:H layer. This layers form a p-i-n single junction. The doped layers set up an internal electric field across the intrinsic a-Si:H layer and establish low loss ohmic electrical contacts between the a-Si:H part of the PVC and the external electrodes [3].

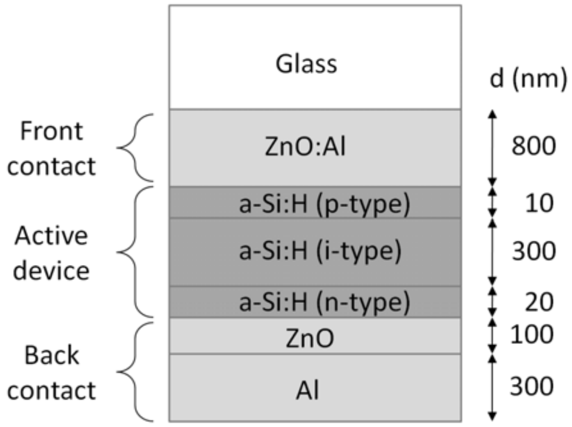


Figure 3 Superstrate PVC configuration of single junction (p-i-n) structure

The thickness of the *i* region should be optimized for maximum current generation. In practice is limit the i-region thickness to around 0.5 μm [5].

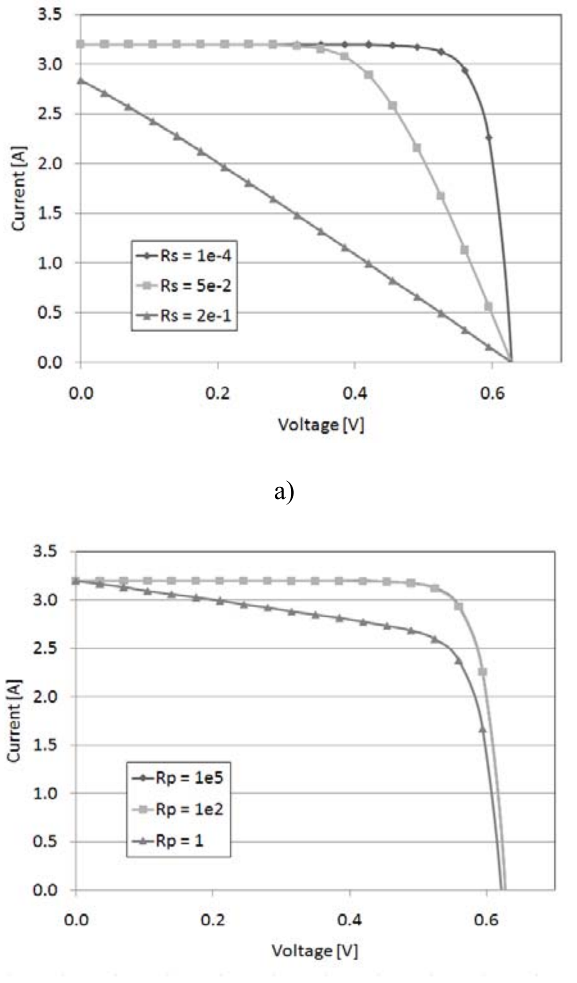
Transparent conducting oxides based on ZnO are promising for application in thin-film solar photovoltaic cells. The upper front contact Zno:Al layer should fulfil several important requirements: high transparency in VIS/near IR solar spectrum; high electrical conductivity; suitable surface texture in order to enhance light scattering and absorption inside the cell; high chemical stability and adhesion to silicon. Moreover, bottom ZnO interlayer between Si and metal (usually Ag) contact is acting as barier and adhesion layer as well as optical matching layer to Ag back contact to improve its reflection of radiation, particularly in near IR region [6]. Optimization of the front contact TCO has proven to be crucial for a high cell efficiency [7].

4. RESULTS AND DISCUSSION

The effect of parasitic resistances R_S and R_P on C-V characteristic is shown in the Fig.4.

As can be seen, for parasitic serial resistance R_S (Fig.4a) the values of the short-circuit current and of the fill factor (it follows too efficiency) can be expressively reduced. At the high values of R_S occur the big reduction of the short-circuit current value I_{SC}. The open-circuit voltage is independent of the series resistance. The product $R_S.I_{SC}$ should never have been greater than 25 mV in praxis (outside temperature 25 °C).

The parallel resistance also degrades the performance of the PVC, Fig.4b.



a)

b)

Figure 4 C-V characteristics of bulk PVC structure (illumination for AM1.5) for modification of serial (a) and parallel resistance (b)

Small values of the parallel resistance heavily degrade the fill factor (i.e. efficiency). Also are the value of open-circuit voltage reduced, the short-circuit current is independent of the parallel resistance.

The concrete values of parasitic resistances, that we used by the simulation with PSpice are:

- serial parasitic resistance R_S: 1e-4, 5e-2, 2e-1 Ω,
- parallel parasitic resistance R_P: 1e5, 1e2, 1 Ω.

Table 1 Selected parameters of bulk PVC structure (illumination for AM1.5)

R_S (Ω)	I_{SC} (A)	V_{OC} (V)	FF (-)	η (%)
1e-4	3.200	0.628	0.825	16.58
5e-2	3.200	0.628	0.604	12.14
2e-1	2.844	0.628	0.261	4.66
R_P (Ω)	I_{SC} (A)	V_{OC} (V)	FF (-)	η (%)
1e5	3.2	0.628	0.825	16.58
1e2	3.2	0.628	0.824	16.56
1	3.2	0.622	0.686	13.65

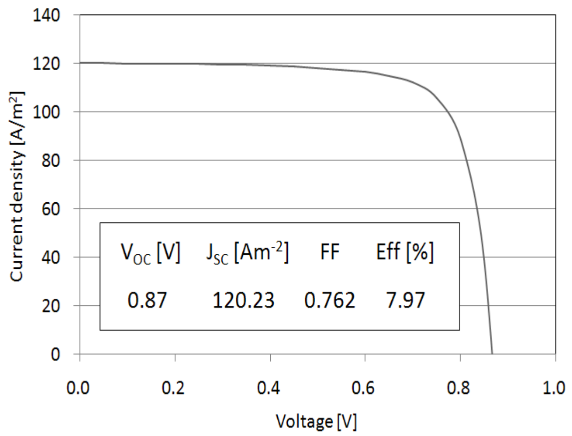


Figure 5 C-V characteristics of TF PVC structure (illumination for AM1.5) for the thicknesses of ZnO:Al layer 800 nm and ZnO layer 100 nm

Selected parameters of illuminated PVC with the parasitic resistances R_S and R_P is shown in the Tab.1. The parameters I_{SC} and V_{OC} are assigned from the graph, parameters FF and η are calculated by (eq. 1). Computer simulations for single junction a-Si:H PVC structure (Fig.3) we compile in ASA software. The thicknesses of particular layers are show in Fig.3. All important electric properties are set direct in the C-V characteristic for illuminated p-i-n PVC structure (Fig.5). Also in this case are the parameters I_{SC} and V_{OC} assigned from the graph, parameters FF and η are calculated by (eq. 1).

For the simulations the next parameters of TCO layers were used (obtainted experimentally at the wavelength 500 nm):

1) ZnO:Al:
   - refractive index n = 2.675
   - absorption coefficient α = 1.712e5 m^{-1}

2) ZnO:
   - refractive index n = 2.0516
   - absorption coefficient α = 7.55e5 m^{-1}

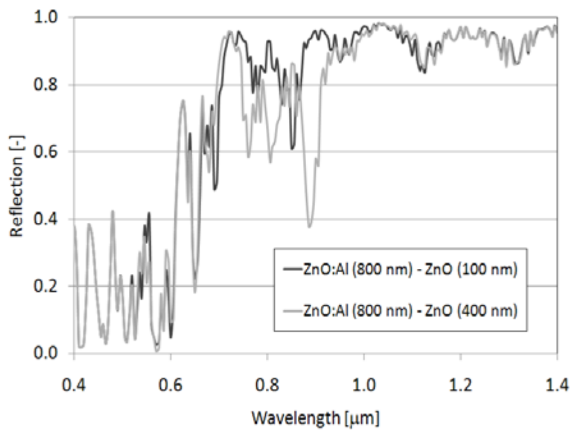


Figure 6 Reflection of TF PVC structure for different thicknesses of ZnO layers

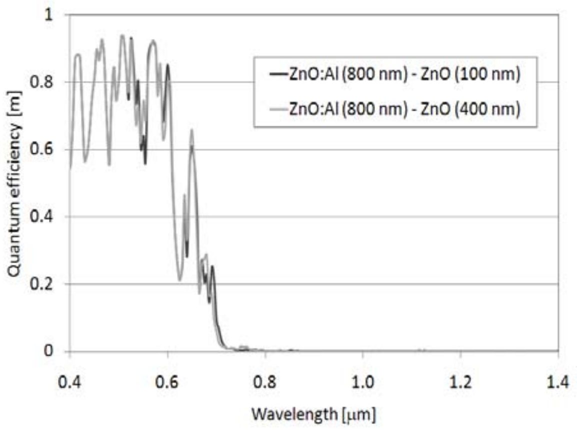


Figure 7 Quantum efficiency of TF PVC structure for different thicknesses of ZnO layers

Reflection and quantum efficiency of selected thin film PVC structures for different thicknesses of ZnO layers a shown on Fig.6 and Fig.7.
Reflection in the near IR region has a tendency to increase with thickness of front ZnO layer. From dependences of quantum efficiency on wavelength result the fact, that the simple TF PVC structure shows lower effectivity in the near IR region.

5. CONCLUSION

Results in PSpice software indicate clearly that the parasitic serial and parallel resistances have a strong influence on the fill factor (i.e. efficiency) of solar cell. Our preliminary simulations in ASA software showed an importance of suitable properties of front TCO contact as well as back reflective layer structure for optimal performance of solar cell. To minimize reflection in the near IR region, i.e. to increase the efficiency, will be possible by using the tandem solar cell structure.

6. ACKNOWLEDGEMENT

Presented work was supported by the MSMT Czech Republic project 1M06031 (ASA software) and partially it has been done in Center of Excellence CENAMOST (Slovak Research and Development Agency Contract No. VVCE-0049-07) with support of project VEGA 1/0220/09 (PSpice software).

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