

**54. IWK**  
Internationales Wissenschaftliches Kolloquium  
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**Information Technology and Electrical  
Engineering - Devices and Systems, Materials  
and Technologies for the Future**



Faculty of Electrical Engineering and  
Information Technology

Startseite / Index:

<http://www.db-thueringen.de/servlets/DocumentServlet?id=14089>

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

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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 ( $\eta$ ).

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

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

where  $FF$  is the fill factor of PVC  $I_m V_m / I_{SC} V_{OC}$  (or

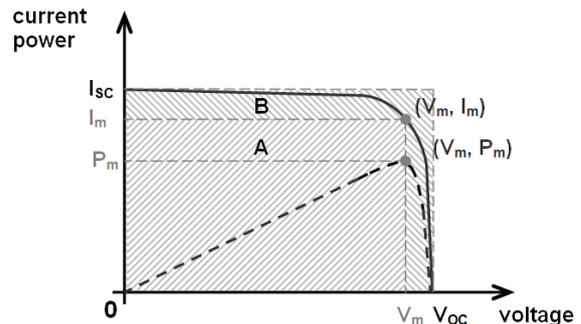


Figure 1 C-V and P-V (dash line) characteristics of illuminated solar cell

area A/area B 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:  $V_m \sim (0.75-0.9) \times V_{OC}$ ,  $I_m \sim (0.85-0.95) \times I_{SC}$  [1]. Efficiency is measured under standard test conditions (temperature of PVC 25°C, irradiance 1000 Wm<sup>-2</sup>, 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 1<sup>st</sup> 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<sup>-2</sup>,  $J_{s2} = 1e-8$  Acm<sup>-2</sup>,  $m_1 = 1$  (ideal diode),  $m_2 = 2$ . We define the size of PVC

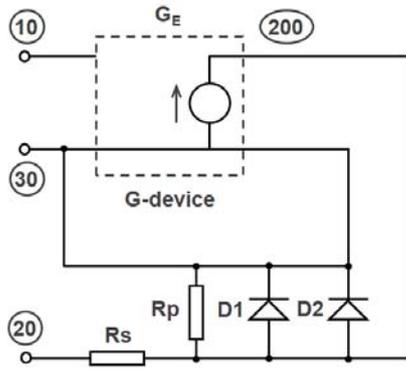


Figure 2 Equivalent circuit of real bulk PVC modelled in PSpice

area  $A = 100 \text{ cm}^2$ . 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:

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

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, 2<sup>nd</sup> and 3<sup>rd</sup> 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)/ $\mu\text{c-Si:H}$  (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

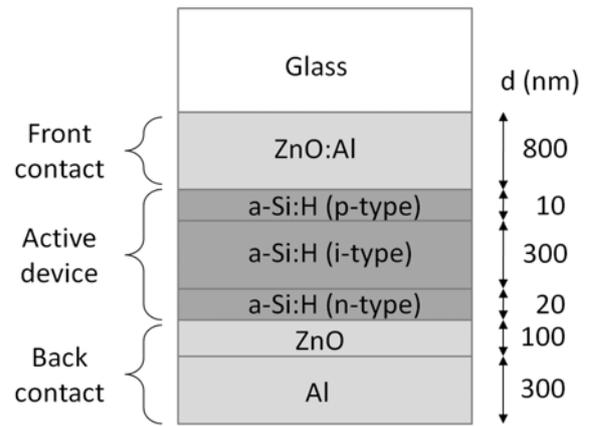


Figure 3 Superstrate PVC configuration of single junction (p-i-n) structure

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].

The thickness of the *i* region should be optimized for maximum current generation. In practice is limit the *i*-region thickness to around  $0.5 \mu\text{m}$  [5].

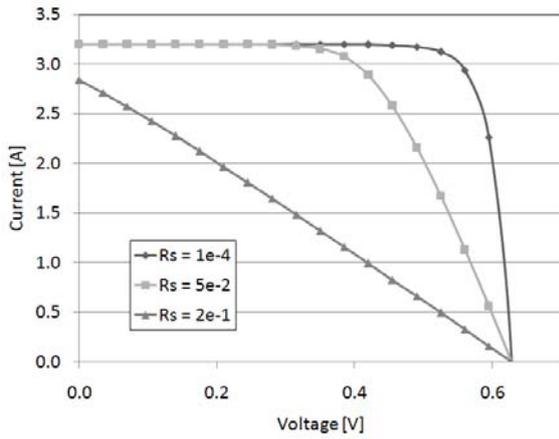
Transparent conducting oxides based on ZnO are promising for application in thin-film solar photovoltaic cells. The upper front contact ZnO:Al layer should fulfil several important requirements: high transparency in VIS/near IR solar spectrum; high electrical conductivity; suitable surface texture in 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 barrier 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

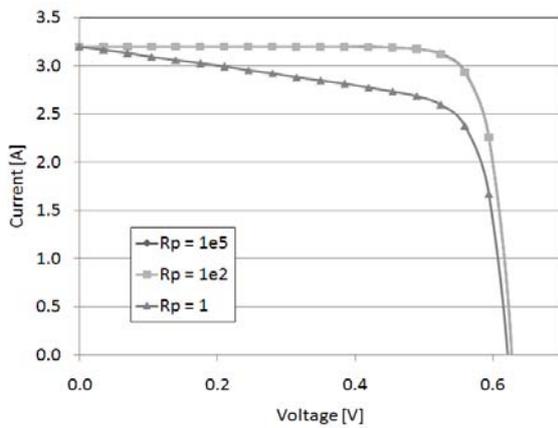
The effect of parasitic resistances  $R_s$  and  $R_p$  on C-V characteristic is shown in the Fig.4.

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  $R_s \cdot I_{SC}$  should never have been greater than 25 mV in praxis (outside temperature  $25^\circ\text{C}$ ).

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  $\Omega$ ,
- parallel parasitic resistance  $R_P$ : 1e5, 1e2, 1  $\Omega$ .

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

$R_S$ ( $\Omega$ )	$I_{SC}$ (A)	$V_{OC}$ (V)	FF (-)	$\eta$ (%)
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
$R_P$ ( $\Omega$ )	$I_{SC}$ (A)	$V_{OC}$ (V)	FF (-)	$\eta$ (%)
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

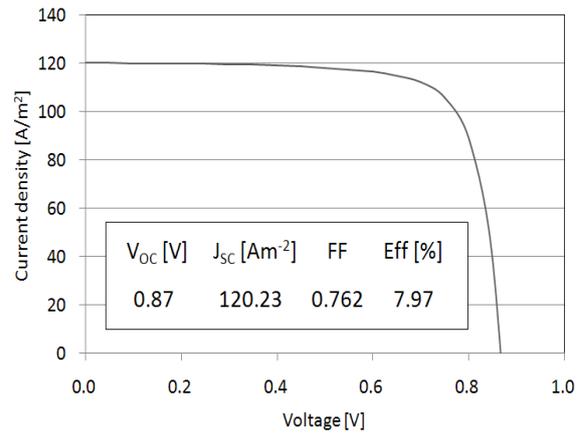


Figure 5 C-V characteristics of TF PVC structure (illumination for AM1.5) for the thicknesses of ZnO:Al layer 800 nm and ZnO layer 100 nm

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  $\eta$  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  $\eta$  are calculated by (eq. 1).

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

1) ZnO:Al:

- refractive index  $n = 2.675$
- absorption coefficient  $\alpha = 1.712e5 \text{ m}^{-1}$

2) ZnO:

- refractive index  $n = 2.0516$
- absorption coefficient  $\alpha = 7.55e5 \text{ m}^{-1}$

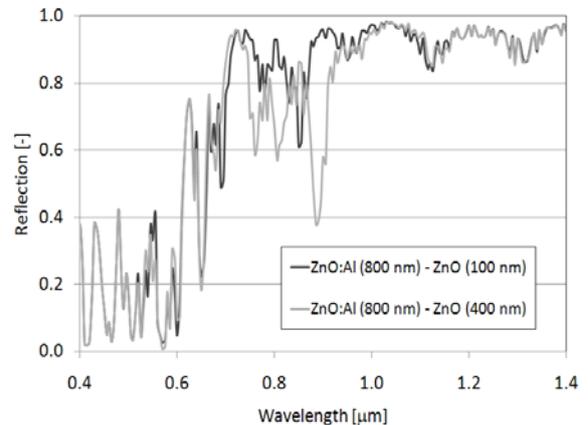


Figure 6 Reflection of TF PVC structure for different thicknesses of ZnO layers

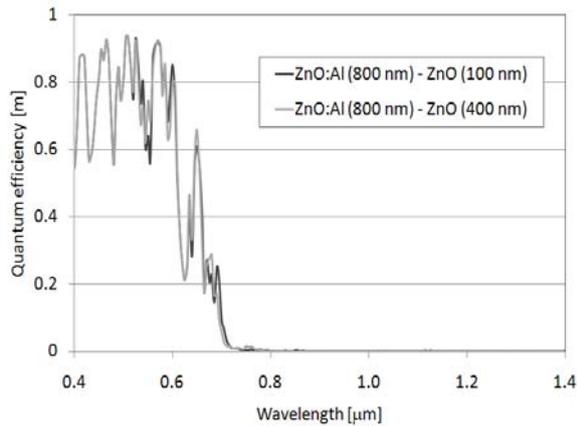


Figure 7 Quantum efficiency of TF PVC structure for different thicknesses of ZnO layers

Reflection and quantum efficiency of selected thin film PVC structures for different thicknesses of ZnO layers is 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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