MODELING CuS–CdSe SOLAR CELL S-SHAPED I-V CHARACTERISTICS

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The process of designing practical photovoltaic applications calls for the availability of dc lumped-parameter equivalent circuit models. Such models help in understanding the work principles of solar cells (SCs), interpreting the *I–V* characteristics and device performances, and optimizing the performance of SCs, through a quantitative simulation[1]. Our work is focused on the determination of the proper equivalent model of CuS–CdSe structure.

The *p*+-*n* thin film $Cu_{1.8}S$–CdSe structure is used in the investigation with the initial thickness of each layer 15 nm and 7μm, respectively. *p*+ is the collector layer with $p = 10^{21}$ cm^{-3} while 10^{15} cm^{-3} is the *n* of the base layer. The *I-V* characteristics were measured over a temperature range 290-340 K. Fig. 1 shows that the electrical characteristics of the investigated solar cell are more complex than conventional photovoltaic devices, varying from an ideal 'J' shape to a non-ideal 'S' shape with a 'kink' in the *I-V* plot when under illumination.

The model from de Castro[2], which consist of two opposite polarity diodes D1 and D2 with shunt resistors $R_{SH,1}$ and $R_{SH,2}$, was chosen as an initial approximation. The I-V characteristics were fitted by the exact closed form analytical solution[3,4]:

$$\begin{aligned} V = IR_S + \frac{n_1 kT}{q} g(x_1) - \frac{n_2 kT}{q} g(x_2) - \\ - \frac{n_1 kT}{q} \log\left[\frac{q}{n_1 kT} I_{0,1} R_{SH,1}\right] + \frac{n_2 kT}{q} \log\left[\frac{q}{n_2 kT} I_{0,2} R_{SH,2}\right], \end{aligned} \qquad (1)$$

where R_S is the series resistance, n_i, $I_{0,i}$ – the ideality factor and saturation current of *i*-th diode, I_{PH} – is the photocurrent, $g(x)=\log(W(\exp(x)))$, W - Lambert W function,

$$x_1 = \log\left[\frac{q}{n_1 kT} I_{0,1} R_{SH,1}\right] + \frac{q}{n_1 kT} R_{SH,1}(I + I_{PH} + I_{0,1}), \tag{2}$$

$$x_2 = \log\left[\frac{q}{n_2 kT} I_{0,2} R_{SH,2}\right] + \frac{q}{n_2 kT} R_{SH,2}(I - I_{0,2}). \tag{3}$$

The fitting was done by using differential evolution method.

The analysis has been shown that i) the series resistance value is less than 10^{-9} Ohm; ii) $I_{02}<10^{-25}$ A in the dark case and opposite second diode must be omitted the dark case. The final equivalent circuit models are shown in Fig.2.

The extracted temperature dependences of diodes parameters are shown in Fig. 3. One can see that the temperature dependence of the D1 saturation current is the same as expected in recombination–tunneling current model[5]:

$$I_{0,1} = I_{00,1}\exp(\beta T). \tag{4}$$

The shunt resistances are thermoactivated:

$$R_{SH,i} = R_{SH,i0}\exp\left(-\frac{E_{R,i}}{kT}\right). \tag{5}$$

It should be noted that in the dark case the knee at about 310~K is observed at temperature dependencies of parameters. Hence the current mechanism changes at this temperature value. Fig. 3 show that the charge transport mechanism in both illuminated and dark thin film $Cu_{1.8}S$–CdSe structure is the same at T<310~K, whereas those are different at higher temperature.

It is known[1] the S-shaped I–V curve could be induced by different reasons: interfacial dipole, charge accumulation at interface, unbalanced charge transportation, and electrode/active layer interfacial Schottky barriers. The obtained results obtained testify that these processes depend on temperature and illumination.

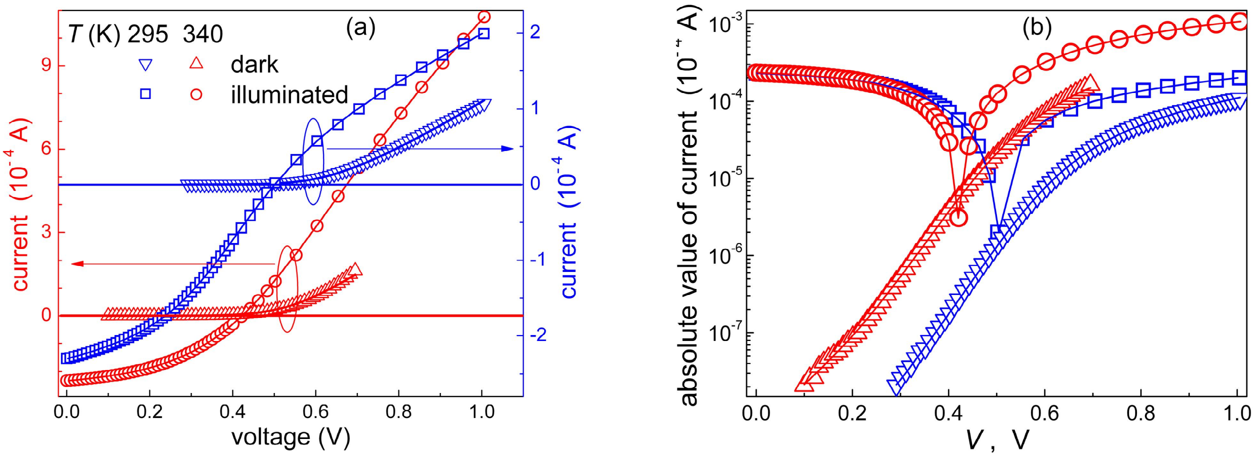

Fig.1. The dark (triangles) and illuminated (circles and squares) I-*V* curves of $Cu_{1.8}S$–CdSe solar cell. The experimental (marks) and fitted (solid lines) results are presented.

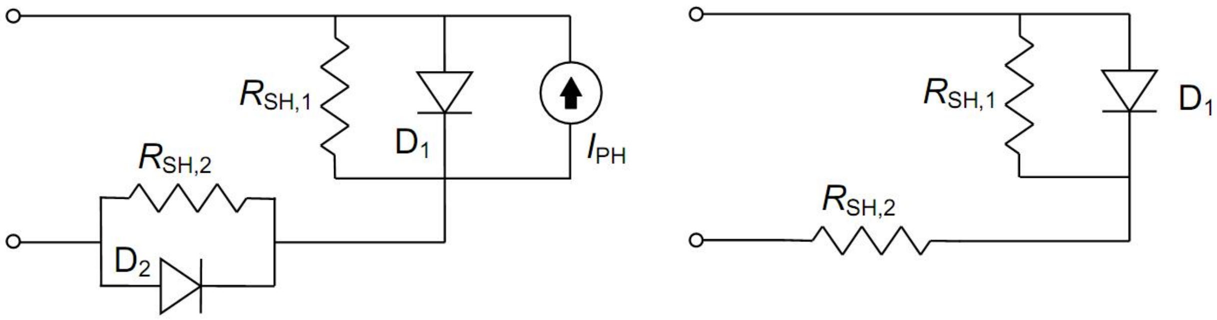

Fig.2. The proposed DC lumped-parameter equivalent circuit model of $Cu_{1.8}S$–CdSe solar cell under illumination (left) and dark condition (right).

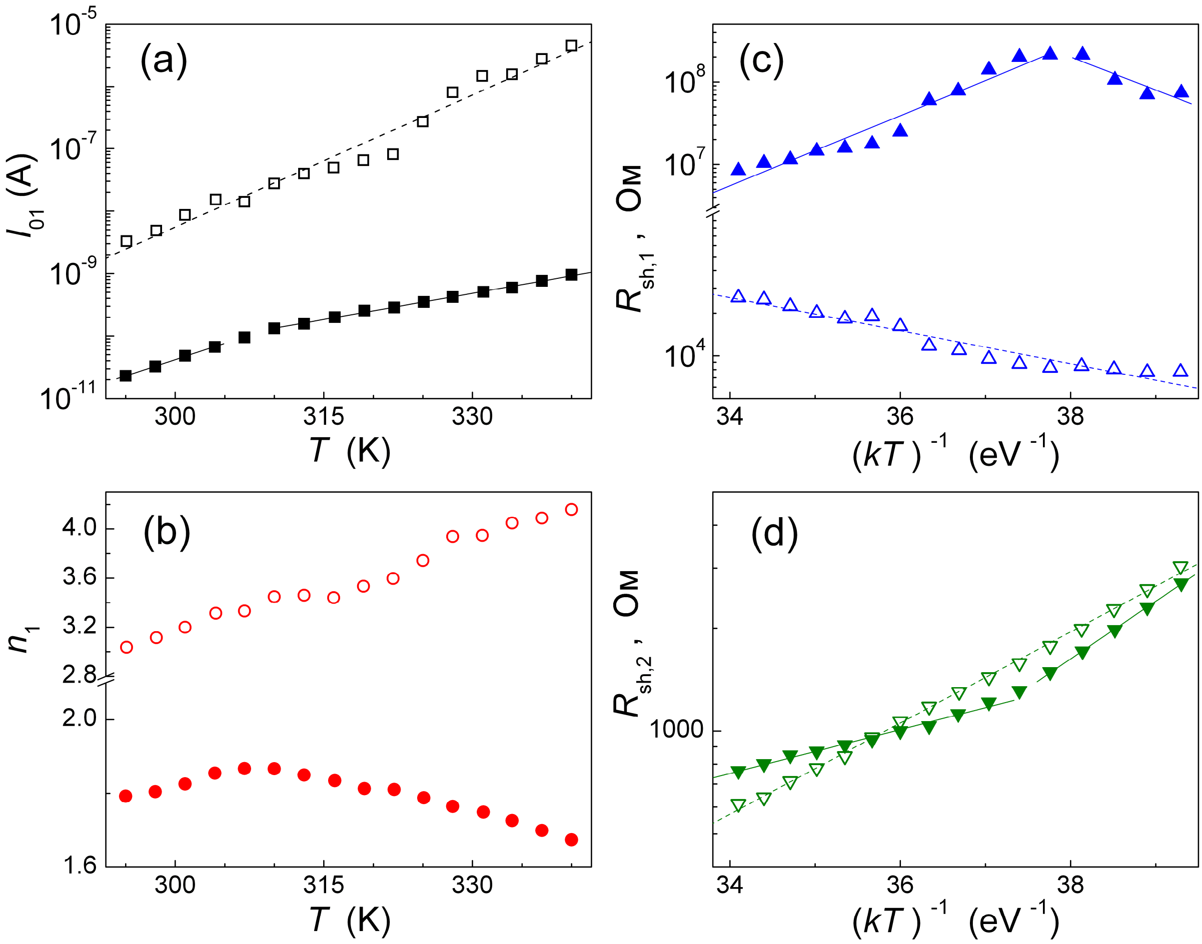

Figure 3. Temperature dependencies of D_1 saturation current (a), D_1 ideality factor (b), D_1 (c) and D_2 (d) shunt resistances. The marks are the experimental results, and the lines are the fitted curves using linear approximation (panels a and b) or Eq. (5) (panels c and d). Open and filled marks corresponds to the iluumination and dark, respectively.

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