

## NUMERICAL SIMULATION OF THE IDEALITY FACTOR OF NON-IDEAL n-Si/p-DIAMOND HETEROJUNCTION DIODES

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A direct numerical method was followed to calculate the ideality factor for non-ideal n-Si/p-diamond heterojunction diode. The simulations were carried out at different temperatures from 300 K up to 360 K. Results showed that the ideality factor decreases as the current increases at fixed voltage and temperature. The temperature dependence of the ideality factor was also investigated. Theoretical values of the ideality factor were found to be close to the experimental data of such system.

(Received September 30, 2010; accepted October 23, 2010)

*Keywords:* Heterojunction diode, Ideality factor, Forward I/V characteristics

### 1. Introduction

The ideality factor of a diode junction is a real quality factor from which one can deduce whether the diode behaves closely or apart from the ideal case. It is one of the important parameters used to describe the junction diode and solar cell's electrical behavior. The parameters are usually the saturation current, the series resistance, the ideality factor, the shunt conductance and the photocurrent. While the saturation current of the diode depends on the carrier transport mechanism across the junction, the ideality factor reflects the influence of various parameters, e.g. presence of interface states, generation-recombination, tunneling, spatial inhomogeneities, etc. Frequently it is a function of temperature and the applied voltage [1-3].

The initial step for extraction of ideality factor ( $n$ ) is the linear approximation of the dark forward current-voltage ( $I/V$ ) plot at a given temperature. Determination of the ideality factor could be used as a measure of the validity of such a method. If the value of  $n$  is approximately 1, such approximation could be considered accurate enough. If  $n > 1.4$  transport mechanisms that produce the deviation from the ideal model should be considered. In non-ideal cases, the linearity of the  $\ln I-V$  plot is no longer occurred. The basic of most methods for obtaining the ideality factor of non-ideal diodes from  $I/V$  curves is the correction of the linear approximation method [4].

In the last decades, several techniques have been introduced to determine the ideality factor. Some of the methods are direct measurement method [5], variable resistor series method [6], normal parameter coordinate method [7,8], direct method to measure  $n$  from illuminated output  $I/V$  curve [9], the generalized area method [10], and analytical method [11]. Jain and Kapoor [12] and Bayhan and Kavasoglu [13] have proposed a simple analytical method using Lambert W-function to extract the ideality factor. A review of techniques to determine the ideality factor of solar cell has been given by Bashahu and Nkundabakura [14].

In the present work, a direct numerical method was followed to calculate the ideality factor for non-ideal heterojunction diodes. The n-Si/p-Diamond system was considered for the simulation at different temperatures.

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## 2. Theory

Current flow across the ideal junction diode under forward bias in dark is usually represented by the equation [15];

$$I = I_o \exp\left(\frac{qV}{nkT}\right) \quad (1)$$

where  $I_o$  is the reverse saturation current,  $V$  is the applied bias voltage,  $n$  is the ideality factor,  $T$  is the temperature,  $q$  is the electron charge and  $k$  is the Boltzmann constant. For non-ideal diodes, the effects of series and shunt resistances are considered, the current-voltage relation becomes;

$$I = I_o \left[ \exp\left(\frac{V - IR_s}{nV_{th}}\right) - 1 \right] + \frac{V - IR_s}{R_{sh}} \quad (2)$$

where  $R_s$  is the series resistance,  $R_{sh}$  is the shunt resistance and  $V_{th} = kT/q$  is the thermal voltage. Equation 2 can be written as

$$\frac{I \left(1 + \frac{R_s}{R_{sh}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} + 1 = \frac{I_o \exp\left(\frac{V}{nV_{th}}\right) \exp\left(\frac{-IR_s}{nV_{th}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} \quad (3)$$

or can be modified to the form;

$$\ln \left[ \frac{I \left(1 + \frac{R_s}{R_{sh}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} + 1 \right] + \frac{IR_s}{nV_{th}} = \ln \left[ \frac{I_o \exp\left(\frac{V}{nV_{th}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} \right] \quad (4)$$

Equation 4 can be expressed in the form

$$\ln(\gamma + 1) + \gamma\alpha = \ln(\beta) \quad (5)$$

where

$$\gamma = \frac{I \left(1 + \frac{R_s}{R_{sh}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} \quad (6)$$

$$\alpha = \frac{R_s \left(I_o - \frac{V}{R_{sh}}\right)}{nV_{th} \left(1 + \frac{R_s}{R_{sh}}\right)} \quad (7)$$

$$\beta = \frac{I_o \exp\left(\frac{V}{nV_{th}}\right)}{\left(I_o - \frac{V}{R_{sh}}\right)} \quad (8)$$

For a heterojunction device, simulation of  $n$  as a function of  $I$  can be proceeded if the values of  $I_o$ ,  $R_s$ ,  $R_{sh}$  and  $V$  are known.

### 3. Results and discussion

To obtain the numerical simulation for the ideality factor of the heterojunction diode, values of the reverse saturation current, the series resistance and the shunt resistance must be determined. The first step is to extract these quantities from the experimental results taken for such diode system. The n-Si/p-diamond heterojunction diodes were chosen. The experimental data of such system were extracted from Saha et al. [16]. Fig. 1 shows the dark forward  $I/V$  plot on semilogarithmic scale at different temperatures from 300 K up to 360 K. The values of  $I_o$  at each temperature can be obtained by extrapolating the forward current curves to zero voltage. The deduced values of  $I_o$  are listed in table 1.

In order to estimate the series resistance established across the neutral region between n and p sides of the diode, the experimental results of Saha et al. [16] were used. From the  $I/V$  curves at each temperature, values of  $\Delta V$  were extracted at different values of  $I$  (where  $\Delta V$  is the difference between the voltage at the curve and the extension of the linear part of the curve at low voltages).  $\Delta V$  was plotted against  $I$  and thus from the slope of the yielded straight line one can calculate the series resistance ( $\Delta V = R_s I$ ). Fig. 2 demonstrates the plot of  $\Delta V$  versus  $I$  at two temperatures 300 K and 360 K. the same procedure was followed to calculate the series resistance at all temperatures. Values of  $R_s$  at different temperatures are shown in table 1.

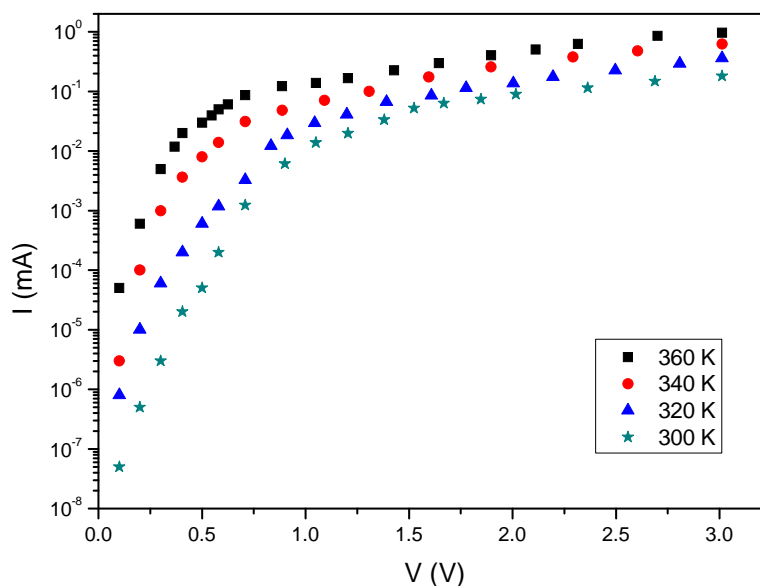


Fig. 1 Forward  $I/V$  characteristics of n-Si/p-diamond heterojunction at different temperatures (extracted from Ref. [16])

Table 1 values used in the simulation at different temperatures.

$T$ (K)	300	320	340	360
$I_o$ (A)	$1 \times 10^{-10}$	$4 \times 10^{-10}$	$1 \times 10^{-9}$	$3 \times 10^{-9}$
$R_s$ (k $\Omega$ )	35	23	12	3.5
$I$ (A) at $V=0.5$ V	$6 \times 10^{-8}$	$5 \times 10^{-7}$	$8 \times 10^{-6}$	$3 \times 10^{-5}$
$R_{sh}$ (k $\Omega$ )	230	230	230	230

Fig. 3 represents the numerical simulation of the ideality factor of n-Si/p-diamond heterojunction diode as a function of the injected current at  $V=0.5$  Volts and temperatures from 300 K to 360 K. The parameters used in the calculations are shown in table 1. One can notice that the ideality factor decreases as the current increases and this trend is being the same at all

temperatures. These results are in good agreement with that obtained by Bayhan et al. [13] in n-CdS/p-Cu(In,Ga)Se<sub>2</sub> heterojunction and also obtained by Alfaramawi [17] in p-ZnTe/p-CdTe heterojunction diodes.

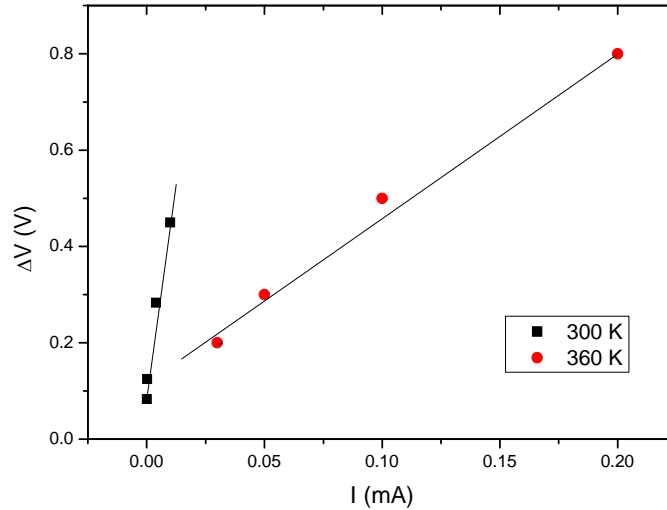


Fig. 2 Plot of  $\Delta V$  versus  $I$  to extract the series resistance at 300 K and 360 K.

The ideality factor was calculated as a function of temperature in the range from 300 K up to 400 K for our system. The calculations were performed at constant voltage ( $V=0.5$  volts). Fig. 4 shows the results of simulation compared with the experimental data of Ref. [16]. For comparison, the calculation of  $n(T)$  was also obtained according to the equation [18]

$$n = \left(\frac{E_{oo}}{kT}\right) \coth\left(\frac{E_{oo}}{kT}\right) \tag{9}$$

where  $E_{oo}$  is a characteristic energy depends on the concentration. In the calculations,  $E_{oo}$  was taken as 63 meV (or  $E_{oo}/k = 730$  K). It is clear from Fig. 4 that our simulation results are close to the experimental data especially at higher temperatures. On the other hand calculations of equation (9) is neither agree with the experimental data nor with our simulations within the range of temperature under investigation.

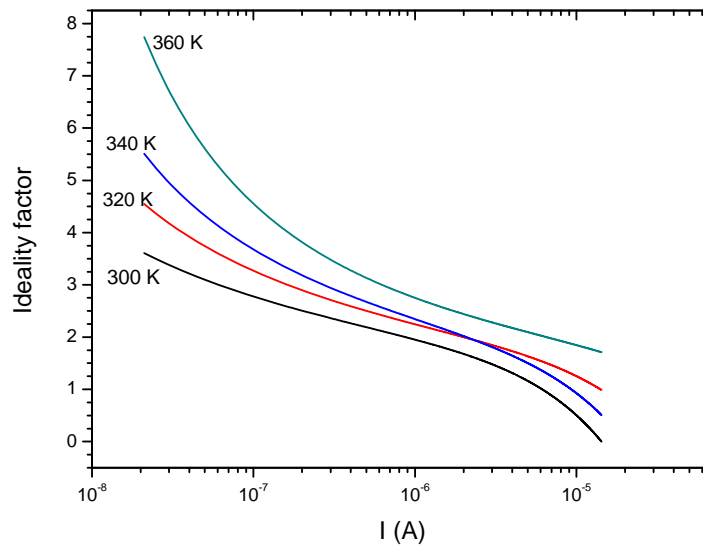


Fig. 3 Simulation of the ideality factor of n-Si/p-diamond heterojunction diode as a function of the current at temperatures from 300 K to 360 K.

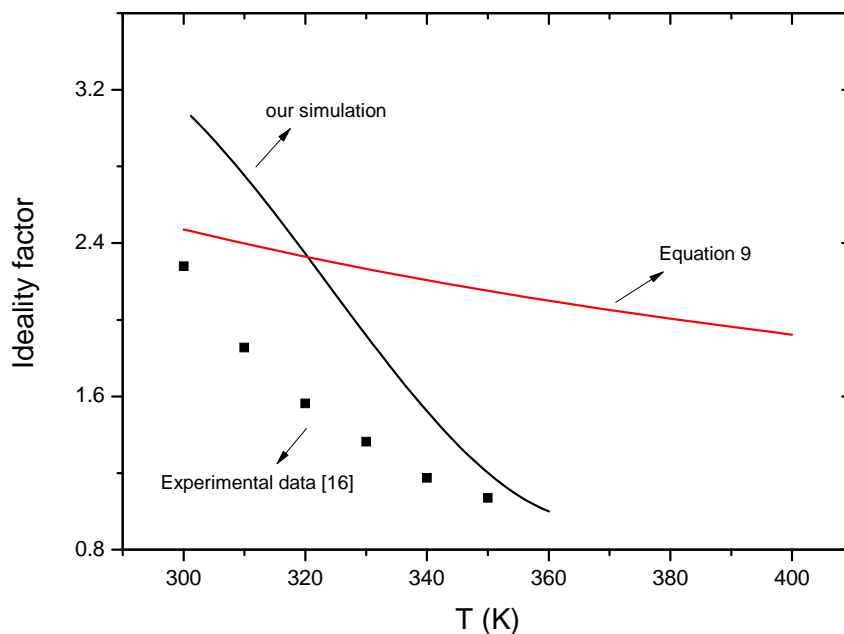


Fig. 4 Simulation of the ideality factor as a function of temperature compared with the experimental data of Ref. [16].

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