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# Estimation of the ideality factor of ZnTe/CdTe *p-p* heterojunction diodes

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Direct analytical method for estimating the ideality factor of ZnTe/CdTe isotype p-p heterojunction diodes is reported. The calculations were performed at two temperatures 300 K and 200 K. Simulations, considering the series and shunt parasitics, showed ideality factor values of 6.9 and 22.4 at 300 K and 200 K respectively. These values were compared with those extracted from the dark current-voltage curves which are 6.5 and 28.2 at the same temperatures. The large ideality factor in this system (particularly at low temperature) was attributed to the presence of high density of interface states (typically ~ $10^{13}$ cm$^{-2}$).

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*Keywords:* Heterojunction diode, Ideality factor, Interface states

## 1. Introduction

Ideality factor is an important parameter in identifying the current transport mechanisms and interfacial properties of heterojunction devices. In particular, the evaluation of the ideality factor versus temperature can give valuable information about the main recombination route in the devices [1].

The values of the ideality factor (*n*) could be estimated directly from the current-voltage (*I-V*) data by calculating the slopes of the straight-line portions of dark log *I vs. V*, ignoring the effects of series and shunt resistances. However, the dark *I-V* characteristics of most of heterojunction solar cells are fully described by an equivalent circuit containing series and shunt resistances elements [2].

During the last decade, several methods have been suggested for extracting the value of *n* from *I-V* characteristics with considerable series and shunt resistances. Some of these methods use the illuminated *I-V* data and the subsequently calculated conductance of the devices [3,4]. Other methods are based on numerical analysis [5,6] and on the Co-content function [7] from the exact explicit analytical solutions of the illuminated *I-V* characteristics. An analytical extraction of the diode ideality factor from illuminated experimental data is also reported by Phang et al. [8].

Recently, Jain and Kapoor [9] have proposed a simple analytical method using Lambert W-function to express the transcendental illuminated current-voltage characteristics of a real solar cell device. Bayhan and Kavasoglu [10] presented a new analytical method for extracting the ideality factor of a p-n junction device using Lambert W-function model and the dark current-voltage data. The extracted values by this method were found to be in good agreement with those calculated experimentally from dark current-voltage characteristics.

In the present work, an analytical method is followed to estimate the ideality factor of ZnTe/CdTe p-p heterojunction. The results, then, would be compared with those obtained from the dark *I-V* characteristics at two different temperatures.

## 2. Theory

The dark forward current of a typical non ideal diode neglecting the effects of series and shunt resistances can be expressed by the relation [11];

$$I = I_o\left[\exp\frac{qV}{nkT}\right] \tag{1}$$

where $q$ is the electronic charge, $k$ is the Boltzmann constant, $T$ is the absolute temperature. The reverse saturation current $I_o$ is a temperature dependent and is usually described by thermionic emission theory as

$$I_o = A^* A\, T^2 \exp\left[\frac{\Phi_b}{kT}\right] \tag{2}$$

where $A^*$ is the Richardson constant, $A$ is the area of the diode and $\Phi_b$ is the barrier height. Under forward bias conditions $I_o$ is considered to be negligibly small with respect to the forward current.

Putting into account the effects of both series and shunt resistances, the complete description of the dark forward current of a typical junction diode can be expressed according to the relation [12];

$$I = \frac{V - IR_s}{R_{sh}} + I_o\left[\exp\left(\frac{q(V - IR_s)}{nkT}\right) - 1\right] \tag{3}$$

where $R_s$ and $R_{sh}$ are the series and shunt resistances respectively. Solution of this equation for $n(I)$ is simply given by the relation;

$$n = \frac{q(V - IR_s)}{kT\left[\ln\left(I\left\{1 + \frac{R_s}{R_{sh}}\right\} - \frac{V}{R_{sh}} + I_o\right) - \ln I_o\right]} \tag{4}$$

For a heterojunction device, an equation containing *n* and *I* can be determined by substituting the experimentally determined values of $I_o$, $R_s$, $R_{sh}$ and $V$ into equation (4).

## 3. Calculations and discussion

Fig. 1 shows the experimental data of the dark forward *(I-V)* characteristics of ZnTe/CdTe heterojunction at two temperatures; 300 K and 200 K. It is obvious that the current increases non-linearly with the applied voltage and the slope of the curves is increasing with rising of the temperature. It is well known that moderately doped heterojunctions with large band-discontinuities are generally rectifying [13]. Chandra and Eastman [14] showed that lightly doped n-AlGaAs/n-GaAs heterojunctions exhibit rectifying behavior. Forrest and Kim [15] showed that n-InGaAs/n-InP heterojunctions exhibit rectifying behavior. On the other hand, for p-p heterojunctions, rectifications take place in many systems, for example, Sweyllam et al. [16] demonstrated that p-ZnTe/P-CdTe heterojunctions exhibit rectification in temperature range down to 200K.

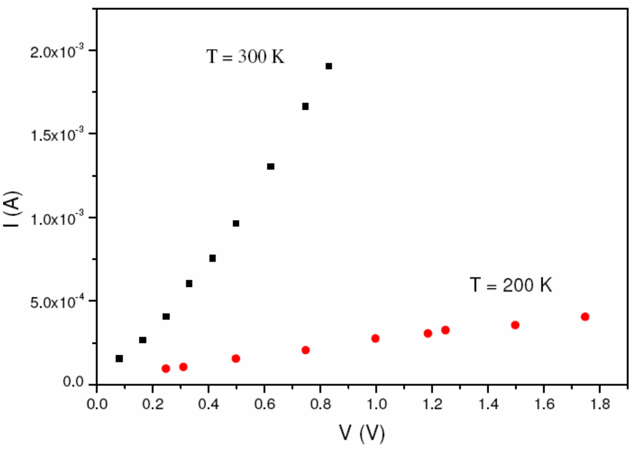

*Fig. 1. The dark forward I-V characteristics of p-ZnTe/P-CdTe heterojunction at 300 K and 200 K.*

Equation (1) can be used to calculate the value of the diode ideality factor from the slope of the linear region of ln $I$ vs. $V$ plots. Fig. 2 shows the plot of ln $I$ versus forward bias voltage at two selected temperatures 300 K and 200 K. From this plot the obtained values of $I_o$, *n* and the slope of the line ( $q / nkT$ ) at the two temperatures are shown in Table 1.

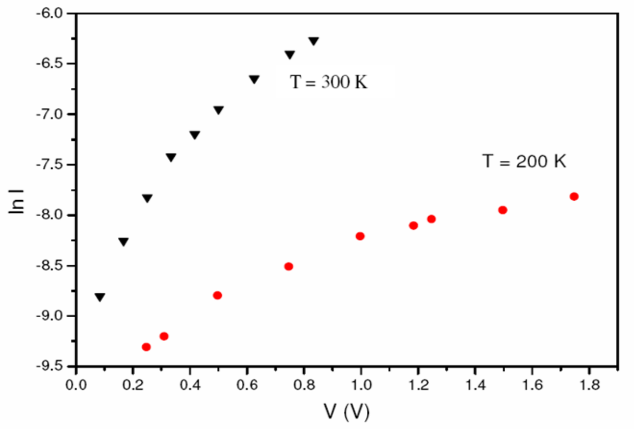

*Fig. 2. ln I versus V at 300 K and 200 K.*

*Table 1. Values extracted from the experimental characterization at 300 K and 200K.*

| T (K) | $I_o$ (A) | *n* | $q / nkT$ |
|---|---|---|---|
| 300 | $9.14 \times 10^{-5}$ | 6.5 | 6.00 |
| 200 | $6.44 \times 10^{-5}$ | 28.2 | 2.05 |

In an attempt to verify the value of the ideality factor, simulations using equation (4) were performed. The values of $I_o$, $R_s$, $R_{sh}$ and $V$ used in the calculations are listed in Table 2.

*Table 2. Values used in the simulations at 300 K and 200 K.*

| Quantity | Value at 300 K | Value at 200 K |
|---|---|---|
| $I_o$ (A) | $9.14 \times 10^{-5}$ | $6.44 \times 10^{-5}$ |
| $R_s$ (Ω) | 10 | 10 |
| $R_{sh}$ (Ω) | $2.3 \times 10^{5}$ | $2.3 \times 10^{5}$ |
| *V (V)* | 0.4 | 0.4 |

Fig. 3 demonstrates typical plots of *n* as a function of *I* at the two temperatures. Values of *n* are deduced from the figure. At T = 300 K the current corresponding to V = 0.4 V is 0.7 mA and then the value of n is 6.9 while at T = 200 K the current corresponding to V = 0.4 V is 0.12 mA and the ideality factor is 22.4.

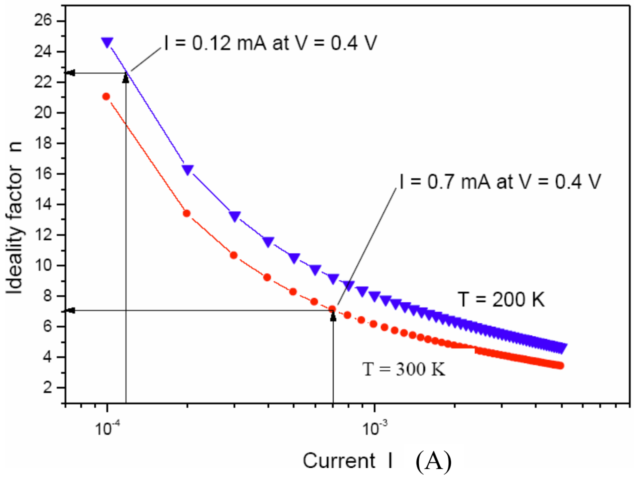

*Fig. 3. Ideality factor as a function of current at 300 K and 200 K.*

It is clear that the theoretical values are in good agreements with that obtained from the experimental characterizations. On the other hand, it is recorded that the values of *n* depend strongly on the temperature. The high values of *n* for ZnTe/CdTe system, particularly at low temperature, may be attributed to the presence of high density of interface states. It was reported by Alfaramawi et al. [17] that the density of state in ZnTe/CdTe heterojunction is of order of $10^{13}$ $cm^{-2}$ for such system. This high value of the interface states density plays an important role to the current mechanism. They act as hole traps and then recombination–generation through the junction space region will take place. This may lead to the high temperature dependence of the ideality factor.

## 4. Conclusions

An analytical method was performed to calculate the ideality factor of ZnTe/CdTe p-p heterojunction diodes at 300 K and 200 K. This method was shown to be applicable for the determination of the ideality factor for such system. Good agreements with the values extracted from the experimental forward dark characteristics were obtained. Relatively high values of the ideality factor were deduced particularly at low temperature range. These large values may be explained in terms of the high density of interface states found in such types of heterojunction diodes.

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