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A new view on image-force lowering effect in Schottky junctions

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Abstract – In this paper, the image force lowering effect from Schottky barrier anomalities in metal-semiconductor contacts has been viewed in based of an Al/p-Si Schootky junction and has been presented a new consideration that is; the dielectric constant should be a function of the temperature.Thus, it was seen that the image force lowering values in two separate temperature have increased in the low temperature despite decrease for ε_s =11.8 constant value at 300 K. In addition, the values of the image force lowering have been obtained as 33.0 meV for 200 K and 16.0 meV for 300 K.

Keywords – Schottky Diodes, Schottky Baarier Inhomogeneities, Dielectric Constant, Image-Force Lowering Effect, Si

I. INTRODUCTION

The interface layer in which is between the metal and semiconductor is an effective layer in Schottky junctions and it affects the stability, reliability and performance of the diode. The position of the electrical charges existing in the interface, the composition, quality and non-stoichiometric structure of the interface induce the interface states. Schottky barrier anomalies in barrier are due to the interface states and they are effective on the other all barrier parameters such as ideality factor and barrier height. It is known that a device which does not have an interface with an abrupt junction is under the ideal contact conditions, and in these cases that ideality factor is 1 and the barrier height is constant; its current mechanism is through of the thermionic emission. However, the current transport mechanism under non-ideal conditions deviates from the thermionic emission theory.

So far, the a lot of the experimental studies have presented that the measured I-V curves demonstrate that there are excess currents, which arise from some current transport mechanisms such as thermionic-field emission and field emission additionally to the thermionic emission current in the junction [1-5]. These excess currents can flow through the barrier and it depends on characteristic parameters such as the temperature of the device, the concentration of dopants, the applied bias, the properties of junction and interface. Consequently, due to these anomalies, ideality factor has the bigger values from one and the barrier height is not stable as a function of the temperature, as the barrier parameters [1].

The other parameter influenced from Schottky barrier inhomogeneities is image force lowering effect. The image-force lowering is a lowering of metal-semiconductor barrier arising from image force interaction with the field at their interface. The barrier height according to image-force lowering effect is written as [1,2],

$$\emptyset_b = \emptyset_b^0 - \Delta\emptyset_b \qquad (1)$$

where $\emptyset_b$ is the barrier height, $\emptyset_b^0$ is the zero bias barrier height and $\Delta\emptyset_b$ is the barrier lowering due to image force lowering effect. Thus, $\Delta\emptyset_b$ is given as [1,2],

$$\Delta\emptyset_b = \left[\frac{qN_i}{8\pi^2\varepsilon_s^3}\left(\emptyset_b - V - \in - \frac{kT}{q}\right)\right]^{1/4} \qquad (2)$$

where $\in$ is the energy difference between the Fermi level and the bottom of the conduction band or the top of the valence band, V is the applied bias, ε_s is semiconductor dielectric constant, N_i is the net ionized state concentration.

The interface region demonstrated the dielectric oxide layer property between metal with semiconductor in the junction plays the important roles over the junction structure and parameters. Moreover, the temperature behavior and the structure of this oxide layer are not known sufficiently. Besides, ε_s semiconductor dielectric constant is related to with behaviors of interface layer and the depletion layer.

So far, in experimental studies upon metal-semiconductor junctions to calculate the image-force lowering effect, ε_s semiconductor dielectric constant has been considered as a constant parameter that is independent from the temperature [1-9] and as a result, it has been seen that the image-force lowering values decrease with decreasing temperature [8]. Finally, it has been reported that Eq. (2) is unsuccessful [7-9].

ε_s semiconductor dielectric constant plays an important role in correctly determination of image-force lowering and N_i net ionized state concentration values as seen in Eq. (2). In this paper is suggested a technique to determine ε_s dielectric constant for anyone measurement temperature in metal semiconductor contact structures. The obtained equation and the method were used for 200 K and 300 K temperatures of an Al/p-Si sample [10] and their ε_s dielectric constant and image-force lowering values were calculated in this research.

II. Materials and Method

Basic Equations

However, in literature on the metal-semiconductor contact structures is widely known that the effect of interface anomalies increase with decreasing temperature and consequently the image-force lowering values must increase in the low temperatures [1,2]. Therefore, to consider as an independent parameter from the temperature in Schottky contacts is not meaningful for ε_s. In a lot of thin film studies separately from the metal-semiconductor contacts, ε_s semiconductor dielectric constant values can be calculated as a function of the temperature using the different charge-transport mechanisms [11-14].

The charge-transport mechanisms in various materials are explained with models such as Schottky, Pool-Frenkel and the charge-limited conduction mechanisms [1,2,6-18]. It is known that Schottky effect and Pool-Frenkel effect are the mechanisms used frequently in thin dielectric films and in the semiconductors [1,2,6-17].

Schottky effect is the image force lowering effect arisen from a process occurring in the interface of the metal with semiconductor (or insulating film) as a result of the image force and the applied bias effect [1,2]. Moreover, Schottky conduction is an electron-limited conductivity mechanism that occurs with fewer defects. However, Pool-Frenkel effect has an analogy effect to well-known Schottky effect. Pool-Frenkel effect occurs with field-assisted thermal ionization and it is a Coulombic potential barrier lowering [18]. In experimental studies, to comment the current transport properties in reverse direction of the diodes is reported that Pool-Frenkel effect is a dominant current transport mechanism in reverse direction [11-13]. Therefore the general I-V expression of Pool-Frenkel effect can be written as [19],

$$I = AA^{*}exp\left(-\frac{q\emptyset_b}{kT}\right) exp\left(\frac{q\beta_{PF}}{kT}\sqrt{\frac{V_r}{d}}\right) \tag{3}$$

where V_r is the applied reverse bias, β_{PF} is Poole-Frenkel constant known as $\beta_{PF} = (q/(\pi\varepsilon_0\varepsilon_s))^{1/2}$ and d is width of the depletion layer and it is written as,

$$d = \left(\frac{2\varepsilon_0\varepsilon_s(V_0-V_r)}{qN_i}\right)^{1/2} \tag{4}$$

where V_0 is the diffusion potential which is determined from extrapolation of a linear $1/C^2$-V_r plot.

In reverse direction in experimental studies made upon thin solid films [11-13] and metal-semiconductor contact [20] is expressed a linear behavior in the curves when is plotted the reverse current versus in form of $V_r^{1/2}$ applied bias. In consequence, experimental ε_s dielectric constant for thin films is obtained as a function of the temperature with using as d sample thickness from slope of this plot [11-13]. However, experimental ε_s dielectric constant for metal-semiconductor contact structures is not obtained using this method and it is reported as a constant parameter for everyone semiconductor sample [1,2,6-9].

The semiconductor depletion layer in Schottky diodes yields the differential capacitance. According to the depletion approximation, the measured differential capacitance is given as [19],

$$\frac{1}{C^2} = \left(\frac{2(V_0+V_r)}{q\varepsilon_s N_i A^2}\right) \tag{5}$$

N_i net ionized state concentration may be calculated classically from slope of C^{-2}-V_r plot with using a constant value of ε_s for semiconductor. However, if one considers that ε_s should vary as a function of the temperature separately from this consideration, then Eq. (6) may be re-considered as,

$$\varepsilon_s N_i = \left(-\frac{2}{qA^2\varepsilon_0\frac{d(1/C^2)}{dV}}\right) \tag{6}$$

If one use in Eq. (3) to Eq. (4) with Eq. (6), then Eq. (3) may be re-written as,

$$lnI = lnI_{PF} + \frac{q\beta_{PF}}{kT\varepsilon_s^{\frac{1}{2}}\left(\frac{2\varepsilon_0}{qm}\right)^{\frac{1}{4}}}\left(\frac{V_r}{(V_0-V_r)^{\frac{1}{2}}}\right)^{\frac{1}{2}} \tag{7}$$

Therefore, according to Eq. (7) may be plotted ln I versus $\left(V_r/(V_0-V_r)^{1/2}\right)^{1/2}$ variation and experimental ε_s dielectric constant from slope of this plot may obtained.

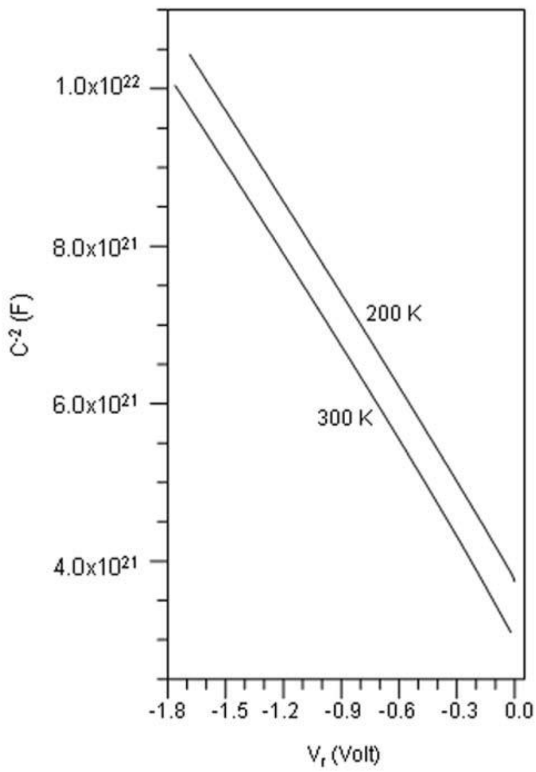

Figure 1. Plot of C^{-2} versus V_r in 200 K and 300 K for a Al/p-Si sample [16].

III. Results and discussions

To obtain ε_s dielectric constant values from Eq. (7) was used I-V_r and C-V_r measurements for 200 K and 300 K temperatures of a Al/p-Si sample.

Fig. 1 shows C^{-2}-V_r plot for 200 K and 300 K temperatures of Al/p-Si. In Fig. 1 C^{-2}-V_r plot is fairly linear for two temperature values. This linear variations present that is low of effects as the series resistance, the deep levels which are electrically active in semiconductor and the minority carriers [20]. From Fig.1 V_0 diffusion potential and N_i net ionized state concentration values was calculated as 0.97 eV, 9.28x10^{15} cm^{-3} for 200 K and 0.81 eV, 9.29x10^{15} cm^{-3} for 300 K respectively.

Fig. 2 presents ln$I$ versus $\left(V_r/(V_0-V_r)^{1/2}\right)^{1/2}$ plot for 200 K and 300 K temperatures of Al/pSi. As seen in Fig. 2, this variation is fairly linear for two temperature values. ε_s values using Eq. (7) was calculated as 8.21 for 200 K and 11.04 for 300 K. This value is reported as 11.8 for Si [2]. The calculated 11.04 value for ε_s value in 300 K is near to 11.8 value of Si. Besides, the barrier height

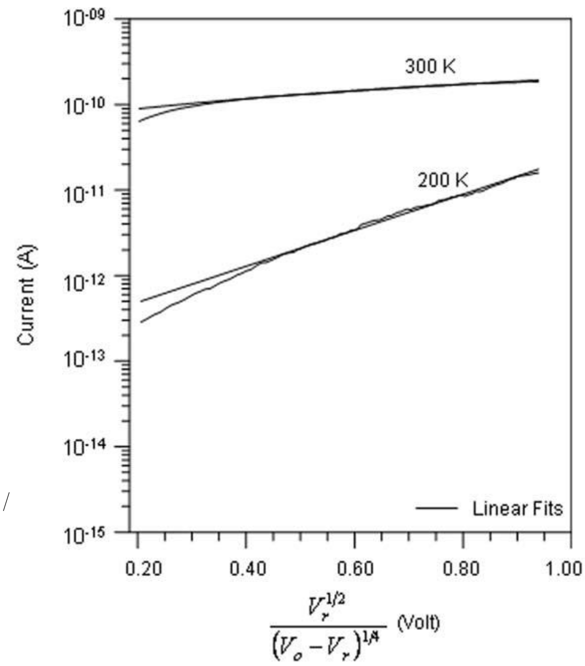

Figure 2. Curves of semi-log(I) versus $V_r^{1/2}/(V_o-V_r)^{1/4}$ in 200 K and 300 K for a Al/p-Si sample [16] and their linear fits.

parameters as the N_i net ionized state concentration and $\emptyset_b$ barrier height values with aiding Eq. (7) using 8.21 and 11.04 values for ε_s was calculated as $3.60\text{x}10^{15}$ cm^3, 1.08 eV for 200 K and as $9.35\text{x}10^{14}$ cm^{-3}, 0.95 eV for 300 K, respectively. However N_i and $\emptyset_b$ values was obtained as $7.87\text{x}10^{14}$ cm^{-3} and 1.11 eV for 200 K and as $7.87\text{x}10^{14}$ cm^{-3} and 1.02 eV for 300 K classically using ε_s =11.8 value of Si .

Image-force lowering values may be calculated using Eq. (2). In consequence, it was obtained as 13.1 meV for 200 K and as 13.7 meV for 300 K with 11.8 constant value of ε_s for Si using Eq.(2) from Fig.1. However, image-force lowering values was calculated as 33.0 meV for ε_s =8.21 in 200 K and 16.0 meV for ε_s =11.04 in 300 K with aiding above expressed new method from Fig.1 and Fig.2.

IV.CONCLUSION

In metal-semiconductor contact studies is a reality that the effect of barrier inhomogeneities have increased in the low temperatures. Therefore is expected that the image force lowering values increase in low temperatures such as behavior of the ideality factor.

In this study was reported a new idea for the behavior of the image force lowering in two separate temperate using an Al/p-Si sample. In consequence was demonstrated that ε_s should be as a function of the temperature. Therefore was seen that the image force lowering values in two separate temperature have increased in the low temperature despite decrease for ε_s =11.8 constant value. To present as the more general to behavior of ε_s and the image force lowering effect in different temperatures is not clear at the present study and further experiments are in progress.

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