ELECTRICAL CHARACTERIZATION OF Au, Al, Ag, ON GaAs SCHOTTKY DIODES

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ABSTRACT

From the extended Norde plot and the current-voltage measurements, Schottky barrier diodes parameters, namely barrier height, ideality factor and series resistance have been compared with the results previously obtained by other workers. The discrepancy between the present results and those previously published is attributed to the effect of both, the quantum mechanical tunneling and the image force barrier lowering.

INTRODUCTION

The most common theory of Schottky barrier diode is based on the thermionic emission model. According to this model the current voltage relationship is given by:

$$I = I_s \{\exp [\beta(V-RI)/n]-1\} \quad (1)$$

with

$$I_s = SA_oT^2 \exp (-\beta\phi_B) \quad (2)$$

where R is the series resistance of the diode, $\beta = q/KT$, S is the area of the diode, A_o is the modified Richardson constant, n is the ideality factor, ϕ_B is the barrier height, and I_s is the saturation current.

For a diode without a series resistance and an ideality factor $n = 1$, the barrier height can be determined by making a ln I vs V plot, this plot will be a straight line whose extrapolated intercept with the zero voltage axis gives I_s. From this I_s value, ϕ_B can be calculated, if A_o is known. If A_o is not known, then two I vs V plots at two different temperatures are necessary to determine A_o. Difficulties will arise, however, if the base material presents a series resistance R to the diode. The straight line part of the plot will then be confined to the voltage interval

$$KT/q << V << IR$$

If the series resistance is large, the linear portion of the plot may disappear and the above graphical method becomes useless. In this case, methods such as numerical curve fitting procedure has to be developed in order to rely on it. Recently some methods were proposed [1-2] to circumvent the presence of high series resistance and to allow the determination of the diode parameters even when a straight portion of the ln I vs V curve is missing. In the original method, Norde [1] introduced an auxiliary function F(V):

$$F(V) = (V/2) - (1/\beta) \text{Ln} (I/SA_o T^2) \quad (3)$$

He considered a simplified case, where $n = 1$ and A_o was known.

The plot of this function showed a minimum and from the position of this minimum, R and ϕ_B can be determined. The original method was extended by other authors [2-5] to the case where the ideality factor was greater than 1 and unknown.

In the present work, the measured I vs V characteristics are used to compare between various approaches to determine the Schottky barrier parameters. Discrepancies between the present results and those previously published will be discussed.

THEORETICAL APPROACH

Norde [1] in his method assumed that $V_D >> KT/q$, where V_D is the voltage across the diode. Eqs. (3) and (1), will give:

$$F(V) = \phi_B + IR - (1/2)V \qquad (4)$$

For the ideal case where R = O, F(V) is a straight line with slope = -1/2 and the extrapolated intercept with F(V) axis gives the barrier height ϕ_B. If, on the other hand there is only a resistance R, we will get

$$F(V) = F_R(V) = (V/2) - (1/\beta) \ln (V/(RSA_oT^2)) \qquad (5)$$

For large voltages this will approach a straight line with slope = +1/2. Evidently, the actual F(V) will be close to the ideal case for small current values, and will approach the $F_R(V)$ curve for large current values. Somewhere between these two extremes F(V) will have a minimum which is the point of interest and from the position of this minimum, the Schottky barrier parameters R and ϕ_B, can be determined.

Differentiating Eq. (4) with respect to voltage and equating dF/dV to zero, Norde obtained an expression for I_o which is the current at the minimum of F(V) and is given by

$$I_o = (1/\beta R) = (KT/qR) \qquad (6)$$

The corresponding voltage V_o is

$$V_o = (1/\beta) + \ln (I_o/SA_oT^2) \qquad (7)$$

and the minimum value of F(V) becomes

$$F(V_o) = (V_o/2) - (1/\beta) \ln (I_o/SA_oT^2) \qquad (8)$$

using the measured values of I_o, V_o, and $F(V_o)$ and Eqs. (6)-(8), Norde obtained.

$$R = (KT/qI_o) \qquad (9)$$

and

$$\phi_B = F(V_o) + (V_o/2) - (KT/q) \qquad (10)$$

Manifacier et al. [2] method lead to a graphical procedure for the evaluation of ϕ_B, n and R. Manifacier started with a simple function F(I):

$$F(I) = V - R_oI \qquad (11)$$

where R_o is an adjustable parameter. It is clear that this function will have a maximum for a certain value I_M of the diode current I as long as the R_o value is chosen such as to have an intersection point with the diode vs V plot. This intersection point is obtained for a R value such that

$$R_{dif(I = O)} > R_o > R \qquad \text{(12}$$

where, $R_{dif(I = O)}$ is the diode differential resistance i the limit of zero current

$$R_{dif(I = O)} = R + (n/\beta I_s) \qquad \text{(13}$$

for voltages such that $\beta(V\text{-}RI)/n > 3$ we have

$$\ln (I/I_s) \approx \beta (V\text{-}RI)/n \qquad (14)$$

and

$$F(I) = (n/\beta) \ln (I/I_s) + (R\text{-}R_o)I \qquad (15)$$

the maximum value F is obtained for

$$dF/dI = (n/\beta)(1/I) + (R - R_o) = 0 \qquad (16)$$

giving

$$I_M = (n/\beta) [1/(R_o\text{-}R)] \qquad (17)$$

using two different values for R_o which satisfy Eq. (12), the values of n and R are easily obtained

$$R = (R_{o2}\, I_{M2} - R_{o1}\, I_{M1})/(I_{M2} - I_{M1}) \qquad (18)$$

$$n = \beta\, I_{MI}\, I_{M2}\, [(R_{o1} - R_{o2})/\, (I_{M2} - I_{M1})] \qquad (19)$$

Eqs.(15) and (2) give

$$F_M = (n/\beta) \ln (I_M/SA_oT^2) + n\, \phi_B - (n/\beta) \qquad (20)$$

Hence

$$\phi_B = (F_M/n) + (1/\beta) [1\text{-} \ln (I_M/SA_oT^2)] \qquad (21)$$

from Eq. (11) the maximum for F corresponds to

$$(dV/dI)I_M = R_o \qquad (22)$$

EXPERIMENTAL PROCEDURE

The GaAs [100] crystals used in these experiments were n-type, the doping concentration was $2.7X10^{18}$ cm^{-3}. Prior to metal deposition, the samples were decreased successively in TCE, acetone and methanol rinsed in DI water, dried carefully and then placed in the vacuum chamber, Edward E306A. Ohmic contacts were formed by successive evaporation of indium followed by silver, then the contacts were annealed for 10 min. at 400°C under N_2 atmosphere. Different front contacts have been formed using Al, Ag, and Au. The metals were evaporated through a shadow mask with circular holes of 1mm diameter.

The metals layers were evaporated from either a tungsten filament or a molybdenum boat at a pressure of about 10^{-5}mb. The technological para-meter for the contact metals are shown in table I.

Table I. Technological parameters for the contact metals.

Front contact	Al	Ag	Au
annealing temperature	150°C	150°C	100°C
annealing time	4 min	5 min	3 min

RESULTS AND DISCUSSIONS

I-V characteristics for Schottky diodes were obtained by metallizing the GaAs wafers with three different metals namely Au, Al, and Ag for a bias voltage up to 1.0 volt. The plot of these characteristics are shown in Figures (1), (2) and (3). Taking $A_o = 8.1$ A cm^{-2} K^{-2}, and $T = 300$ K, the Schottky barrier parameters were determined by two methods namely Norde's method (first method) and Manifacier et al., method (second method).

In the first method the series resistance and the barrier height are determined. By drawing F(V) vs V according to Eq. (3), the minimum value $F_m(V)$ can be determined as shown in Figure (4) for the different diodes.

The minimum value of F(V) vs V curve, is used to determine the minimum values of voltage and current V_o and I_o, for the different Schottky diodes. These values of voltages and currents were used in Eqs. (9) and (10), to obtain the values of the series resistances and the barrier heights of the diodes.

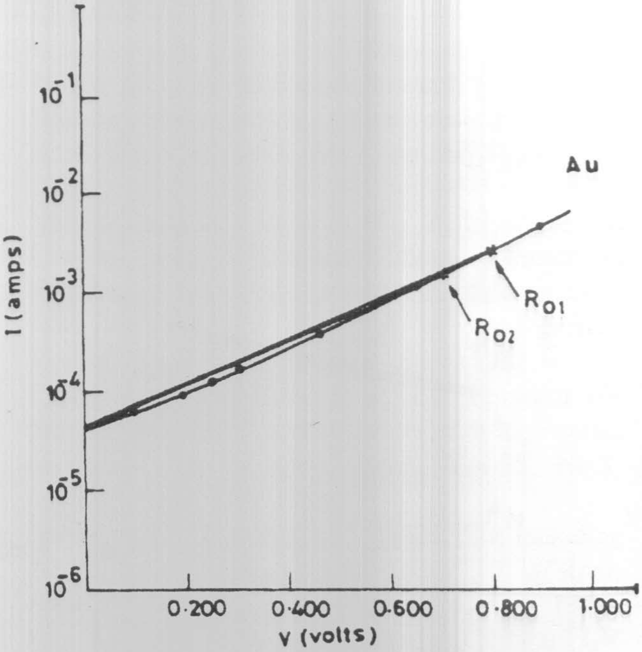

Figure 1. Measured current-voltage characteristics of Au-contact with R_o values at two points.

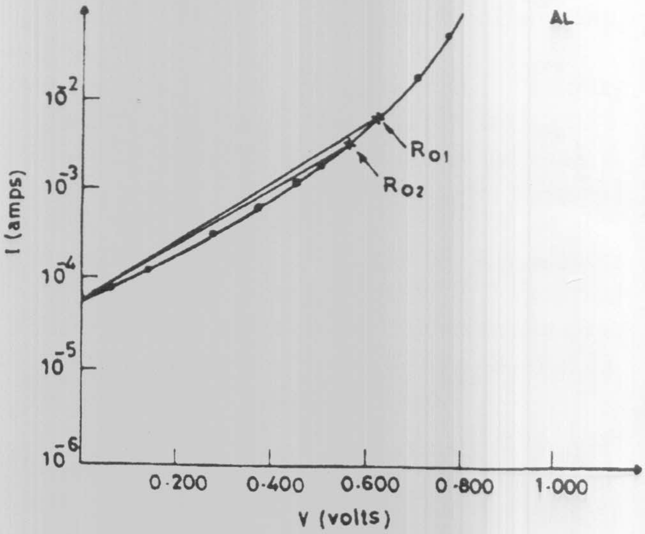

Figure 2. Measured current-voltage characteristics of AL-contact with R_o values at two points.

In the second method, the diode parameters, series resistance, barrier height and ideality factor for each Schottky diode has been determined. The R_o values included in Eq. (11) were obtained to satisfy the condition $R_{dif(I=O)} > R_O > R$. Two values R_{o1} and R_{o2} have been determined by intersecting the line IR_o with the I vs V characteristic as shown in Figures (1), (2) and (3).

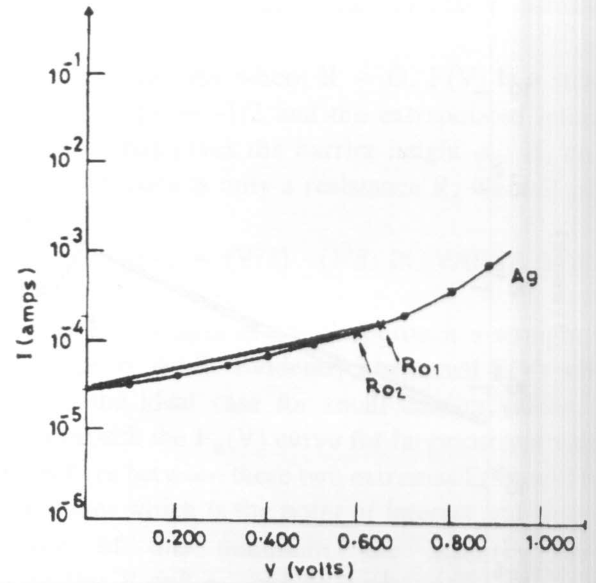

Figure 3. Measured current-voltage characteristics of Ag-contact with R_o values at two points.

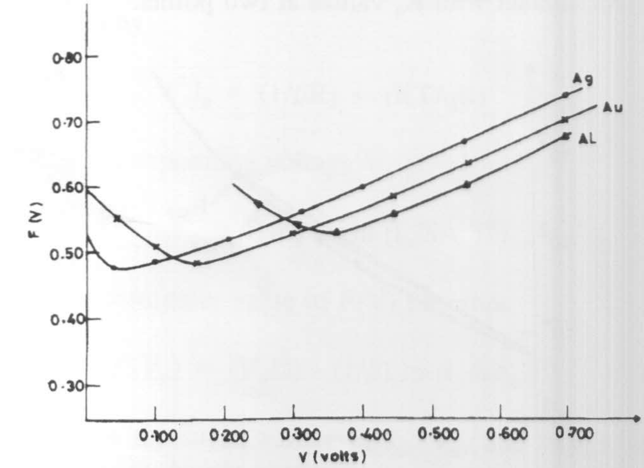

Figure 4. Experimental plots of F(V) vs V fpr the three different Schottky diodes.

For each of the Schottky diodes, the curves F(I) vs I were drawn according to Eq. (11) for R_{o1} and R_{o2} and shown in Figures (5), (6) and (7). From these curves a maximum current I_M could be obtained at the maximum of F(I). The values, R_{o1}, R_{o2}, I_{M1} and I_{M2} were substituted in Eqs. (18-21) to determine the Schottky barrier parameters, namely, the series resistance, the ideality factor and the barrier height.

Schottky diode parameters using measured characteristics and Manifacier et al., method are shown in table II.

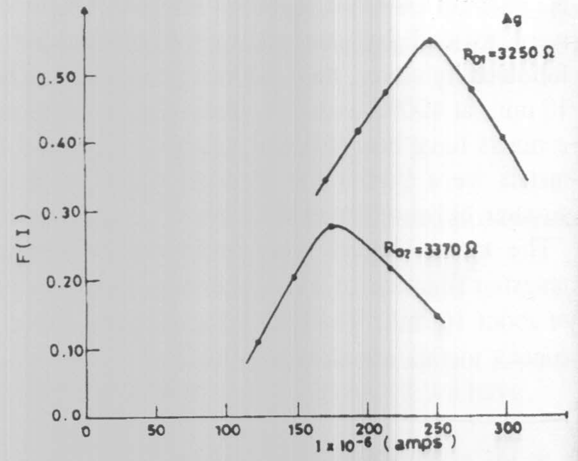

Figure 5. Plot of F(I)-V for the Ag Schottky diode a two values of series resistance.

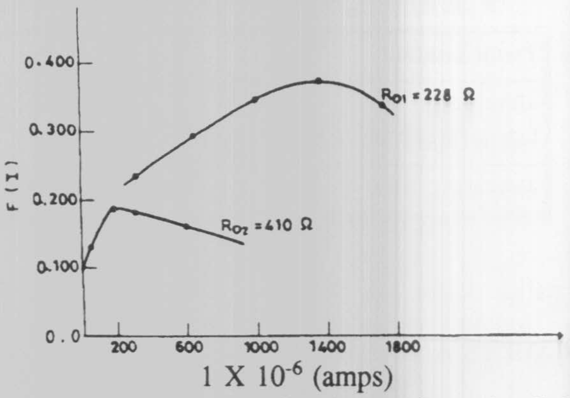

Figure 6. Plot of F(I)-V for the Au Schottky diode at two values of series resistance.

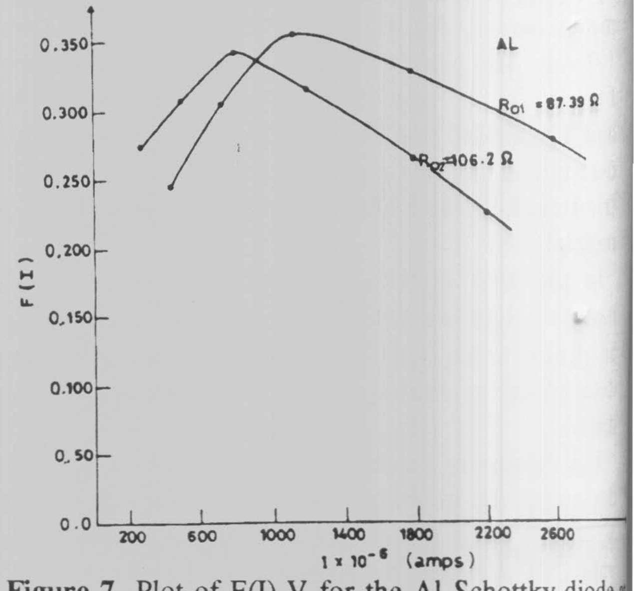

Figure 7. Plot of F(I)-V for the Al Schottky diode a two values of series resistance.

Table II. Schottky diode parameters.

	Al	Ag	Au
ϕ_B	.6068 or .6126	.4485 or .4460	.5727 or .6558
R	37.23	3110	202.456
n	1.43	1.4	1.284

Barrier heights obtained using the present values were smaller than those obtained using C vs V technique by other workers [6,7,8,9] see table III.

Table III. Comparison of the various values of ϕ_B obtained by different workers [6,7,8,9] using C vs V measurements.

Reference Metal	Mc Lean [7]	Newman [8]	Smith [6]	Mead [9]
Ag	0.94-0.96	0.97	0.88	0.90-0.95
Au	0.96-1.02	1.02	0.95	0.33-0.98
Al	0.82-0.86	0.85-0.9	—	0.78-0.81

This discrepancy may be attributed to the difference in nature of the C vs V and I vs V measurement techniques, barriers heights deduced from them are not always the same. In C vs V measurements the differential capacitance of the depletion region induced by a small a.c signal superimposed on a d.c bias is measured. Since only the edge of the depletion layer is modulated, the barrier height is extrapolated by a linear fit to the $1/C^2$ vs. V_a plot, where V_a is the applied bias. Barrier lowering effects which cause band bending to occur close to the metal-semiconductor interface are therefore not probed. On the other hand barrier height measured by the I vs V method which is based on the transport of electrons across the metal-semiconductor interface includes barrier lowering and quantum mechanical tunneling effects, and so an effective barrier height is measured. Image force barrier lowering and quantum mechanical effects may be the main factors contributing to the schottky barrier lowering.

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