ANALYSIS OF I-V MEASUREMENTS ON GaAs SCHOTTKY DIODES WITH Al, Au AND Ag METALLIZATION CONTACTS

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ABSTRACT

A theoretical and experimental study has been made on n-GaAs Schottky diodes in which the metal and semiconductor are separated by a thin interfacial film. A generalized approach is taken towards the interface states which considers their communication with both the metal and the semiconductor. Diodes with different metallization contacts namely Al, Au and Ag were fabricated with interfacial films ranging from 22 A° to 131 A° in thickness, and their characteristics are related to this model. Contributions of other currents such as the generation - recombination and leak currents caused by the inhomogeneities and defects at a biased junction are taken into account. Taking the above mentioned mechanisms in our calculations for the different contact metallization, an outstanding agreement between theory and experiment was obtained.

INTRODUCTION

It is well known that when a metal contact is evaporated onto a chemically prepared n-GaAs surface the metal and semiconductor are not in intimate contact. An interfacial film of atomic dimensions inevitably separates the two. The effect of this film on the characteristics of the contact has been recognized by Turner and Rhoderick [1].

The interface states are usually divided into two groups. One of these groups communicates readily with the metal, the other group with the semiconductor, this is a result of the distribution of the interface states in space as well as in energy over the GaAs forbidden gap.

The densities of interface states in each of these groups are dependent upon the thickness of the interfacial film. For the states that are located at the GaAs/oxide interface, the communication with the metal decreases with increasing film thickness. The wave functions for electrons in the interface states extend over a distance of the same order as the interfacial film thickness. Such a model has been used in the past by Cowley [2]. With this as the starting point, a basis is established for the interpretation of the experimental results. The work relates the properties of the interfacial region to the diode characteristics in a quantitative manner. The charging of the interface states takes place by:

a. Electrons tunnelling between these states and the metal and by

b. Interaction with the electrons in the conduction and valence bands of the semiconductor.

The population of these states is chiefly determined by the process which takes place more readily. Assuming that the states are located at the oxide/GaAs interface, their communication with the metal becomes more difficult as the diode thickness increases. For sufficiently thick films, these states are in equilibrium with the GaAs.

THEORETICAL APPROACH

The I-V characteristic

The forward current in the case of a Schottky contact with an interfacial film for V > 3KT/q is given by [3]

$$I_1 = I_o \exp (qV/nKT) \tag{1}$$

where n is the diode ideality factor, K is the Boltzmann constant, q is the electronic charge, V is the applied voltage, T is the temperature and I_o is the extrapolated saturation current. In the case of a Schottky contact with an interfacial layer the extrapolated current I_o is given by

$$I_o = A\, A^*\, T^2\, \theta_n \exp(-q\phi_{BO}/KT) \qquad (2)$$

where A is the diode area, A* is the effective Richardson constant, (for GaAs $A^* = 8.1\ Acm^{-2}K^{-2}$), ϕ_{BO} is the barrier height at zero bias, θ_n is the transmission coefficient across the thin interfacial layer and is expressed as

$$\theta_n = \exp(-a\, X^{1/2}\, \delta) \qquad (3)$$

where $$a = 2/\bar{h}\, (2\, m_n)^{1/2} \qquad (4)$$

$\bar{h}$ is the modified Planck's constant, m_n is the tunnelling effective mass, X is the mean tunnelling barrier, and δ is the thickness of the interfacial layer where electrons tunnel through.

When the interfacial layer is present, the barrier height $q\phi_B$ which is usually determined from the extrapolated saturation experimental current I_o, is an apparent barrier height. It is given by

$$q\phi_B = KT \ln(A\, A^*\, T^2/I_o) \qquad (5)$$

$q\phi_B$ is related to $q\phi_{BO}$ (zero bias barrier height) through the relation:

$$q\phi_B = q\phi_{BO} + a\, X^{1/2}\, \delta\, KT \qquad (6)$$

Other mechanisms may be present, from which is the generation - recombination current I_2 [4], given by:

$$I_2 = I_{gr}\, [\exp(qV/2KT) - 1] \qquad (7)$$

where

$$I_{gr} = Aqn_i w/2\,\tau \qquad (8)$$

is the generation - recombination saturation current, n_i is the intrinsic carrier concentration, w is the depletion layer width and is the effective electron lifetime.

When other mechanisms of current flow are taken into account, the current is expressed as

$$I = I_1 + I_2 + I_3 \qquad (9)$$

where I_3 is the leakage current characterized by the leak resistance R_L which is determined from the slope of the experimental I-V curve. The expression f

current becomes:

$$I = I_o\, [\exp(q(V-IR_s)/KT)-1] + I_{gr}\, [\exp(q(V-IR_s)$$

$$/2KT)-1] - (V-IR_s)/R_L$$

where the voltage drop on the series resistance introduced into the expression for current.

RESULTS AND DISCUSSIONS

The GaAs [100] crystals used in these experi were n-type, the doping concentration was 2.7 cm^{-3}. The zero bias barrier heights, ideality factor series resistances for the different metallization con were taken from a previous work done by the a [6] are shown in Table (I).

Table I. Schottky diode parameters

	Al	Ag	Au
ϕ_{BO}	0.6126	0.4485	0.6558
R_s	37.23	3110	202.45
n	1.43	1.4	1.284

I-V characteristics for Schottky diodes were obta by metallizating the n-GaAs wafers with three diffe metals namely Au, Al and Ag for a bias voltage u 1.0 volt. The plot of these characteristics are show Figures (1-3) (Thick line). The surface states den D_s has been calculated from the following Eq.[5]

$$D_s = (\epsilon_s/qw)\, [(1-C_2)/(C_2 n-1)]$$

where ϵ_s is the semiconductor permittivity, and C a dimensionless quantity given by

$$C_2 = \epsilon_i/(\epsilon_i + q^2\delta D_s)$$

where ϵ_i is the static permittivity of the interfa layer.

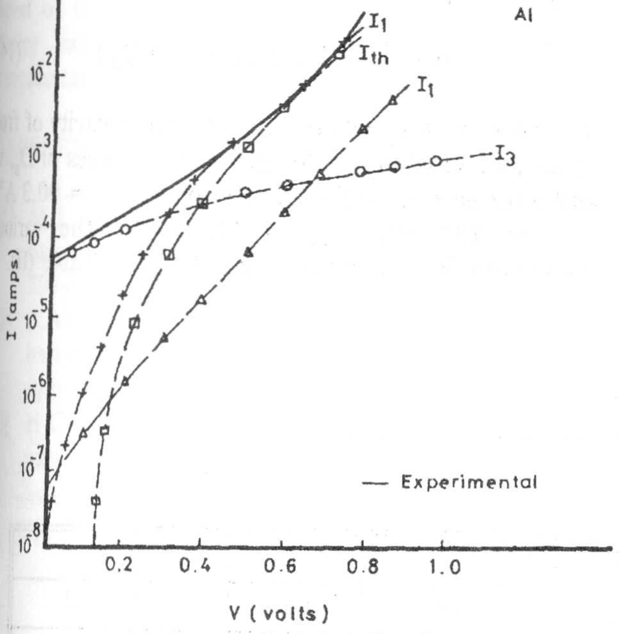

Figure 1. A typical fit of experimental data for the various current components for Al/n-GaAs.

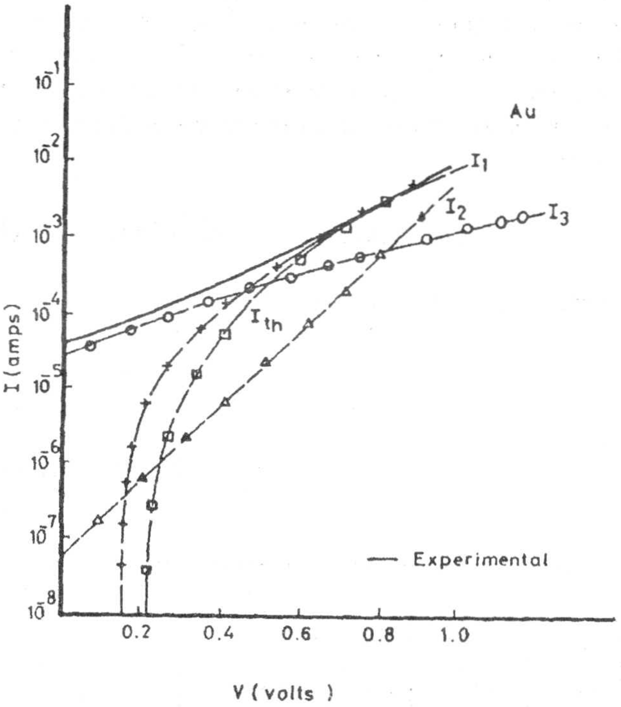

Figure 3. A typical fit of experimental data for the various current components for Au/n-GaAs.

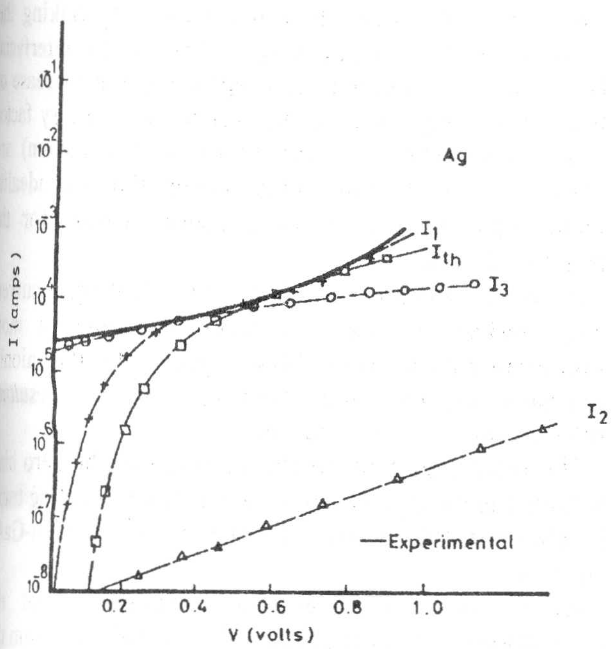

Figure 2. A typical fit of experimental data for the various current components for Ag/n-GaAs.

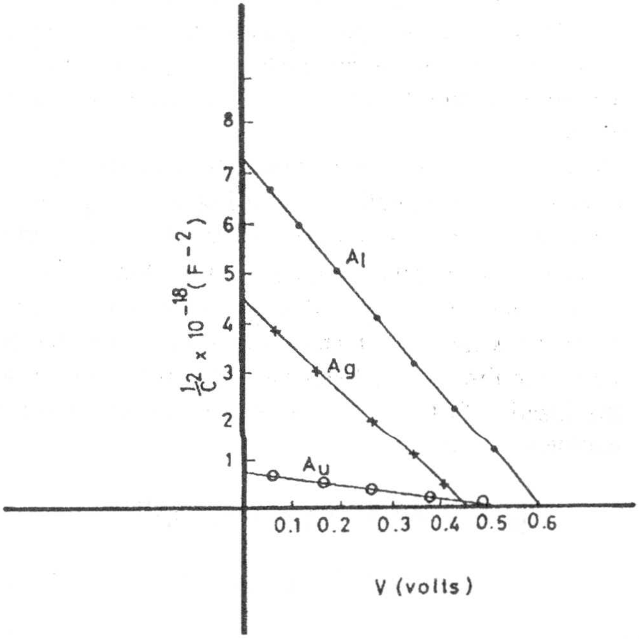

Figure 4. C^{-2} vs V plots for the different metallization contacts fabricated on the same type of substrate n-GaAs.

The C^{-2} vs V plot for the different metallization are shown in Figure (4). We notice from these curves that the slopes are constant, therefore we can deduce that the density of interface states are constant and C_2 can be written as follows from the slope of the C^{-2} vs V plot [5].

$$C_2 = 2/[q\epsilon_s N_D A^2 (dC^{-2}/dV)] \qquad (13)$$

where N_D is the doping concentration
C_2 = 0.53, 0.64, 0.70 for Al, Ag and Au metallization respectively. The ideality factor c be given as [5]

$$n = 1 + \delta/\epsilon_i [\epsilon_s/w + q D_s]$$

Taking $\epsilon_i = 4 \epsilon_o$ where ϵ_o is the permittivity space and substituting the appropriate values of and n for each metallization we found δ_{AL} = 90 δ_{Ag} = 131 A°, δ_{Au} = 22.3 A°. The parameters for the contacts are shown in Table

Table II. Various parameters for MIS diodes on n-GaAs.

	n	C_2	$\Delta\phi$	$wx10^{-5}$	$D_s x10^{10}$	$\delta/\epsilon_i x10^{16}$	δ(A°)	V_o	θ_n
Al	1.43	.53	.134	2.6	52.96	2.54	90.3	.60	181.2
Ag	1.40	.64	.0146	4.7	53.36	3.69	131	.44	1.75
Au	1.28	.70	.176	9.95	20.95	6.20	22.3	.53	897.8

θ_n has been determined from Eq. 2 for each metallization, from the experimental curves. Having determined θ_n and δ for each metallization the mean tunnelling barrier height X has been calculated for each metallization.

The various calculated conduction mechanisms are shown for each metallization in Figures (1-3) where I_1 is the thermionic - emission current when the interface-states have been taken account of i.e taking the barrier as $q\phi_B$ and I_{th} is the thermionic emission current without taking the interface states into consideration, i.e taking the barrier height as $q\phi_{Bo}$ but incorporating the ideality factor n in the expression of thermionic emission current i.e

$$I_{th} = A A^* T^2 \exp[(-q\phi_{Bo})/(KT)] \exp [q(V - I_{th} R_s)/(nKT)] \qquad (15)$$

I_2 is the generation recombination current and I_3 is the leakage current.

I noticed that when I took the interface states into consideration an outstanding agreement between theory (I_1) and experiment (thick line) was achieved.

Moreover I noticed that the curves I_1 (takin increase of the barrier height due to the inter layer into account) and I_{th} (neglecting the incre the barrier height but incorporating the ideality n into the expression for thermionic emission identical at high bias. This means that the id factor calculated is a good representation fo interfacial layer.

It is a matter of fact that leakage cu characterized by the resistance R_L plays a important role at lower biases, while the thermi emission current gets dominant in the res relationships at higher biases.

The main argument of the increase in the zero barrier height ϕ_{Bo} is due to electrons tunnelling localized in the interfacial layer close to the n- surface.

Hence we may make a conclusion that fluctuations of the experimental data deduced fro fabricated Schottky barrier diodes with diff fabricating conditions are mainly due to the varia of the interfacial layer properties such as the inte layer thickness, density of the surface states and energy level of the surface states [7] and that the ideality factor calculated by Norde plot [8] is a good representation of the interfacial layer.

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