MODULATION EFFECT DUE TO THE INJECTION OF MINORITY CARRIERS IN GaAs SCHOTTKY

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ABSTRACT

The forward I-V characteristics of n - GaAs(100) Schottky barrier diodes for different metallizations have been studied up to high current densities. Modulation has been observed in these experiments. Conductivity has been determined as function of the current density. In accordance with Scharfetter, Jager and Kosak, we found that the modulation increases with the barrier height. Although in contradiction with Manifacier, we found that modulation exits even for low resistivity substrate.

INTRODUCTION

Schottky barrier diodes are majority carriers devices. In view of this, Schottky - diodes have been analyzed as one carrier system [1-2]. In some cases however, deviations from the pure majority carrier conduction behaviour are observed. Several authors [3-4] pointed out that hole injection may considerably contribute to the forward current of Schottky diodes.

From the thermionic-emission-diffusion theory, the J-V characteristics for majority carriers is given by [1]

$$J = A^{**} T^2 \exp(-q\phi_B/KT)(\exp(qV/KT)-1) \qquad (1)$$

Where A^{**} is the effective Richardson constant and ϕ_B is the effective barrier height for electrons, taking into consideration the barrier lowerings (the image force barrier lowering and the quantum-mechanical tunnelling lowering).

Approximating this equation for $V > 3KT/q$ and taking into account the dependence of A^{**} and ϕ_B on the applied voltage V, Eq.(1) is reduced to

$$J = J_s \exp(qV/nKT) \qquad (2)$$

Where J_s is the saturation current density and n is a constant usually close to unity, called the ideality factor of the diode.

The minority carrier injection ratio γ was evaluated by Scharfetter [3] in the high injection range as

$$\gamma = J_n / J_p + J_n = ni^2 . J_n / b N_D^2 J_s \qquad (3)$$

Where J_n is the electron current density, J_p is the hole current density, n_i is the intrinsic concentration, N_D is the doping concentration, and b is the mobility ratio = μ_n/μ_p where μ_n and μ_p are electron and hole mobilities.

Scharfetter has pointed out that the minority carrier injection ratio is low and constant at low current densities, but increases linearly with J_n at elevated current densities. This increase is caused by the electric field appearing in the neutral zone of the diode, i,e in the epitaxi-layer adjacent to the space charge region as shown in Figure (1). At very high hole injection, γ increases to its upper limit,

$$\gamma_{max} = \mu_p / \mu_n + \mu_p \qquad (4)$$

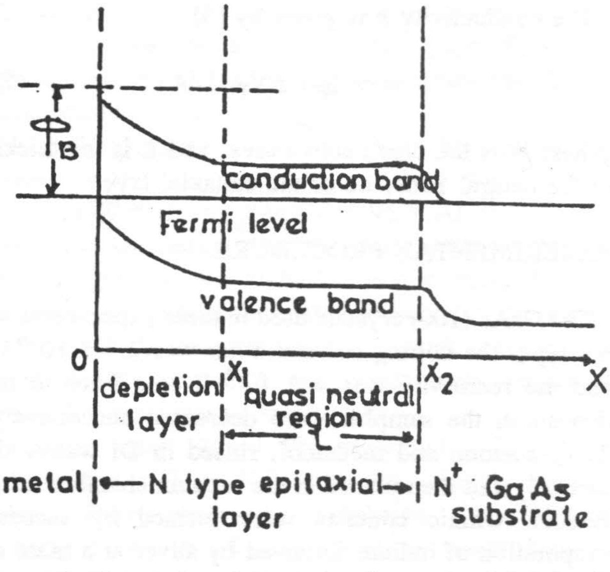

Figure 1. Energy-band diagram of an epitaxial Schottky barrier diodes. [3].

Due to this hole injection, the forward characteristic of the Schottky diode deviates markedly from its usual shape, and so modulation can be observed, i,e a decrease of the series resistance of the neutral region with the increase of the forward current, and this is only possible by the increase of the charge carriers in the neutral zone [5-6].

THEORETICAL APPROACH

The effect of "modulation" of the neutral zone conductivity has to be separated quantitatively from the basic data of the forward characteristic of the Schottky barrier diode. In the range of low current densities, the characteristic obeys an exponential law as given by Eq. (2), but only as the whole forward voltage remains concentrated on the potential barrier of the space charge layer. As the carrier density rises the voltage drop across the series resistance R_s of the neutral zone becomes an illegible part of the forward voltage. If R_s remains constant even at high current densities, the characteristic will take the normal shape. If the series resistance of the neutral zone decreases with increasing currents, the forward characteristic deviates from the normal curve as indicated in Figure (2), and this is only possible by an increase of the carrier density in this zone since the electron mobility does not increase at higher electric fields.

Modulation exists if, when drawing the relation ΔV_F - I_F (where ΔV_F is the voltage drop in the neutral zone or epitaxial layer see Figure (2)), a curved line is obtained.

The conductivity σ is given by [5]

$$\sigma = I_F / \Delta V_F . L/A \qquad (5)$$

Where A is the diode active area, and L is the thickness of the neutral zone, i.e of the epitaxial layer.

EXPERIMENTAL PROCEDURE

The GaAs (100) crystals used in these experiments were n - type, the doping concentration was $2.7 * 10^{18}$ cm^{-3} and the resistivity was $4 * 10^{-4}$ Ω cm. 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 E360A. Ohmic contacts were formed by successive evaporation of indium followed by silver at a mass ratio of 3 : 1, then the contacts were annealed for 10 min at 400 ° C under N_2 atmosphere.

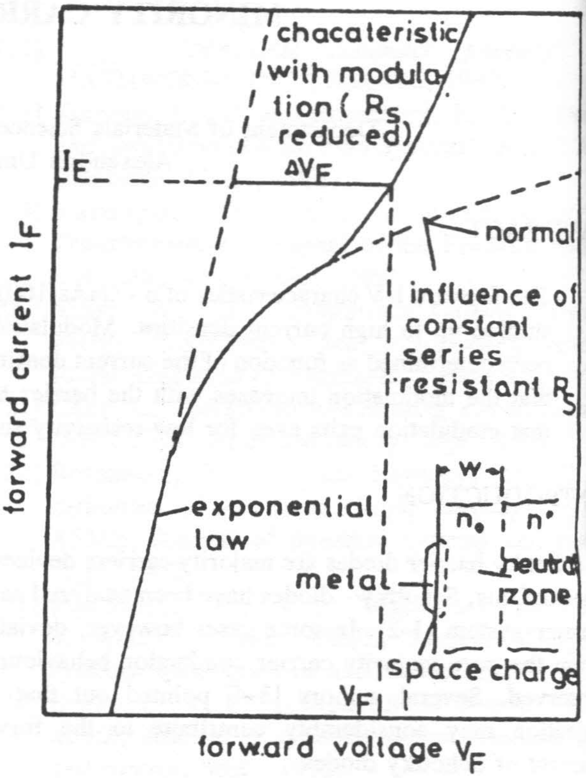

Figure 2. Schematic forward characteristic of a Schottky diode exhibiting the modulation effect. [5].

Different front contacts have been formed using Al, Ag and Au. The metals were evaporated through a shadow mask with circular holes of 1 mm 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 parameters for the contacts 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 DISCUSSION

I-V characteristics for Schottky diodes are 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 Figure (3). Barrier heights and corresponding ideality factors have been obtained in a previous work [7] and are shown in Table (II).

Table II. Schottky diode parameters.

	Al	Ag	Au
ϕ_B	.6068	.4485	.5727
n	1.43	1.4	1.284

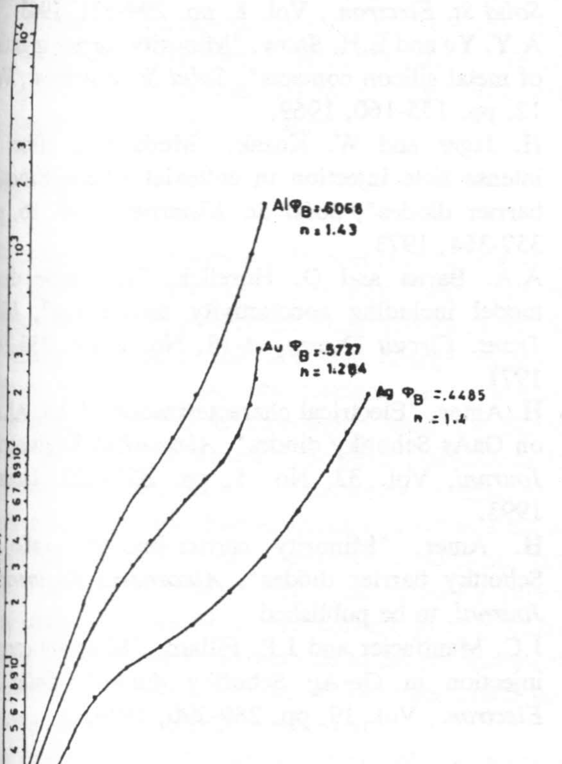

Figure 3. Measured I-V curves for the different metallizations.

The ΔV_F - I_F diagrams obtained by analyzing the forward characteristics as described in the previously are shown in Figure (4). From this figure it can be clearly seen that modulation is more pronounced for the diode with the larger barrier height.

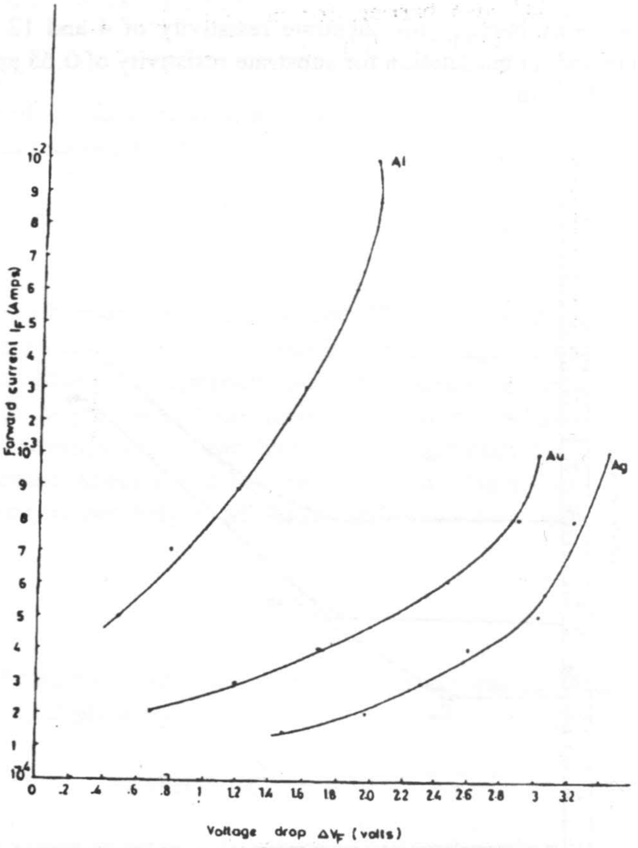

Figure 4. Forward characteristics of the neutral-zone series resistance metal/ n-n* GaAs diodes as obtained by the V_F-I_F analysis.

The conductivity σ for each diode is shown in fig.5. They are plotted on a bilogarithmic paper. From this figure we notice also that the highest barrier has also the highest conductivity.

The critical minority current ratios obtained from a previous work [8] were γ_o (Al) = 1.90 * 10^{-12}, γ_o(Au) = 4.49 * 10^{-13}, γ_o(Ag) = 1.96 * 10^{-15}.

Here also we notice that the diode with the highest barrier height has the highest injection ratio. Various parameters concerning the different Schottky diodes are listed in table III among them is J_{mo} which is the critical current density at which the conductivity begins to increase for the different metallizations.

Manifacier and Fillard [9] presented the J - V characteristics at T = 300 K for Ag - Ge(N) Schottky barrier. They observed modulation for substrate resistivity of ρ = 10 Ω cm and no modulation for substrate resistivity of ρ = 0.23 Ω cm.

Jager and Kosak [5] observed modulation for Pd - Si

Schottky barrier, for substrate resistivity of 4 and 12 Ω cm and no modulation for substrate resistivity of 0.65 and 0.15 Ω cm.

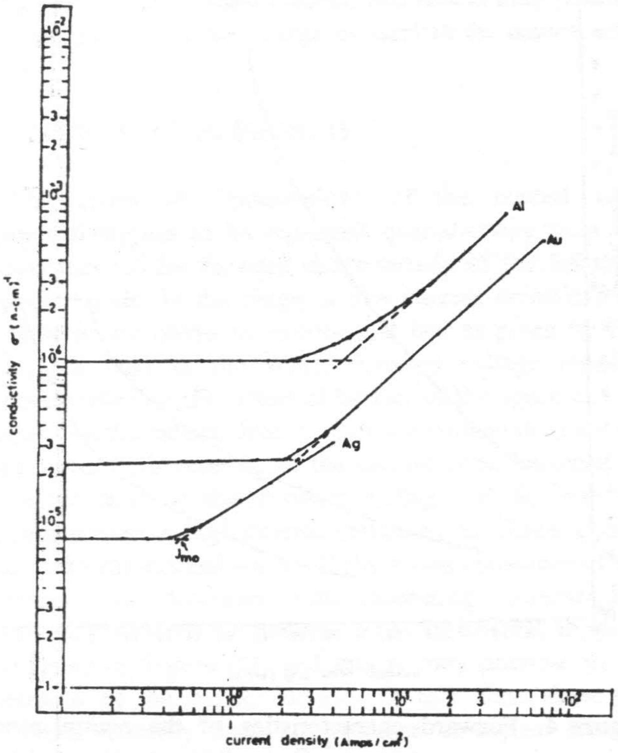

Figure 5. Calculated conductivity as function of the current density for the different metallizations.

Table III. Various diode parameters.

	Al	Au	Ag
ϕ_B	.8077	.7703	.6299
γ_o	$1.9 * 10^{-12}$	$4.49 * 10^{-13}$	$1.96 * 10^{-15}$
J_{mo}	4	2.8	.5
σ_o	10^{-4}	$2.2 * 10^{-5}$	$8 * 10^{-6}$

CONCLUSION

It has been proven that not only modulation increases with the barrier height, but even for high doping substrate (low resistivity of $4 * 10^{-4}$ Ω cm) modulation can also be obtained. Schottky diodes n-GaAs(100) fabricated with Al, Ag and Au metallizations and meetings the same technological parameters of having a low forward voltage drop at large current densities should be used to fabricate high current Schottky rectifiers with high reverse blocking capabilities.

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