IMPEDANCE OF GAAS P-I-N DIODES

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ABSTRACT

A computer model of GaAs p-i-n diodes shows that when the i-layer thickness is greater than about four times the diffusion length, diode forward resistance may be high. Comparison with measured I-V characteristics suggest that diodes now have i-layers with lifetimes of about 10^{-7}s.

INTRODUCTION

GaAs p-i-n diodes have been used as photodiode detectors for some considerable time. Their use as a rf switch element is comparatively recent (1), and currently there are several manufacturers offering devices commercially. The reason for this time lag was the following perceived difficulty: with the carrier lifetime of 10^{-8}s, the ambipolar diffusion length is of the order of 3 microns, and hence diodes of i-layer thicknesses of 3 microns or greater may have poor forward resistance, leading to high insertion loss or poor isolation in the low impedance state when used as a switch. This is in contrast to the silicon p-i-n diode where the diffusion length is several times the i-layer width, and forward bias modulation of the intrinsic layer results in low resistance. However, commercial diodes are now availabe in a variety of different layer thicknesses, from 3 microns to as much as 30 microns, with low forward resistance, at much lower current compared to the silicon diodes, and with switching times of less than 10 ns. This suggests that carrier lifetime is in the 10^{-7}s region.

The simple analytic theory which assumes equal electron and hole mobility is not applicable to the GaAs p-i-n diode, due to the large mobility ratio, electrons to holes, in the range 10-30. The more sophisticated theory (2) which accounts for this large ratio predicts some interesting results. However, the theory is only valid at very high injection level, and the range of bias conditions from low bias to high values is not accounted for. Thus, to cover the range of bias conditions, we have chosen to model the device numerically. We are also in the process of obtaining simulation results of diode impedance as a function of frequency, which we hope to present at the meeting. In this report, the results of the simulation under steady state conditions are discussed.

Analysis of the high injection case of the p-i-n diode has been discussed in considerable detail elsewhere (2). The results of this derivation are: the forward voltage drop across the diode is a minimum when the ambipolar diffusion length is half the i-layer thickness, and the drop increases very rapidly as the i-layer becomes thicker than four times the diffusion length. The simulation results are discussed in terms of J-V curves, and appear to confirm these results.

SIMULATIONS

The simulation follows the usual pattern of the solution of the Poisson and continuity equations for electrons and holes. Since the high injection case also has to be considered, the Newton's method was used, as the Gummel scheme showed lack of convergence at high injection levels. The choice of the overshoot parameter in the Newton's method was a modified form of the Banks and Rose (3) formulation, with specified upper and lower limits being imposed as required. Convergence was very rapid, except at exceedingly short life times.

The choice of diode structure was mainly governed by associated time-dependent simulations (not reported here). The diode has a n^- region for the i-layer, and the transition between the n^- and p^+ and n^+ has the doping tapered over a small region in each case. The p^+ and n^+ density was set at $10^{17}cm^{-3}$, which is low for these devices, although other simulation results have been obtained for higher densities. The recombination terms included the usual form of the Schockley-Read single level traps, Auger recombination and radiative recombination. Since the p^+ and n^+ densities are low, the control mechanism for recombination was due to traps and not due to Auger or radiative recombination effects.

The p^+n^- and n^-n^+ barrier heights were obtained by calculating N_C and N_V, using effective masses for the electrons and holes, 0.065 m_0 and 0.5 m_0 respectively. The usual form of velocity-field curve was assumed for electrons, and the hole velocity was assumed to saturate at high fields monotonically. Einstein's relationship was assumed to hold, and thus the diffusion coefficient is estimated from the velocity.

RESULTS

Two sets of results are presented here, and in all cases the n^-layer was assumed as 10^{13} cm^{-3}. In the first set of results, the n^-layer thickness is

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varied frm 3 microns to 20 microns with the carrier lifetime τ as 10^{-8}s. The J-V plots for this case are shown in Figure 1. Note that the ideality factor at lower currents is close to unity, and becomes larger at higher currents. The current density in the 20 micron diode is lower than the others for the same bias, which suggests that the diode i-layer modulation becomes poor when $W_i/L_a > 4$, where W_i is the i-layer thickness and L_a the diffusion length.

The second set of results has the diode n^-layer as 10 microns, and the life time in the i-layer is varied from 10^{-6}s to $3x10^{-10}$s. The diffusion length varies from about 30 microns to 0.5 microns, and the W_i/L_a ratio varies from 0.33 to about 20. The results are shown in Figure 2, and the same trend is observed: the current does not rise far enough when W_i/L_a is larger than 4 (10^{-9}s and $3x10^{-10}$s) for adequate i-layer modulation. Plotted in this figure is the measured J-V curve of a 10 micron layer 100 micron diameter diode. The slope of this curve is very close to the 10^{-7}s case, and this suggests that n^-layer carrier lifetime is about 10^{-7}s in the diode, which explains why the GaAs p-i-n diode is now successful.

Other results will be presented at the meeting.

SUMMARY

Numerical simulation of the GaAs p-i-n diode under forward bias has been carried out. The results of these simulations suggest that i-layer modulation may not be adequate when the i-layer thickness is greater than four times the diffusion length. The reason for the success of current commercial diodes is because the carrier lifetime is about 10^{-7}s.

REFERENCES

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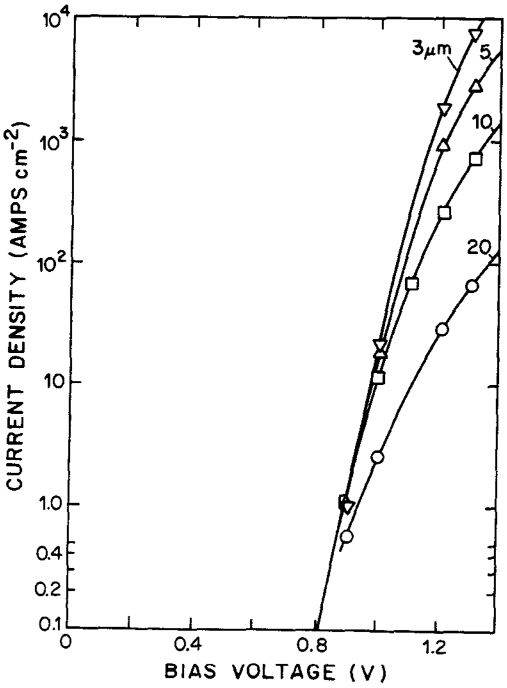

Figure 1. Current density against bias voltage for GaAs p-i-n diode, n^-layer density 10^{13} cm^{-3}, $\tau = 10^{-8}$s for different i-layer widths.

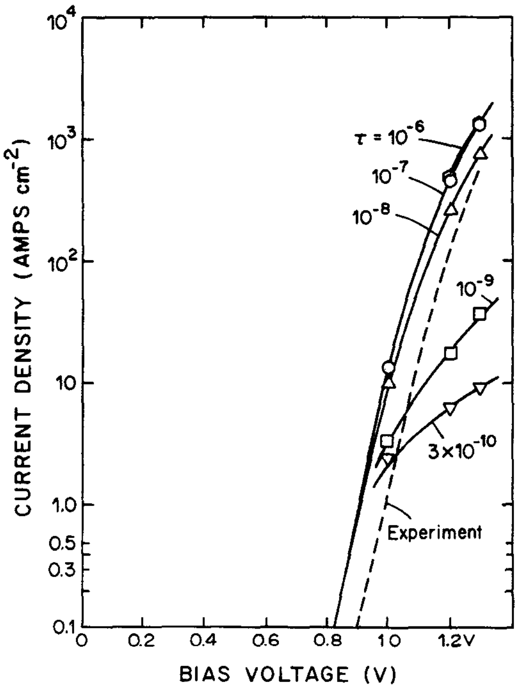

Figure 2. Current density against bias voltage for GaAs p-i-n diode, n^-layer density 10^{13} cm^{-3}, width 10 microns, for different values of τ.