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Temperature Dependence of Ionization Rates in GaAs

by

Y. J. Chang*and S. M. Sze**

The ionization rate is one of the most important material parameters of semiconductors. Its temperature dependence has profound effect on the avalanche breakdown voltages of p-n junctions and on the operational characteristics of many semiconductor devices including IMPATT diodes and avalanche photodetectors [1]. The ionization rates of electrons and holes in GaAs are measured herein over the temperature range 77°K to 373°K using photomultiplication method. The results are then compared with the modified Baraff theory [2, 3], in order to establish a functional dependence of the ionization rate on temperature.

It has been verified [3] that the temperature dependence of the ionization rates in silicon can be expressed by the modified Baraff theory which correlates the rates with three material parameters: E_I the ionization threshold energy; λ, the average carrier mean free path due to phonon scatterings; and E_p, the average energy loss per phonon scattering. The values of E_I for best fit are aprorimately three-halves of the band-gap energy, and λ and $<E_p>$ are given by

$$\lambda = \lambda_0 \tan(E_p/2kT) \tag{1}$$

and

$$<E_p> = E_p \tanh(E_p/2kT) \tag{2}$$

where λ_0 is the high-energy low-temperature asymtotic phonon mean free path, and E_p is the optical phonon energy. For GaAs the value [4] of E_p is 0.035eV which is only slightly greater than the room-temperature thermal energy (KT=0.026eV). Thus a large temperature variation of the ionization rates is expected in GaAs.

The room-temperature ionization rates for electrons and for holes in GaAs are found to be equal 5 . Hence the multiplication

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* Formerly a graduate student of National Chiao-Tung University Hsinchu, Taiwan, China

* * Now with Bell Labs, Murray Hill, New Jersey, U.S.A.

factor M is given by

$$1 - \frac{1}{M} = \int_0^W \alpha \, dx \tag{3}$$

where W is the width of the depletion layer. For one-sided abrupt junctions we have the following expressions for the maximum electric field E_m and the related ionization rate $\alpha(E_m)$:

$$E_m = [2qN_B(V+V_{bi})/\varepsilon_s]^{1/2} \tag{4}$$

and

$$\alpha(E_m) = E_m \frac{d}{dV}(1 - \frac{1}{M}) \tag{5}$$

where N_B is the background doping and Vbi is the built-in voltage. The corresponding relations for linearly graded Junctions are:

$$E_m = [9qa(V+V_{bi})^2/32\varepsilon_s]^{1/3} \tag{6}$$

and

$$\alpha(E_m) = \frac{1}{\pi} \frac{d}{dE_m} \int_0^{E_m} (1 - \frac{1}{M}) \sqrt{\frac{qa}{8\epsilon_s(E_m - E)}} \, dE \tag{7}$$

where a is the impurity gradient.

The GaAs p-n junctions are fabricated by masked diffusion process 5 . The junction properties of some GaAs diodes are listed in Table I. The background doping and the impurity gradient are obtained from the capacitance measurement which also determines the electric field-voltage relationship. The photomultiplication setup is similar to that described by Lee et al 6 . A dewar with optical windows is used for low temperature measurement at 77°K (liquid nitrogen) and 178°K (frozen aceton). An electric heater in the flow of hot nitrogen is used for high - temperature measurement. Once the dependence of the multiplication factor on applied voltage is determined, the ionization rate can be computed from Eqs. 4 and 5 for abrupt junctions or Eqs. 6 and 7 for linearly graded junctions.

A typical set of the measured ionization rates is shown in Fig 1. We note that as the temperature increases the ionization rate at a given field decreases. In order to compare the results with the modified Baraff theory, the experimental data are replotted on the Baraff curves shown in Fig. 2. At a given temperature the only adjustable parameter to fit a particular curve is the average carrier mean free path λ. From the value of λ obtained from the best fit, one can deduce from Eq. 1 the asymtotic mean free path λ_o. For the diodes listed in Table I and over the wide temperature range, it has been found that λ_o. only varies slightly and is within the range 60 ± 6 A. It is thus clear that λ_o is a fundamental material parameter which is essentially independent of temperature or the impurity doping profile.

In summary, the temperature dependence of the ionization rate, α, in GaAs has been obtained over the range 77^oK to 373^oK. For a given electric field α is found to decrease with increasing temperature. It is established that the modified Baraff theory can adequately describe the functional dependence of α on temperature. The value of λ_o is 60 ±6 A which is in good agreement with the λ_o value of 58 ± 5 A deduced by Crowell and Sze from room-temperature measurement [3].

References

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Table I. Junction properties of zinc diffused GaAs at room temperature

Breakdown Voltage (V)	λ_o (Å)	Capacitance Law	V_{bi} (Volts)	Background Doping or Gradient*
20	60	$V^{-1/2}$	1.45	2.1×10^{16} cm^{-3}
25	63	$V^{-1/2}$	1.40	1.9×10^{16} cm^{-3}
30	54	$V^{-1/3}$	1.30	1.5×10^{21} cm^{-4}
37	58	$V^{-1/3}$	1.28	6.0×10^{20} cm^{-4}

* Value calculated from C-V measurement.

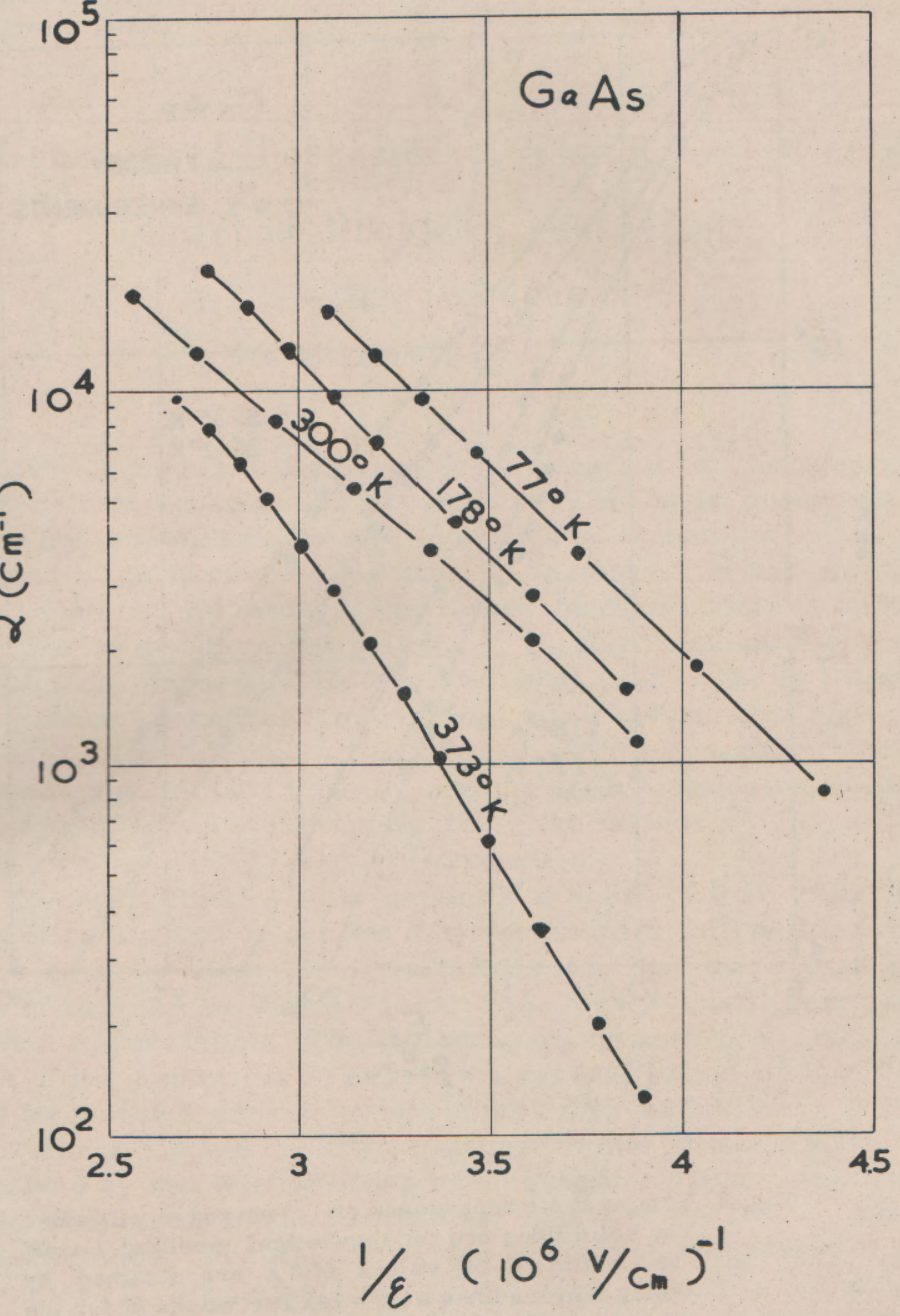

Fig. 1. Temperature dependence of ionization rates in GaAs versus reciprocal electric field.

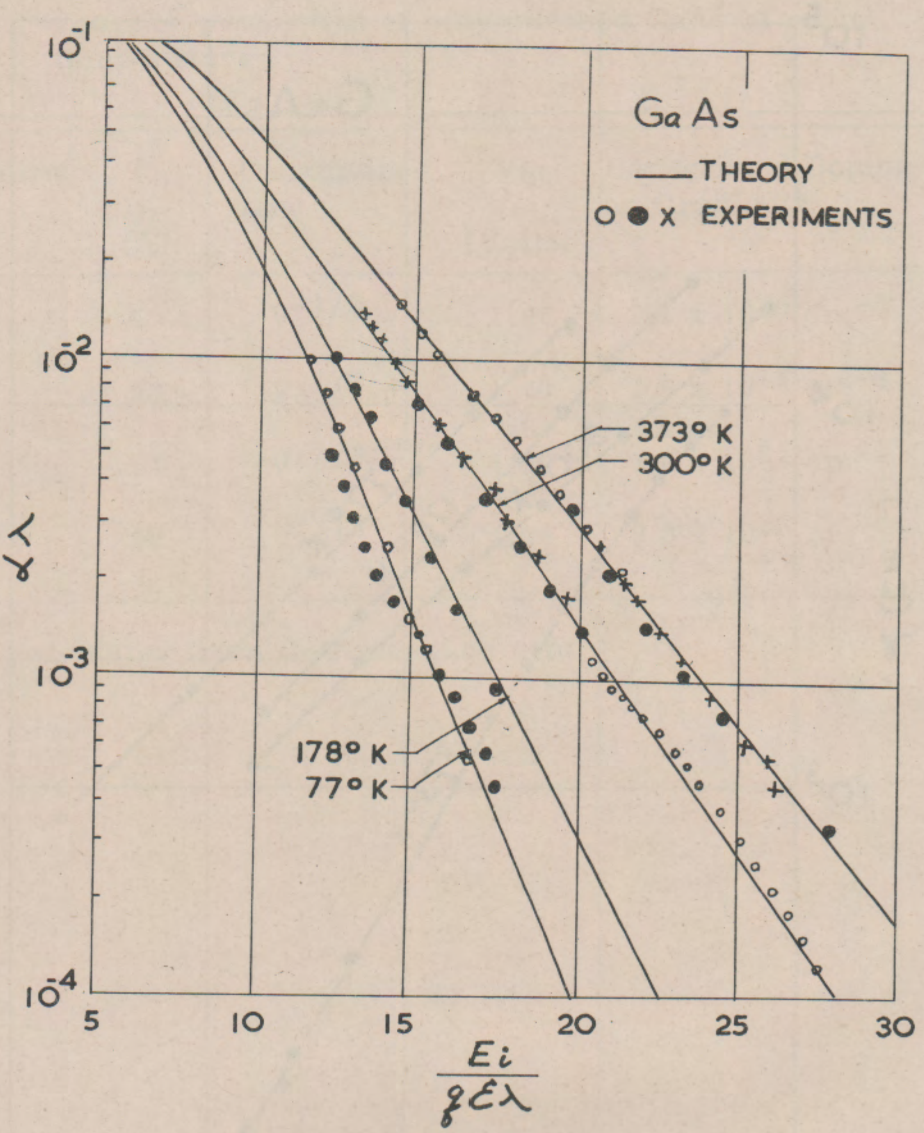

Fig. 2. Temperature dependence of versus x E_I/qE . The solid lines are the theoretical modified Baraff curves (for $x > 14$, values of $\alpha\lambda$ are obtained by taking tangent lines at $x = 14$). The values of for the experimental data are as follows,

373°K : • 65A, 0 63A, x 54A.

300°K : • 60A, 0 58A, x 63A.

178°K : • 60A.

77°K : • 57A, 0 63A.