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Position Dependence of Average Electron Velocity in a Submicrometer GaAs Channel

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Abstract. The Monte Carlo method has been applied to obtain the average electron velocity at different positions of a submicrometer GaAs channel in the presence of a position-independent electric field. Velocity-distance curves are presented for channel lengths of 0.1, 0.2, and 0.5 μm and for lattice temperatures of 300 and 77 K. The curves show significant effects of collisions and boundary conditions.

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The velocity of electrons at different distances from the injecting end of long samples of GaAs has been studied by several workers [1, 2]. It has been found that the velocity rises from the end point and reaches a peak value at a short distance of the order of 0.15 μm and then gradually decreases to a steady value. This so-called velocity overshoot has given rise to the speculation that very high-speed logic devices [3] and high-frequency FET's may be realised by using submicrometer channels. The transient-velocity characteristics of such short channels are, however, likely to be different from those for long channels because of the presence of the second boundary. We have studied earlier the transient and steady-state electron velocity averaged over the whole sample of a submicrometer channel using a Monte Carlo model for the lattice temperature of 300 K [4]. These calculations indicated that the average velocity in a submicrometer channel may be significantly larger than the maximum velocity in long channels. Specifically, in an 0.2 μm long sample the highest average velocity is 4.8×10^7 cm/s and in a 0.1 μm long sample it is 5.4×10^7 cm/s, whereas the value for a long sample is 2.7×10^7 cm/s. The Monte Carlo method has now been applied to study the electron velocity at different positions of the channel in the presence of a position-independent electric field, as considered in earlier computations [1, 2, 5, 6]. The contact is assumed to be ohmic and the total number of electrons in the sample is assumed to be independent of time and field. To ensure this constancy, when an electron leaves the sample at one end, an electron is injected in the simulation with a lattice-temperature Maxwellian velocity from the opposite end [7, 8]. All the complexities of the band structure (including non-parabolicity and multiplicity of valleys) and of the scattering mechanisms have been taken into account in accordance with the model C of [9] except that the energy exchange in acoustic collisions is also included. The average electron velocity $\langle v(d)\rangle$ in the direction of the field at any position d of the sample was obtained by using the formula

$$\langle v(d)\rangle = \sum_i v_i(d)\Delta t_i \Big/ \sum_i \Delta t_i ,$$

where $v_i(d)$ is the velocity of the simulated electron in its ith flight across d, and Δt_i is the time it spends in the range $d \pm \Delta d/2$ during that flight.

The velocity-distance curves are presented in Fig. 1 for the channel lengths of 0.1, 0.2, and 0.5 μm, for fields of 10 and 50 kV/cm and for lattice temperatures of 300 and 77 K. We have also included, for comparison, the velocity-distance $(v-d)$ curves obtained when the collisions are omitted.

We find that the velocities initially increase almost identically with distance d for channels of different lengths approximately as d^n. The values of the index n for the different temperatures and fields are collected in

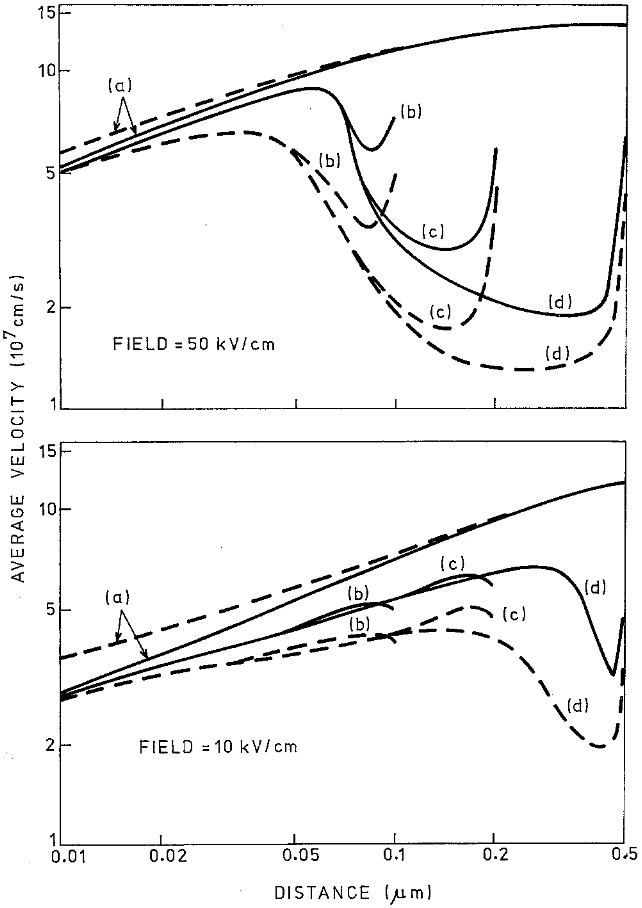

Fig. 1. Average velocity vs. distance; solid line for 77 K, dotted line for 300 K. *a* Collision-excluded model. *b–d* Collision-included model for the lengths of 0.1, 0.2, and 0.5 μm, respectively

Table 1. Values of the index of velocity-distance relation ($v \propto d^n$). (A Collisions included, B Collisions omitted)

Lattice temperature [K]	Field [kV/cm]	*n* for Model	
		A	B
300 K	10	0.20	0.27
	50	0.30	0.33
77 K	10	0.25	0.37
	50	0.38	0.40

Table 1. We note that the values of *n* vary with the temperature and the field. The index *n* has higher values when collisions are omitted. However, in every case the value is smaller than 0.5, the value expected for ballistic motion excluding the effect of initial velocity and band nonparabolicity. The absolute values of velocity when the collisions are omitted are also significantly higher and the difference is larger at 300 K than at 77 K.

The effect of inter-gap scattering when it occurs is found to affect the characteristics from a distance somewhat shorter than that at which the voltage is equal to that corresponding to the gap separation (i.e., 0.3 V). This may be understood considering that when an electron suffers inter-gap scattering, its velocity is randomised and the motion of the electrons scattered in the backward direction affects the average velocity at shorter distances. These considerations also explain the observed characteristics near the contacts. We note that at the source end the average velocity is lower when the collisions are included even though the electrons are injected with the same average velocity in both the collision excluded and collision included models. Electrons travelling towards the source end after scattering at some point within the sample cause this lowering. Near the drain end again electrons travelling in the reverse direction with velocities comparable to those travelling in the forward direction would be few in number. This is because electrons injected from the boundary have velocities corresponding to the lattice temperature which is significantly lower than that of accelerated electrons. This causes the increase in average velocity near the drain end.

The results presented in this note thus show that the collisions affect significantly the velocity-distance curves for GaAs channels down to lengths of 0.1 μm at 300 K and also at 77 K. The effect is very prominent near the contacts when inter-gap scattering occurs. It is also significant even when voltages are such that inter-gap scattering does not occur. The so-called ballistic model [10, 11] for the analysis of short channel GaAs devices should therefore be considered to be a simplification of the problem, as has also been discussed earlier [12–14].

References

1. J.G. Ruch: IEEE Trans. ED-**19**, 652 (1972)
2. T.J. Maloney, J. Frey: J. Appl. Phys. **48**, 781 (1977)
3. H. Rees, G.S. Sanghera, R.A. Warriner: Electron. Lett. **13**, 156 (1977)
4. B.R. Nag, M. Deb Roy: Appl. Phys. A **31**, 65 (1983)
5. M. Brauer: Phys. Stat. Sol. (b) **81**, 147 (1977)
6. G. Hill, P.N. Robson, A. Mejerfeld, W. Fawcett: Electron. Lett. **13**, 235 (1977)
7. Y. Awano, K. Tomizawa, N. Hashizume, M. Kawashima: Electron. Lett. **18**, 133 (1982)
8. J. Zimmerman, E. Constant: Solid-State Electron. **23**, 915 (1980)
9. S. Kratzer, J. Frey: J. Appl. Phys. **49**, 4064 (1978)
10. M.S. Shur, L.F. Eastman: IEEE Trans. ED-**26**, 1677 (1979)
11. M.S. Shur, L.F. Eastman: Solid-State Electron. **24**, 11 (1981)
12. K. Hess: IEEE Trans. ED-**28**, 937 (1981)
13. T.H. Glisson, C.K. Williams, J.R. Hauser, M.A. Littlejohn: *VISI Electronics: Microstructure Science* (Academic, New York 1982) p. 99
14. D.K. Ferry, J. Zimmerman, P. Lugli, H. Grubin: IEEE Electron. Dev. Lett. EDL-**2**, 228 (1981)