ABSTRACT

Recent results concerning spatial and temporal transport in submicron devices identify significant aspects of the role of boundary conditions, scaling for suggesting new materials, and structural device changes. These results are discussed as a means of achieving high speed and high frequency devices.

INTRODUCTION

There are several recent results concerning spatial and temporal transport in submicron devices that are likely to have an impact on the design of future high frequency sources. These results, which emerge from Monte Carlo, and momentum moment equation solutions to the "Wigner-Boltzmann" quantum transport equation.
H. L. GRUBIN ET AL.

\[
\frac{3f_w}{\frac{\partial}{\partial t}} + \frac{p}{m} \frac{3f_w}{\frac{\partial}{\partial x}} - \frac{2}{\hbar} \left\{ \sin \frac{\hbar}{2} \left( \frac{\partial}{\partial x} \frac{\partial}{\partial p} \right) \right\} V(x) f_w(x,p) = \frac{3f_w}{\frac{\partial}{\partial t}} \text{coll}, \quad (1)
\]

and the Boltzmann transport equation (BTE)

\[
\frac{3f}{\frac{\partial}{\partial t}} + \frac{p}{m} \frac{3f}{\frac{\partial}{\partial x}} + \frac{p^2}{2m} \frac{3f}{\frac{\partial}{\partial p}} = \frac{3f}{\frac{\partial}{\partial t}} \text{coll}, \quad (2)
\]

identify crucial aspects of boundary conditions, the role of scaling in choosing suitable materials, and the significance of alterations in otherwise simple device structures for achieving high speeds. These topics are reviewed below. (It is noted: In equation (1) the position gradient in the brackets operates only on the potential energy, \( f \) is a single coordinate and momentum distribution function \( f_w \) is a single coordinate and momentum distribution function

\[
f_w(x,p) = \frac{1}{2\pi\hbar} \int dy \psi^* (x + \frac{y}{2}) \psi (x - \frac{y}{2}) e^{ipy/\hbar} \quad (3)
\]

and \( \psi(x) \) represents the state of the system in the coordinate representation).

SCATTERING MODIFICATIONS TO BALLISTIC TRANSPORT

Ballistic transport implies carrier transport unimpeded by interactions (electrostatic, or otherwise) with other carriers, or with scattering events. The extent to which scattering centers are sensed by transiting electrons is therefore of significance. The first set of calculation shown, Figure 1 (Ref. 2), represents scattering events in GaAs for a collection of electrons entering a uniform field region with an initial energy of approximately 0.30eV. Intervalley \( T-L \) energy separation for this Monte Carlo calculation is 0.33eV. It is seen that, with the exception of very high fields, approximately 50% of the carriers are unscattered over the first 500 \( \AA \).

The velocity versus distance curves for this calculation are displayed in Figure 2 (Ref. 2), and it is seen that high speeds over useful distances can be achieved even in regions where a high number of scattering events has occurred. The optimum conditions for this appear to require moderate fields, generally near the threshold field for electron transfer, and moderate injection energies. The dependence on the latter is displayed in Figure 3 (Ref. 2), where the lowest achievable velocities over a distance of 1500 \( \AA \) are for entry electrons with zero initial velocity. It is also seen that an optimum