Hotelectron velocity overshoot in Ga0.47In0.53As

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Hot-electron velocity overshoot in $Ga_{0.47}In_{0.53}As$

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Velocity overshoot phenomena in $Ga_{0.47}In_{0.53}As$ to the application of uniform electric fields are investigated using recent values of the material parameters. The effects of the ambient temperature and of the doping concentration are studied. The material is found to yield peak drift velocities larger than those in GaAs. The values of the peak velocity are greater for short lengths of the active region, low impurity concentration, and low ambient temperatures.

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Hot-electron velocity overshoot in semiconductors has received considerable attention in recent years in connection with high-frequency submicron devices.[1-3] While most of the work in this direction has been confined to GaAs, the promising material $Ga_{0.47}In_{0.53}As$ remains ignored except for a brief report.[4] The parameters of the alloy semiconductor are now known fairly accurately, and it seems timely to study in some detail the transient response of hot electrons in the material. We report here calculations of velocity overshoot in $Ga_{0.47}In_{0.53}As$ at lattice temperatures of 300 and 77 K for applied fields in the range 10–20 kV/cm. A pure material and an impure material with a doping concentration of 3×10^{17} cm^{-3} are considered. The calculated results are used to obtain favorable conditions for a high average drift velocity in a submicron device, and are compared with those for GaAs.

We consider a uniform semiconductor material subjected to a steady electric field. The nonsteady state or the transient response of hot electrons can be studied either by solving the moment equations based on a displaced Maxwellian distribution function or by using the ensemble Monte Carlo method.[1] The displaced Maxwellian approach is exact when electron-electron scattering is predominant in energy and momentum exchanges. The minimum electron concentration required for such predominance[5] is about 10^{16} cm^{-3}. Even when electron-electron scattering is not so predominant the displaced Maxwellian method yields transient response results for GaAs comparing well with those of the ensemble Monte Carlo technique.[1,3] The equilibrated velocity results for GaAs and GaInAs, calculated by the two methods, also agree reasonably well with each other and with experimental data.[6,7] The displaced Maxwellian method is simpler and is free from statistical fluctuations; it takes less computing time, and is particularly advantageous when conditions of the problem or the parameters are to be varied. The calculations reported here are obtained on the basis of a displaced Maxwellian distribution function.

TABLE I. Several material parameters of $Ga_{0.47}In_{0.53}As$ used in the calculations.

Effective mass (m^*)	$0.042m_0$
Γ-L valley separation ($\Delta_{\Gamma L}$)	0.55 eV
Γ-L intervalley deformation potential ($D_{\Gamma L}$)	7×10^8 eV/cm
Alloy scattering potential (ΔU)	0.42 eV
Acoustic deformation potential (Ξ)	9 eV

$Ga_{0.47}In_{0.53}As$ is a direct-gap semiconductor with Γ, L, X ordering of the conduction-band minima. Polar optic, acoustic, alloy, intervalley, and ionized impurity modes of scattering are considered here. Several important material parameters related to the Γ valley and now known with better accuracy than that when the previous calculations were reported,[4] are shown in Table I. In particular, the values of $\Delta_{\Gamma L}$ and ΔU are taken from Refs. 8 and 9. The value of $D_{\Gamma L}$, given in Table I, has been found for GaAs from optical studies of relaxation times.[10] As $D_{\Gamma L}$ for other compounds are not definitively known but are expected to be of similar magnitude, the use of the same value for GaInAs appears reasonable. The other material parameters are taken from a recent review by Littlejohn *et al.*[11] A discussion of the reasonableness of these parameters is also included in Ref. 11.

The electric field is assumed to be switched on at time $t = 0$. The drift velocity of the electrons $v(t)$ as a function of time is first found. The average drift velocity over a distance d is then determined from the relationship

$$\bar{v} = \frac{d}{t} = \frac{1}{t}\int_0^t v(t')dt', \tag{1}$$

where t is the transit time for the distance d.

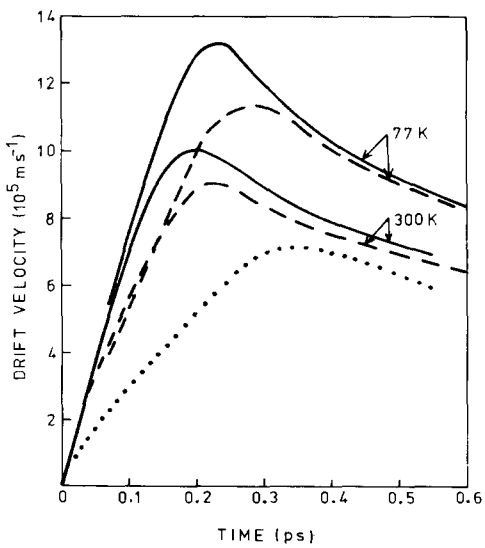

FIG. 1. Drift velocity vs time for an applied field of 20 kV/cm. The solid curves give the calculated values for GaInAs without ionized impurity scattering; the dashed curves give the same considering ionized impurity scattering for a doping concentration of 3×10^{17} cm^{-3}. The dotted curve gives the values for GaAs at 77 K and a doping concentration of 3×10^{17} cm^{-3}.

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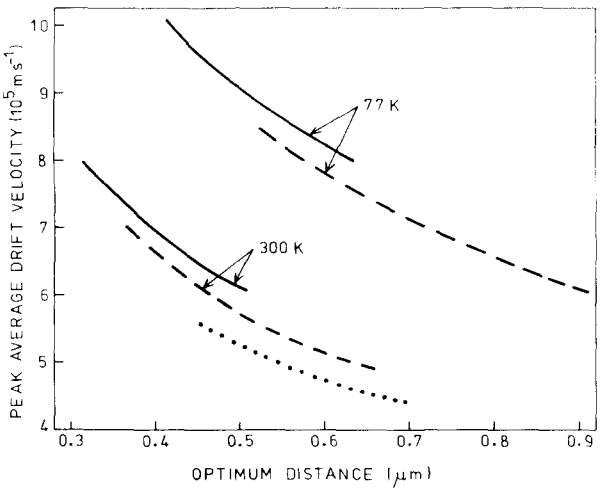

FIG. 2. Variation of the peak average drift velocity with optimum distance. The solid, dashed, and the dotted curves have the same significance as in Fig. 1.

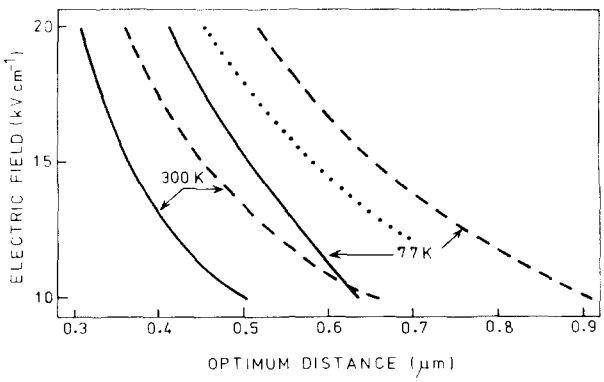

FIG. 3. Variation of the electric field with optimum distance. The solid, dashed, and the dotted curves have the same significance as in Fig. 1.

Figure 1 shows the variation of the drift velocity $v(t)$ as a function of time for an applied electric field of 20 kV/cm at lattice temperatures of 300 and 77 K. As the electric field is switched on, the electron drift velocity begins to rise; and when the electron energy attains a value close to $\Delta_{\Gamma L}$ electron scattering becomes more efficient due to nonequivalent intervalley transfer. As a result, a peak appears in the velocity-time curve.[1] At a lower lattice temperature, the peak velocity is larger and occurs at a later time. This sort of behavior accrues from the fact that at lower temperatures the scattering probability due to absorption of phonons is small so that the electrons can drift in the field for a longer time and attain a higher velocity before relaxing energy by emitting intervalley phonons. Ionized impurity scattering provides an additional means of momentum relaxation; its inclusion reduces the drift velocity and broadens the peak, as shown in Fig. 1. For small times in the region of 0.05 ps, the drift velocity is found to be insensitive to changes in lattice temperature or impurity concentration. For such smaller times, scattering has not occurred and the electrons move almost ballistically in the applied field, the drift velocity being determined by the band structure of the material. When a long time has elapsed after the application of the field, the average energy of the electrons is large and the ionized impurity scattering, being Coulombic in nature, does not much influence the drift velocity, as seen in Fig. 1.

When the electric field is reduced from 20 to 10 kV/cm the general nature of the curves shown in Fig. 1 remains unaltered. The drift velocities are however reduced, and the peak is broadened and shifted to a higher time. At 10 kV/cm the rate of energy gained from the field decreases so that the carriers drift in the field for a longer time before acquiring sufficient energy for nonequivalent intervalley scattering.

The nature of the curves shown in Fig. 1 predicts that the average drift velocity $\bar{v}$ will be a maximum for some value of d, referred to as the optimum distance. The values of the peak average drift velocity against the optimum distance are plotted in Fig. 2. The electric field values giving these peak average drift velocities are shown in Fig. 3. We find that for shorter lengths of the active region the optimum values of the average drift velocity and the electric field are larger. The peak average drift velocity can be enhanced and the corresponding electric field can be decreased by reducing the impurity concentration. The peak average drift velocity can also be enhanced by lowering the lattice temperature, but in this case the electric field has to be increased.

A point of interest is to compare the results with those for GaAs. The Γ-point effective mass in $Ga_{0.47}In_{0.53}As$ is smaller than that in GaAs while the Γ-L energy separation is larger. Velocity overshoot is therefore expected to be greater in the alloy semiconductor. Although this superiority of $Ga_{0.47}In_{0.53}As$ is somewhat offset by the detrimental effects of alloy scattering,[12] we find a considerable improvement with a reasonable value of the alloy scattering potential. We include in Figs. 1–3 the results calculated for GaAs at 77 K and an ionized impurity concentration of 3×10^{17} cm^{-3}. Figures 1 and 2 show that the peak values of v(t) and $\bar{v}$ in GaAs are about 0.6 times the corresponding quantities in GaInAs.

In conclusion, velocity overshoot is more significant in GaInAs than in GaAs. Particularly large drift velocities can be achieved for short lengths of the pure material at low lattice temperatures.

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