An Influence of Electron–Electron Scatterings to Distribution Functions

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The aim of this work lies on prevailing some aspects where the presence of electron–electron scatterings affect carrier transport phenomena, focusing on velocity overshoots and hot carrier populations. The ensemble Monte Carlo(EMC)technique was utilized for this purpose. The implemented models are found in literatures[1,2,3]; The MC code includes a simple non-parabolic band structure (nonparabolicity $\alpha = 0.5eV^{-1}$), six types of intervalley phonon scatterings, the intravalley acoustic phonon scattering(assumed to be elastic), the impurity scattering (Brooks–Herring + Ridley's statistical screening), the binary short–range e–e scattering(Brooks–Herring).

Two types of screening conditions were set up; The n type impurity concentration $n_{imp} = 10^{17}cm^{-3}$, and carrier concentration $n_{ele} = 10^{18}cm^{-3}$ were set up, where the e–e scattering rate, P_{e-e}, amounts to the order of $10^{13\sim14}sec^{-1}$, which scattering process is the most significant. Hereafter, we call it the stronger e–e scattering condition. A similar occasion is realized near the n^+n–intrinsic n region of n^+nn^+ devices, where the carrier population outnumbers the background impurity concentration. In MOSFETs inversion layers, carrier concentration exceeds substrate doping concentration. Another set-up, $n_{imp} = 10^{18}cm^{-3}$, $n_{ele} = 10^{18}cm^{-3}$, was also used, where P_{e-e} is the order of $10^{12\sim13}sec^{-1}$. In the latter set-up, the e–e scattering loses its importance because of screening due to the balanced positive impurity charge.

First shown were, in Fig.1, transient responses of drift velocity and average energy for the "turn–on" and "turn–off" transients. The presence of the e–e scatterings did not seem to affect these quantities significantly even in the stronger e–e scattering condition. Examples of the energy distribution functions were ploted in Fig. 2. All distributions have almost the same average energy(0.35 eV). Despite the same average energy, some differences were observed in the profiles.In the absence of e–e scatterings, a hump-like structure(indicated by the arrows) was observed at earlier periods. It is attributed to the "lucky-drift component"[4], which is formed by such electrons that are accelerated toward the electric field direction without being scattered. As expected from the randomizing nature of e–e scattering, a hump structure was obscured in the strong e–e scattering condition. However, the peak do not shift significantly in its position, irrespective of the presence of e–e scattering. Hence, the velocity overshoots were not affected. From the transient distribution functions, population ratios of "hot carriers (energy $\geq 1.1eV$)" were considered. In the turn–on transients, hot carriers becomes more abundant at earlier periods when the e–e scattering is active. This enhancement factor was as large as 2 in the stronger e–e scattering condition, while it was unity for the weaker e–e scattering condition.

In summary, the presence of e–e scatterings have little influence on macroscopic transport characteristics, such as drift velocity and average energy. However, in microscopic views, the e–e scatterings modify the distribution profile. Hence, hot carrier population is affected. In heavily doped regions, the e–e scattering rate is not large, despite of abundant carriers, because of the screening contributed by ionized impurities with the opposite sign.

References

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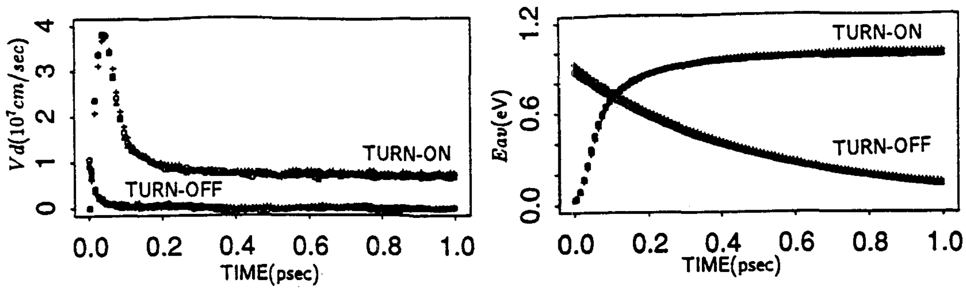

Fig. 1 The transient response in the drift velocity and average energy. Activated are phonon scattering (marked with circles), phonon and impurity scatterings (triangles) and phonon, impurity, and e–e scatterings(crosses). In the turn-on transient, an electric field ($300kV/cm$) was applied. The turn-off transient started when the electric field was switched off after the electrons had been heated up to the steady-state. The active scattering mechanisms are phonon scatterings (circle), phonon and impurity scatterings (triangle), and phonon and impurity and e–e scatterings (cross). n–type impurity $n_{imp} = 10^{17}cm^{-3}$, the carrier concentration $n_{ele} = 10^{18}cm^{-3}$.

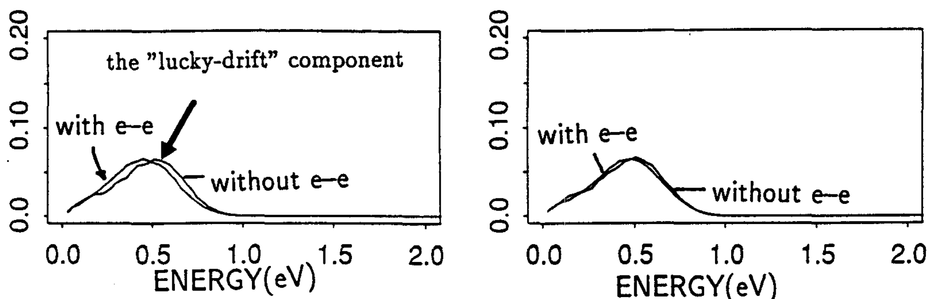

Fig. 2 Some of transient distribution functions with the same average energy. An electric field of $300kV/cm$ was applied. Time is ~0.05psec. $n_{imp} = 10^{17}cm^{-3}$, $n_{ele} = 10^{18}cm^{-3}$(Left). $n_{imp} = 10^{18}cm^{-3}$, $n_{ele} = 10^{18}cm^{-3}$(Right). Pointed by the arrow is the "lucky-drift" component which is apparent when the e–e scattering is excluded.

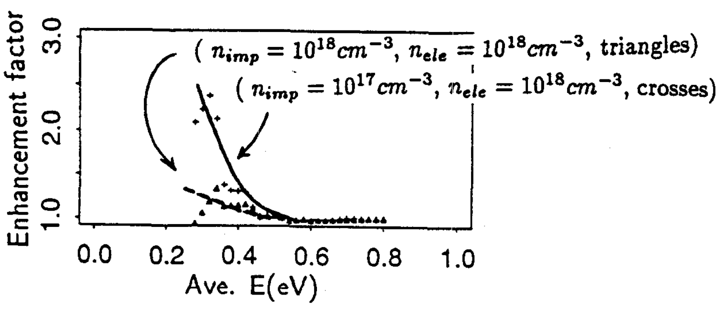

Fig. 3 The "hot–carrier" population enhancement due to e–e scatterings. The enhancement factor is defined as the ratio of "hot carrier" populations with and without e–e scatterings, i.e. $n(\varepsilon \geq 1.1eV)$ with e–e scat./$n(\varepsilon \geq 1.1eV)$ no e–e scat. Plotted is the enhancement factors for a stronger e–e scattering condition ($n_{imp} = 10^{17}cm^{-3}$, $n_{ele} = 10^{18}cm^{-3}$, crosses) and for a weaker condition ($n_{imp} = 10^{18}cm^{-3}$, $n_{ele} = 10^{18}cm^{-3}$, triangles).