Experimentally Verified Majority and Minority Mobilities in Heavily Doped GaAs for Device Simulations

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ABSTRACT

Low-field mobility and velocity versus electric field relations are among the key input parameters for drift-diffusion simulations of field-effect and bipolar transistors. For example, most device simulations that treat scattering from ionized impurities contain mobility or velocity versus field relations based on the Born approximation (BA). The BA is insensitive to the sign of the charged impurity and is especially poor for ionized impurity scattering because of the relatively strong scattering of long-wavelength carriers, which have low energies, and therefore violate the validity condition for the BA. Such carriers occur at high symmetry points in the Brillouin zone and are critical for device performance.

There has been a tendency in the past to assume that majority and minority mobilities are equal. This assumption can lead to incorrect interpretations of device data and thereby misleading design strategies based on such simulations. We have calculated the majority electron and minority hole mobilities in GaAs at 300K for donor densities between 5×10^{16} and 1×10^{19} cm^{-3} and the majority hole and minority electron mobilities for acceptor densities between 5×10^{16} and 1×10^{20} cm^{-3}. We have included all the important scattering mechanisms for GaAs: acoustic phonon, polar optic phonon, nonpolar optic phonon (holes only), piezoelectric, ionized impurity, carrier-carrier, and plasmon scattering.

The ionized impurity and carrier-carrier scattering processes have been calculated with a quantum mechanical phase-shift analysis to obtain more accurate matrix elements for these two scattering mechanisms. These calculations are the first to use such an analysis for minority carriers scattering from ionized impurities and from majority carriers in GaAs. For example, Figure 1 compares the total scattering rate for majority electrons due to ionized impurities based on exact phase shifts (solid curve) and on the BA of Brooks-Herring (dashed curve). We will present additional data that show the differences between the BA and exact phase-shift analyses for majority and minority electron velocity-field relations obtained by Monte Carlo calculations. Figures 2 and 3 show that the calculated low-field mobilities are in good agreement with experiment, but predict that at high dopant densities, minority mobilities should increase with increasing dopant density for a short range of densities. This effect occurs because of the reduction of plasmon scattering and the removal of carriers from carrier-carrier scattering because of the Pauli exclusion principle. Some recent experiments support this finding. Figure 4 gives low field electron and hole mobility ratios as functions of the dopant density. The values of $\mu_n(p-type)/\mu_n(n-type)$ are given by the solid curve, and the values of $\mu_p(n-type)/\mu_p(p-type)$ are given by the dashed curve. The dopant densities have been normalized to N^0 equal to 1×10^{16} cm^{-3}. These results are important for device modeling because of the need to have reliable values for the minority mobilities and velocity-field relations.

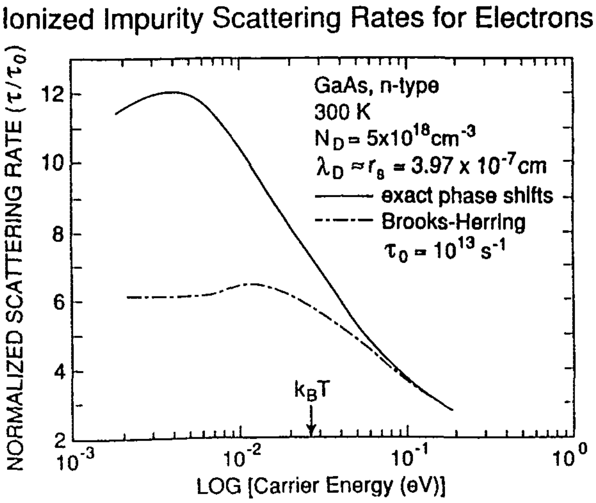
Ionized Impurity Scattering Rates for Electrons

Figure 1

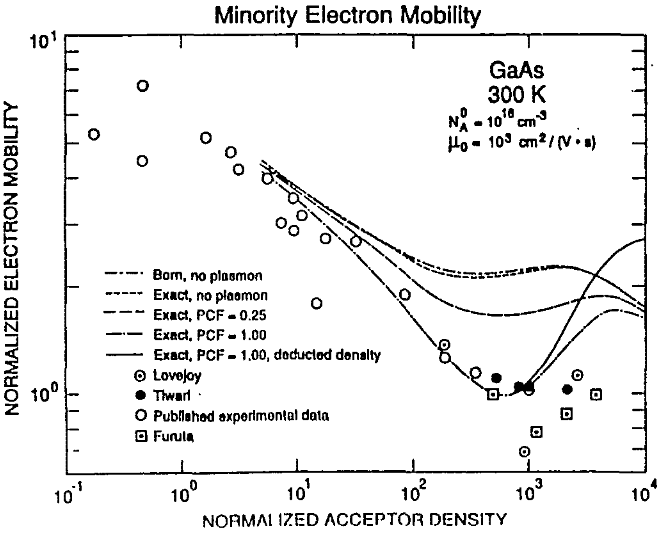
Minority Electron Mobility

Figure 3

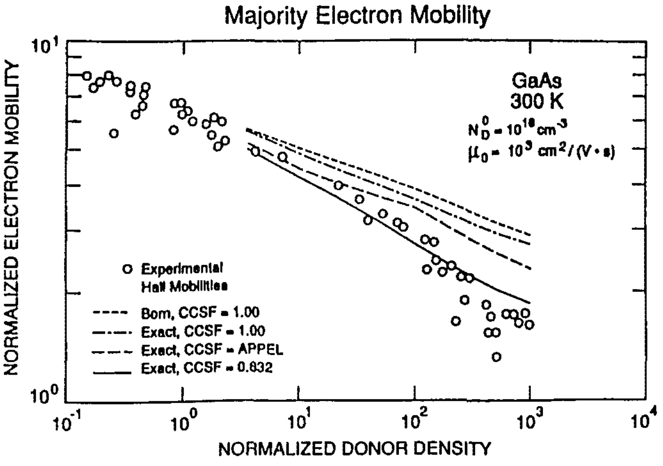
Majority Electron Mobility

Figure 2

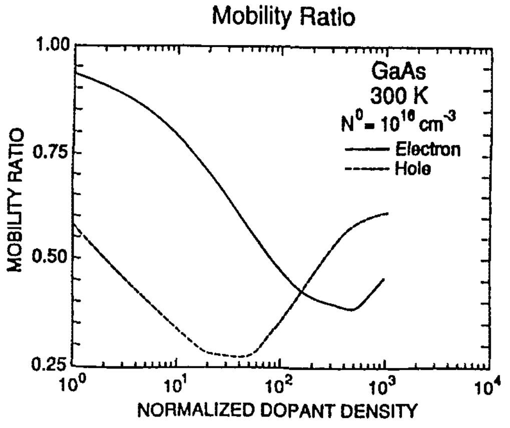
Mobility Ratio

Figure 4