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B — 5 — 6 Analyses of 2D Electron Transport at a GaAs/AlGaAs Interface (Invited)

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The interest in high speed electron transport in heterojunctions and superlattices has been stimulated by the introduction of the novel technique of modulation doping in GaAs/AlGaAs superlattices.[1] In these structures electrons leave their parent donors in the AlGaAs and encounter reduced ionized impurity scattering in the GaAs. Currently achieved Hall mobilities of quasi-two-dimensional (2D) electrons in a selectively doped GaAs/$Al_xGa_{1-x}As$ (x=0.3) heterostructures exceed 10^6 $cm^2/V\cdot s$ at 4.2 K.[2] Under device operations, however, the field effect mobility was not so high as Hall mobilities.[3]

In this talk a review will be given on the high speed transport properties of 2D electronic system and on the cooling mechanisms in hot electron conditions in such heterostructures to analyze the high frequency performances of the devices. It will be shown that electrons can be rapidly accelerated at low electric fields in the 2D states and reach high energies to interact with polar optical phonons in the GaAs layer. The electron scattering process has been well reflected in the electric field dependence of mobility. Hall measurements with high field pulse techniques gave us notable information about the field effects of the sheet electron density as well as the mobility.

We found the intrinsic mobility of 2D electrons at 80 V/cm which is expected to be fully determined by the electron phonon interactions. Mobilities in any types of the samples with different heterostructures or sheet electron densities tend to the same value μ = 75000 $cm^2/V\cdot s$ at 80 V/cm with increasing electric field. This result shows that at this critical electric field the scattering mechanism changes from the Coulomb scattering dominant process to the phonon scatterings. The electron-phonon interaction in the 2D electronic system is incompletely understood at present. We will focus our attention on the screening effects of polar coupling with longitudinal optical phonons as well as of ionized impurity scattering by high density electrons in the heterostructures.

In order to get more insights into these mechanisms the heated electron temperature and cooling process under applied electric fields were studied through analyses of quantum oscillations in magnetoresistance at low temperatures.[4] We report the direct observation of polar optical phonon emission and of inter-subband transfer of 2D electrons in the relatively high density system such as

$N_s = 1.5 \times 10^{12}\ cm^{-2}$. In the Fourier transformed data two series of oscillations have been observed with increasing electric field in addition to the fundamental Shubnikov – de Haas oscillation. First series enhanced by the electric field is assigned to be magnetophonon resonance which indicates the resonant cooling of 2D hot electrons by emissions of polar optical phonons in the GaAs layer. Second series is the low frequency Shubnikov-de Haas oscillation associated with 2D electrons in the second subband. This detection can be understood that the electric field causes predominant intersubband transfer of 2D electrons from the ground subband into the second subband. These data evidently demonstrated the cooling process of high energy 2D electrons under electric fields in the GaAs/AlGaAs heterojunctions. From analyses of the electron transition process cooling down to the low energy states by emissions of polar optical phonons, the electron distribution function must be considerably deformed. In the energy states lower than the Fermi energy by about $1/2(\hbar\omega_{LO})$, the enough empty states should exist in order to allow resonant transition observed as the magnetophonon resonance. We can estimate the electron temperature of the 2D Fermi gas to be at least around 40 K at low electric fields less than 1 V/cm.

Finally we will also discuss variations of the electron distribution in a real space. Electrons accelerated by high fields move up to 2 or 3 dimensional high energy states and then get transferred into the AlGaAs layer.[5] The only indirect evidence of this real space transfer of electrons in the GaAs/AlGaAs heterostructures has been observed by the simple current voltage characteristics. Here we present some experimental results which might indicate variations of the real space electron distribution in the heterostructures.

References

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