Optical signatures of electron mobility in quantum wells containing two subbands

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The two-dimensional electron gas (2DEG) in modulation-doped heterostructures have been not only the research topics studied both theoretically and experimentally but also actively applied to various electronic components such as high electron mobility transistors (HEMTs). HEMTs based on InAlAs/InGaAs quantum wells have been widely studied for their transport properties where the various scattering mechanisms by phonon, by ionized impurities, by alloy disorder, and by surface roughness.[1] On the other hand, in the viewpoint of optical properties, Fermi-energy edge singluarity (FES) [2] have a main topic for discussions in the similar structures. We note the transport properties in 2DEG systems are determined by the electrons near the Fermi energy, and whether those electrons are localized or delocalized determines the character of the material. Therefore, by paying careful attention to the analysis of optical properties in regard to their counterparts in transport ones, one can possibly find a new route to finding the nexus between them, thus, to probing the carrier dynamics.

Here, photoluminescence measurements were carried out to be comparatively analyzed with magnetic field dependent Hall data as a function of temperature 10-300 K). The samples were grown by molecular-beam epitaxy and consists of a 500 nm $In_{0.52}Al_{0.48}As$ buffer layer on InP substrate, 12 nm of $In_{0.53}Ga_{0.47}As$ (with an elelctron density of 3.4×10^{12} cm^{-2}), a 4-nm spacer of undoped $In_{0.52}Al_{0.48}As$ including a delta-doped sheet of Si (4.5×10^{12} cm^{-2}), 20 nm of undoped $In_{0.52}Al_{0.48}As$, and finally 5-nm-thick cap layer of n-doped $In_{0.53}Ga_{0.47}As$ to form the ohmic contact. The PL spectra were obtained by using Ar-ion laser (514.5 nm) with excitation power around 200 W/cm^2. This heavy doping results in Fermi-energy of 132 meV, which is larger than the 2nd quantum well subband.

Figure 1. shows PL spectra obtained at various temperatures, where the decrement at each subband and at FES behaved differently. Two subbands in conduction bands (e1, e2) are optically allowed for transition from the lowest heavy-hole level (h1), owing to the asymmetry of the structure. We note the FES smeared out faster than subband levels (e1h1 and e2h1) in the figure. The FES is well known to be originated from multiple scattering of electrons at the Fermi level, which also probably influence the carrier mobility related with each subband. In this regard, we analyzed PL based on phenomenological Gaussian line-shape fitting as a function of increasing temperature to represent the degree of multiple scattering at each subband in Fig. 2. Above 100 K, The peak height ratios, $I(E_F)/I(e1h1)$ and $I(E_F)/I(e2h1)$ manifest the different behavior.

To compare the optical results with transport properties, we investigated whether the carriers in the first subband dominates the transport by performing mobility spectrum analysis [3] as shown in Fig. 3. From this analysis, the lareger carrier density in first subband resulted in as 3 times larger mobility in the frist subband, while the relative mobility in the 1st subband compared to 2nd subband was more enhanced with increasing temperature. We could observe qualitatively similar behavior in PL spectra as shown in Fig. 2

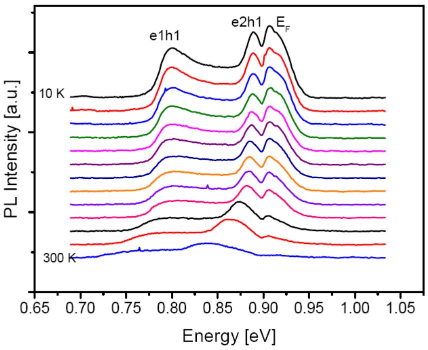

Fig.1. PL spectra as a function of temperature from 10 (top) to 300 K

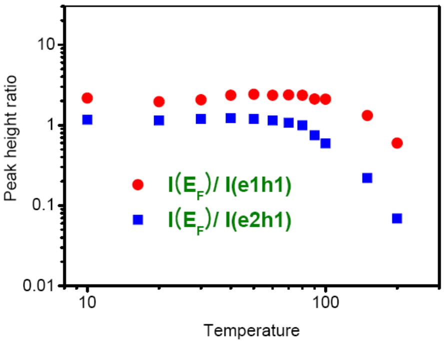

Fig. 2. PL intensity ratio for two subbands, compared with the strength at FES.

The mobilities of the first and second subband are enfluenced by different scattering mechanisms. In particular, at high temperature region, above 100 K, we found $T^{-1/2}$ dependence for the first subband in contrat to $T^{-3/2}$ for the second subband. To understand which scattering mechanism is dominant at each subband, the mobilities calculated by scattering theory (lined curves) were compared with the experiments (scattered curve) following the conventional analysis scheme [4]. This comparative study implies there could be new route to probing carrier transports by employing optical methodologies.

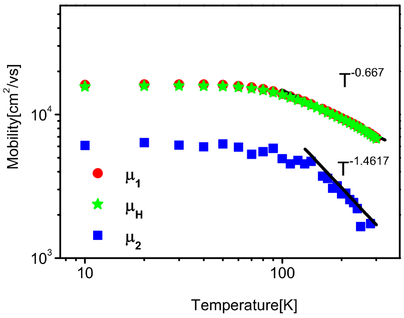

Fig. 3. Temperature-dependent Hall mobility

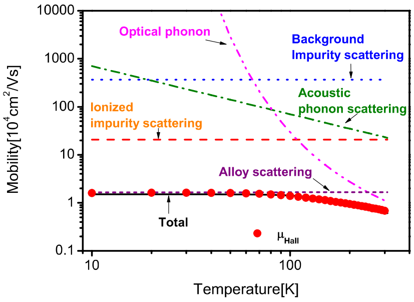

Fig. 4. Measured and calculated mobility versus temperature

1. See e.g., D. Chattopadhyay, "Electron mobility in $In_{0.53}Ga_{0.47}As$ quantum wells", Phys. Rev. B, 38, 13429 (1988) and references therein.

2. M. S. Skolnick *et al.*,"Observation of a many-body singularity in quantum well luminescence spectra", Phys. Rev. Lett. 58, 2130 (1987)

3. W. A. Beck and J. R. Anderson, “Determination of electrical. transport using a novel magnetic field-dependent Hall technique” J. Appl. Phys. 62, 541 (1987).

4. W. Walukiewicz *et al.*, "Electron mobility in modulation-doped heterostructures", Phys. Rev. B 30, 4571 (1984)