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Electric Field Induced Recombination Centers in GaAs

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1. Introduction

In recent years, many efforts have been done for investigations of electric field effect in quantum wells. This effect is very apealing for opto-electronic devices. Chemla *et al.* investigated lateral electric field effect in GaAs/AlGaAs quantum well[1][2][3]. They applied pulsed high electric field parallel to quantum well layers to investigate high-speed electro-optical modulation due to Stark effect or Frantz-Keldysh effect. In the present experiment, we investigated stability of exicitons in the quantum well under lateral electric field by photoluminescence (PL) method. When low electric field (1 kV/cm) was applied at low tempratures ($\leq$ 100 K), we observed considerable changes in the PL spectra; the PL associated with the recombination between the lowest quantum levels quenched and new peak appeared in the lower energy region. Since the electric field is much lower than that dissociates the excitons, we suggest that this phenomenon is caused by the electric field induced new recombination centers in which carrier lifetime is shorter than that of the exitonic recombination. Similer PL quenching was observed in GaAs and AlGaAs single layer crystals. We think, therefore, this phenomenon is a common characteristic of GaAs and AlGaAs.

2. Experimental procedure

Samples used in the present experiment were MBE-grown GaAs/$Al_{0.5}Ga_{0.5}As$ Single Quantum Wells (SQW) with the well width of 10 MLs, and GaAs and $Al_{0.45}Ga_{0.55}As$ single layers. To apply uniform electric field, Au-Ge-Ni electrodes separated by 2 mm width were evaporated and alloyed on the sample surface. DC bias was applied between the electrodes and the spacing between the electrodes were excited either by Ar laser (488 nm) or He-Ne laser (633 nm) for PL measurement. The resulting spectra were scanned at a wavelength range of 50 nm using CCD. By repeating the scanning every one second, we also measured the PL response due to the applied electric field.

3. Results and Discussion

At the zero bias condition, a single PL peak was observed at 658 nm which corresponds to the transition between the lowest electron and hole levels of the SQW. When the sample was biased at 200 V (1 kV/cm), the PL quenched and new peak apperared at the larger wavelength region at 672 nm as shown Fig. 1 when the sample was excited by Ar laser. By scanning the PL repeatedly, we observed that this PL quenching is slow and it takes about 10 s to reach the steady state condition. When electric field was removed, the PL spectra recovered to the initial state. This recovering process is even slower than quenching process and it takes about 20 s. From these results, we recognized that the responce of PL spectra to the external electric field is very slow. To examine whether the excitation of AlGaAs barrier layer is important for the phenomenon, the same measurement was performed with He-Ne laser which is little absorbed by the AlGaAs layer. The result was completely the same as that excited by Ar laser. We also performed the same measurement on GaAs and AlGaAs single layers. As a results, we also observed PL quenching. In the latter case, however, no new peak appeared (Fig. 2). Therefore PL quenching caused by the applied electric field is a common characteristic of GaAs, AlGaAs *etc.*

Since the PL quenching occurs at low electric fields ($<$ 1 kV/cm), it is not due to the exciton dissociation which occurs at relatively high electric field ($\sim$ 100 kV/cm). Thus, it should be tenable to assume that new recombination centers are induced under electric field. To investigate the mechanisms of this PL quenching, we performed following experiment. It is important to see whether the new recombination centers are induced by only the electric field, or by the cooperative effect of field and photoexcitation. The result shown in Fig. 1 was obtained by applying electric field to the photoexcited sample. So, to determine relationship between electric field and phtoexcitation, we changed the order of appling electric field and phtoexcitation. When phtoexcitation was performed on the electric field applied sample, the results were different between SQW and GaAs single layer. In the case of SQW, immediately after phtoexcitation, PL spectra was the same as non-biased case and then quenching occurred indicating that the creation of recombina-

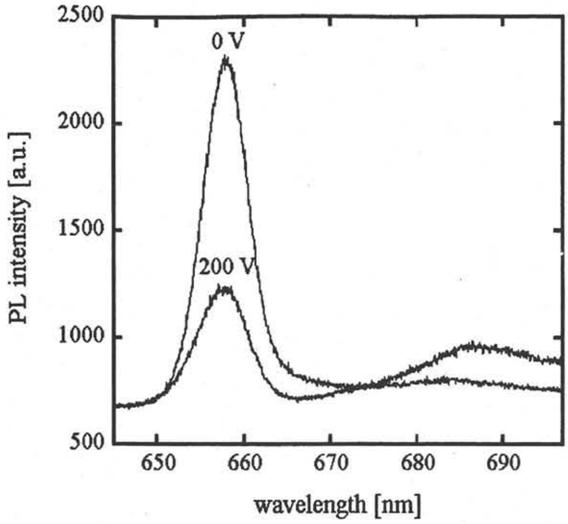

Fig. 1: PL spectra of GaAs/AlGaAs SQW at 7 K, non-biased and biased at 200 V. Peak spectum quenched and new peak appeared when static electric field was applied parallel to the QW layer.

tion centers should be a cooperative effect. On the other hand, in the GaAs single layer, PL is already quenched immediatly after photoexcitation indicating that the new centers are induced by only the electric field. This discrepancy can be explained by considering the current under electric field. In the SQW sample, electric current crossing the electrodes is very low ($\sim 10^2$ μA), while in the GaAs single layer, the sample current was as high as few mAs. Since either photoexcitation or substantial electric current is needed in addition to electric field to induce this phenomenon, some ionized atoms should be related to the phenomenon.

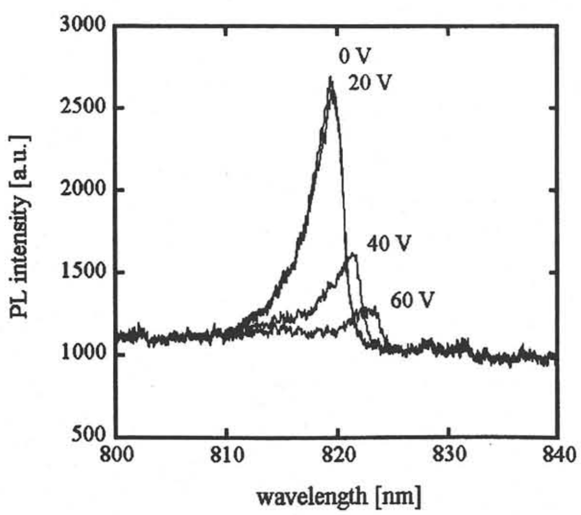

Fig. 2: PL spectra of GaAs single layer at 7 K, under various bias voltages. With applied elctric field intensity increased, PL intensity decreased. At bias voltage 20 V, PL spectra quenching was hardly seen.

Based on the experimental results descrived above, we propose a model which explains this phenomenon. Some impurity atoms at the lattice sites are charged by photoexcited electrons (or holes), or accelerated electrons in the unexcited sample. The electric field may cause the displacement of the charged atomes to the interstitial sites, thus creating new recombination centers. From the observation of slow PL response to applied electric field, the creation of new centers may be related to the displacement of atoms from the lattice points. These new recombination centers have potential barrier in conduction band, and electrons which are accelerated by electric field or excited by photons can pass the barrier and are caught in these centers. Recombination lifetime of electrons which are caught in these centers is shorter than that of excitonic recombination. Under sufficiently strong electric field, almost all the electrons pass the barrier and this electric field induced recombination process becomes dominant. Therefore PL spectra change when electric field is applied to the crystal. This phenomenon occurs only at low temperatures. This is probably due to the thermal excitation of charges from the charged atoms at high temperatures.

4. Conclusions

In conclusion, we investigated electric field effect on PL characteristics in GaAs/AlGaAs SQW and GaAs and AlGaAs single layers. We observed quenching of PL spectra at low temperatures when static low electric field was applied to the sample. We think this phenomenon is due to new recombination centers induced by electric field.

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