Coupled 2D-Electron-Exciton System under Microwave Irradiation

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The interaction of excitons (X^0) with a dilute 2DEG leads to the formation of bound electron-exciton complexes, negatively charged excitons (X^-), that dominate the low-temperature photoluminescence (PL) of modulation-doped quantum wells (QWs) [1, 2]. The dynamical properties of the X^-, namely their formation (recombination) processes and the possibility of their in-plane motion, are of central interest. Previous experiments carried out at 2DEG densities near the metal-insulator transition [1, 3], resulted in conflicting conclusions as to whether X^-s are mobile or localized. An important demonstration of mobile charged excitons could be the observation of classical (microwave) cyclotron resonance.

In order to study the dynamical properties of charged excitons in wide range of the 2DEG density (10^8-10^{11}) cm^{-2}, we use undoped mixed type I - type II QWs (MTQWs) where n_{2D} is varied by short-pulsed photoexcitation. The sample consists of 5 periods of narrow (~2.6nm) and wide (~20nm) GaAs QWs separated by barriers having two adjacent layers: AlAs (~10nm) and $Al_{0.3}Ga_{0.7}As$ (40nm). Electrons photoexcited in the narrow QW by short He-Ne light pulses, transfer into the wide well, and these electrons have a long lifetime there due to a slow tunneling of the holes photoexcited in the narrow QW [4]. A cw Ti-sapphire laser light at E =1.6 eV excites e-h pairs in the wide QWs whose PL and its excitation (PLE) spectra are measured at *various delays* after the He-Ne-light pulses terminated (see inset of Fig. 1). The effect of microwave (mw) irradiation on the PL and PLE spectrum is studied by applying pulse-modulated mw radiation of 36 GHz (8mm) with variable delays relative to the He-Ne-light pulses.

The PL and PLE spectra obtained at increasing He-Ne light pulse duration, are shown in Figs. 1a, b and thus, the entire evolution from free exciton to X^- and to 2DEG with increasing n_{2D}, was studied. The PL and PLE spectra were measured for various time delays after the He-Ne light pulses, and these spectra did not change for delay times less than 10^{-2}s. This shows that n_{2D} does not change for a long time after photoexcitation. Application of mw irradiation results in a significant PL intensity redistribution between the exciton and X^- bands (Fig. 2). The same PL spectral redistribution was observed during the mw pulse as well as after the mw pulse termination, thus the mw-induced PL change lasts for a long time (~10^{-2} sec).

The mw irradiation heats up free charged particles and thus, affects the X^0 and X^- formation and decay processes. Since the latter processes as well as the electron cooling have short relaxation times (less than 10^{-9} sec), it is expected that the mw irradiation will induce PL intensity redistribution between X^0 and *free mobile* X^- <u>only</u> during the mw pulse. The mw-pulse electron heating results also in a decreased density of localized electrons which recovers with a long relaxation time. When a magnetic field is applied perpendicularly to the QW plane, efficient mw heating can be observed at a 2D-free electron (free X^-) cyclotron resonance.

The optically detected (by the PL intensity change) electron cyclotron resonance (ODCR) in the coupled system of electrons, excitons, and X^- is studied for various n_{2D}. Our study shows that the long-lived mw-induced PL changes are caused by a decrease in the localized electron density that leads to a reduced density of the localized X^-. These experiments unambiguously show that the excitons are captured by localized electrons and form localized charged exciton complexes at n_{2D} values as high as 5.10^{10}cm^{-2}.

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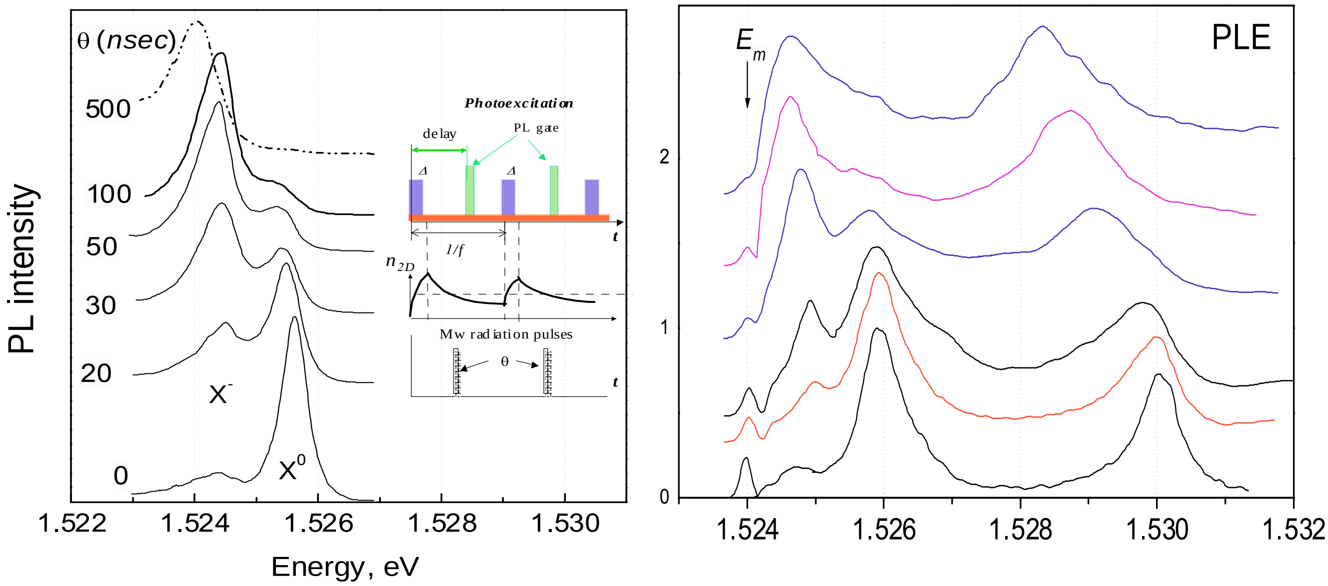

Fig. 1. PL and PLE spectra measured at various He-Ne light pulse duration θ. Two strong PLE bands correspond to the heavy (e-hh) and light (e-lh) exciton transitions. Inset shows time diagrams of photoexcitation, 2DEG density relaxation and mw irradiation.

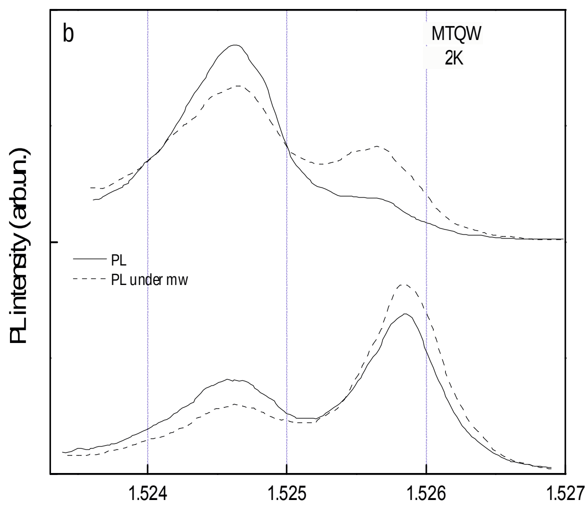

Fig2. The effect of mw irradiation on the exciton-trion PL in the MTQW. The mw effect is shown for θ= 0.02 (bottom) and 0.1 μsec (top). The in-put mw power is ~0.5mW.