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Bleaching compensation in GaAs/AlGaAs quantum wells by above-barrier illumination

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Abstract. We report an experimental study of the nonlinear response of single GaAs/AlGaAs quantum well. It was shown that bleaching effect manifested as reversible exciton spectral lines broadening can be suppressed by additional above-barrier illumination.

1. Introduction

One of the most promising alternatives to current silicon-based electronics is the information processing in purely optical way [1–3]. Exciton and excitonic complexes in A3B5 nanostructures strongly interact with light due to the relatively large oscillator strength and could serve as a physical model of two-level system that draws special attention in the area of optical computing. However bleaching effect manifested as reversible exciton spectral line broadening limits usefulness of GaAs/AlGaAs structures in informational photonics.

Earlier it was shown that at relatively weak and intermediate intensities exciton bleaching is observed while spectrally integrated peak intensity in the absorption spectrum remains the same [4]. The main mechanism of bleaching is said to be broadening of the exciton line induced by scattering of excitons on carriers and exciton-carriers complexes. Carriers captured in QW reveal long-lived kinetics in microsecond scale [5]. Moreover PL signal from electron hole pair could be clearly detected up to tens of second after excitation due to non-exponential decay of carrier concentration [6, 7]. Bleaching effect could be reduced by lowering of Al percentage in $\text{Al}_x\text{Ga}_{1-x}\text{As}$ QW barriers down to few percent [8].

Carriers could be observed even in nominally undoped quantum wells (QWs) grown by Molecular Beam Epitaxy (MBE) due to the unintentional doping. Presence of carriers in QW leads to the formation of a peak in the photoluminescence (PL) spectrum at energies below exciton recombination line [9]. This peak corresponds to the exciton-carrier bound state – trion. Additional optical pump could lead either to the buildup or to the reduction of charge carriers concentration in QW depending on the pump spectral position relative to the band gap [10]. Alterations in carriers concentration or even in their sign [11] may be revealed by analysis of opposing changes in trion and exciton peak amplitudes in PL.

PL spectroscopy is generally used for detection of such charged exciton complexes [5, 9–11]. Still it could not give the full picture of the exciton dynamics due to the difficulty of the factorization of the exciton resonance width. We propose the Brewster angle reflection



spectroscopy [8, 12, 13] as a tool enabling independent measurement of the radiative width and nonradiative broadening of the exciton resonance. In this work we present a joint study of exciton resonance bleaching in single QW by means of PL and reflection spectroscopies and suggest possible means to control and eventually suppress this parasitic effect.

2. Experiment

The sample E296 grown by MBE contains nominally undoped single 12 nm GaAs QW with $\text{Al}_{0.28}\text{Ga}_{0.72}\text{As}$ barriers. We use Ti:Sapphire laser as a broadband probe for reflection spectra measurement. The sample was kept at 5 K in a closed-loop helium cryostat and spectra were detected by a spectrometer equipped with a CCD detector. An additional tuneable cw-laser, 650 nm and 532 nm lasers (referred further as red and green respectively) are used as pumping light sources for studying of light-induced bleaching under different excitation conditions.

The reflection spectrum is well described by the Lorentz curve [14, 15] when light is linearly polarized perpendicularly to the sample surface and angle of incidence coincides with Brewster angle:

$$K_R(\omega) = \frac{\Gamma_R^2}{(\omega - \omega_0)^2 + (\Gamma_R + \Gamma_{NR})^2}, \quad (1)$$

where ω_0 – frequency of exciton resonance, Γ_R – radiative width, Γ_{NR} – nonradiative broadening.

3. Results and discussion

In the case of resonant pump excitation to the light-hole exciton resonance (LH-exc) a bleaching of the reflection at the heavy-hole exciton resonance (HH-exc) was observed [8, 12]. This effect has monotonous dependency on the pump intensity and is related to the scattering of excitons on excessive pump generated carriers accumulated in the QW. Observation of electron-related shake-up lines in magneto-PL in the case of LH-exc excitation proved negative sign of carriers and unintentional n-doping of the sample [16].

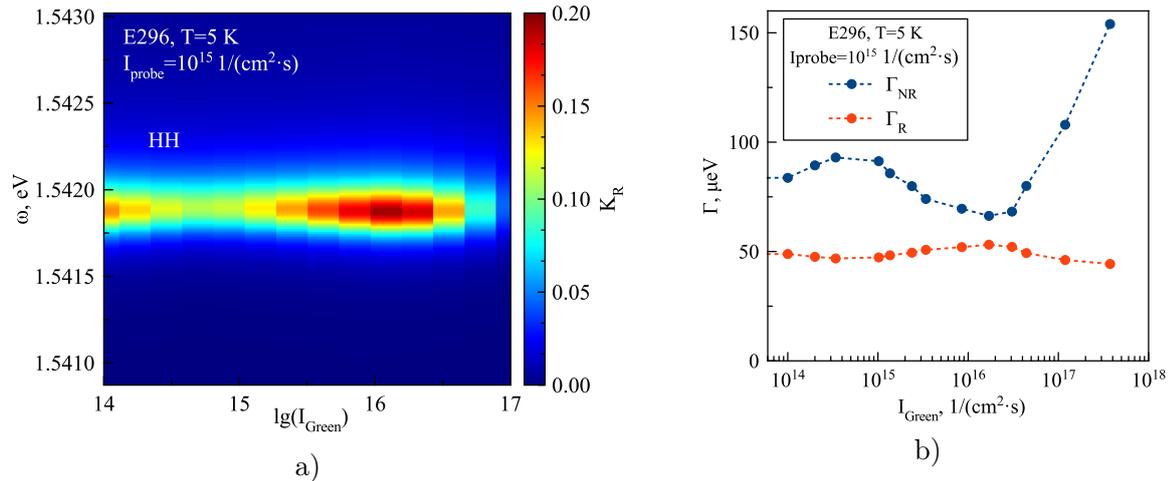


Figure 1. Dependence of $K_R(\omega)$ (a), Γ_R and Γ_{NR} (b) on above-barrier pump intensity I_{Green} .

On the contrary non-resonant above-barrier pump ($\lambda = 532 \text{ nm}$) leads to the non-trivial behaviour of $K_R(\omega)$ (Fig.1). Parameters Γ_R and Γ_{NR} were extracted from reflection spectra using (1). At weak pump intensity reflection spectrum is similar to the unpumped case and broadens with rising pump intensity. But starting from $I_{Green} = 10^{15} \text{ 1/(cm}^2 \text{ s)}$ the trend becomes opposite. Intermediate intensity pumping reduces bleaching – Γ_{NR} and $K_R(\omega_0)$ reach

its minimum and maximum respectively at $I_{Green} = 10^{16} \text{ 1/(cm}^2\text{s)}$. More intensive pump causes bleaching again.

Γ_R remains constant in the whole range of pump intensities, so $K_R(\omega)$ behaviour is determined by Γ_{NR} changes. We attribute non-monotonous Γ_{NR} dependence on I_{Green} to the change of the charge carriers density in QW. Above-barrier pump creates positively charged carriers flow into QW that recombine with resident electrons at $I_{Green} = 10^{16} \text{ 1/(cm}^2\text{s)}$. This situation is similar to one analyzed in [9–11], however we detect two reversing point with the monotonous rise of I_{Green} .

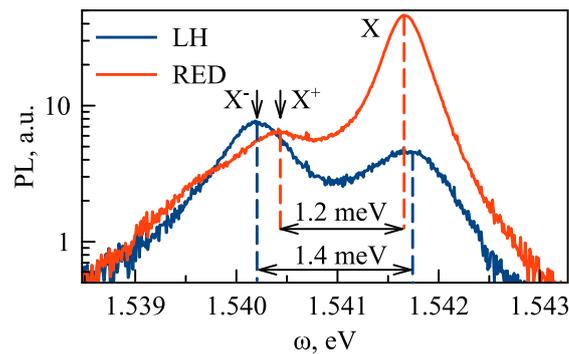


Figure 2. PL spectra at resonant (blue curve) and non-resonant (red curve) pumping.

Change of the sign of charge carriers in QW was further proved by PL spectroscopy. Fig 2 illustrates PL spectra at LH-exc and non-resonant above-barrier pumping ($\lambda = 650 \text{ nm}$). In both cases at energies below HH-exc resonance new lines emerge. These lines correspond to the luminescence from charged exciton complexes – negative X^- and positive trions X^+ in the case of resonant and nonresonant above-barrier excitation respectively. Difference in trion signs is also proved by difference of trion binding energies ($\Delta_{X^-} = 1.4 \text{ meV}$ and $\Delta_{X^+} = 1.2 \text{ meV}$).

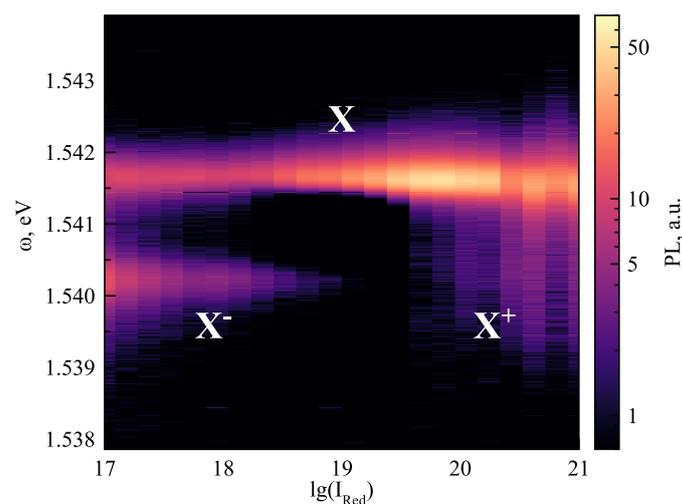


Figure 3. Dependence of PL spectrum on above-barrier pump intensity I_{Red} .

By fine tuning of above-barrier pumping intensity we can observe change from negative trion state to the positive one through the point of full charge compensation in QW (Fig. 3) as in [11].

At compensation point PL signal from neutral exciton state (X) reaches its maximum and PL signal from trions disappears. Quenching of X^- line is a result of compensation of resident electrons in QW. Further accumulation of holes in QW causes buildup of the peak corresponding to the recombination of X^+ trions.

4. Conclusion

By means of PL and reflection spectroscopy the bleaching effect in GaAs/AlGaAs QW in the presence of above-barrier illumination was investigated. The independence of the radiative width Γ_R on the pump intensity was found. At certain above-barrier illumination intensity nonradiative broadening Γ_{NR} reaches its minimum corresponding to the compensation of exceeding charge carriers within QW. As a result above-barrier illumination could be used for control of carriers sign as well as their full compensation.

5. Acknowledgments

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