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Optical emission and Rayleigh scattering in semiconductor superlattices in magnetic fields

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Abstract

We studied the Rayleigh light scattering and the optical emission in GaAs–(Al,Ga)As superlattices with ordered and intentionally disordered potential profiles, correlated and uncorrelated, in external magnetic fields. We find that the intentional disorder along z affects the resonant Rayleigh scattering and the optical emission. The external magnetic field in the same direction allows to modify the exciton localization and to study the relative modification of the light scattering and of the emission spectra.

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Keywords: Ligh scattering; Disordered systems; Superlattices; Exciton dephasing

In last years a great amount of work has been devoted to the study of the intentional and unintentional disorder in low-dimensional semiconductor systems, through the investigation of the physical properties of semiconductor superlattices (SL's). In particular, SL's are convenient to study the effect of an intentional disorder along the growth direction [1].

In the present work we study the resonant Rayleigh light scattering (RRS) and the optical emission in GaAs–Al_x-Ga_{1-x}As ordered SL's and in SL's with intentional disorder along the growth direction z, placed in an external magnetic field. RRS is phenomenon which take place in all directions, and which arises from the spatial fluctuation in the resonant frequency that, because of the strong dispersion near the resonance, leads to corresponding fluctuations in the refractive index. RRS has been successfully used to study the exciton localization and coherence dephasing in semiconductor structures [2–5].

The samples are three n^+–i–n^+ heterostructures grown by MBE with an SL in the intrinsic region. All the SL's are 200 periods long and are made with GaAs wells and $Al_{0.35}$ $Ga_{0.65}$As barriers. In the OSL both the wells and the barriers are 3.2 nm wide. In the random SL (RSL) 142 wells have a thickness of 3.2 nm, while 58 wells have a thickness of 2.6 nm and these last ones are places randomly in the SL. Also the so-called random dimer SL (DSL) has 142 wells 3.2 nm wide and 58 wells 2.6 nm wide, but in this case these 2.6 nm wells appear only in pairs placed randomly in the SL. In this last sample the disorder exhibits the desired short-range spatial correlation. While in the OSL the carriers are delocalized due to the presence of the SL miniband along z, in the RSL the intentional disorder localizes the carriers. Instead in the DSL the correlated disorder induces a carrier delocalization along z. These effects have been observed experimentally by optical and vertical transport experiments [6].

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In Fig. 1 we report a series of spectra (luminescence plus scattered light) measured on the three SL at a magnetic field of 3 T. In the same figure we report the PL excitation (PLE) spectra detected at the maximum of the PL. The PL and RRS spectra of the three SL's are clearly dissimilar, due to the different electronic structure of the SL's. In particular, they are wider in the two disordered SL's then in the ordered one, owing to their intentional disorder which affects directly the linewidth. We can note that the PL and RRS of the DSL are asymmetric. The high-energy shoulder at around 1.705 eV of the PL and RRS of the DSL can be attributed to excitonic transitions in the 3.2 nm isolated wells.

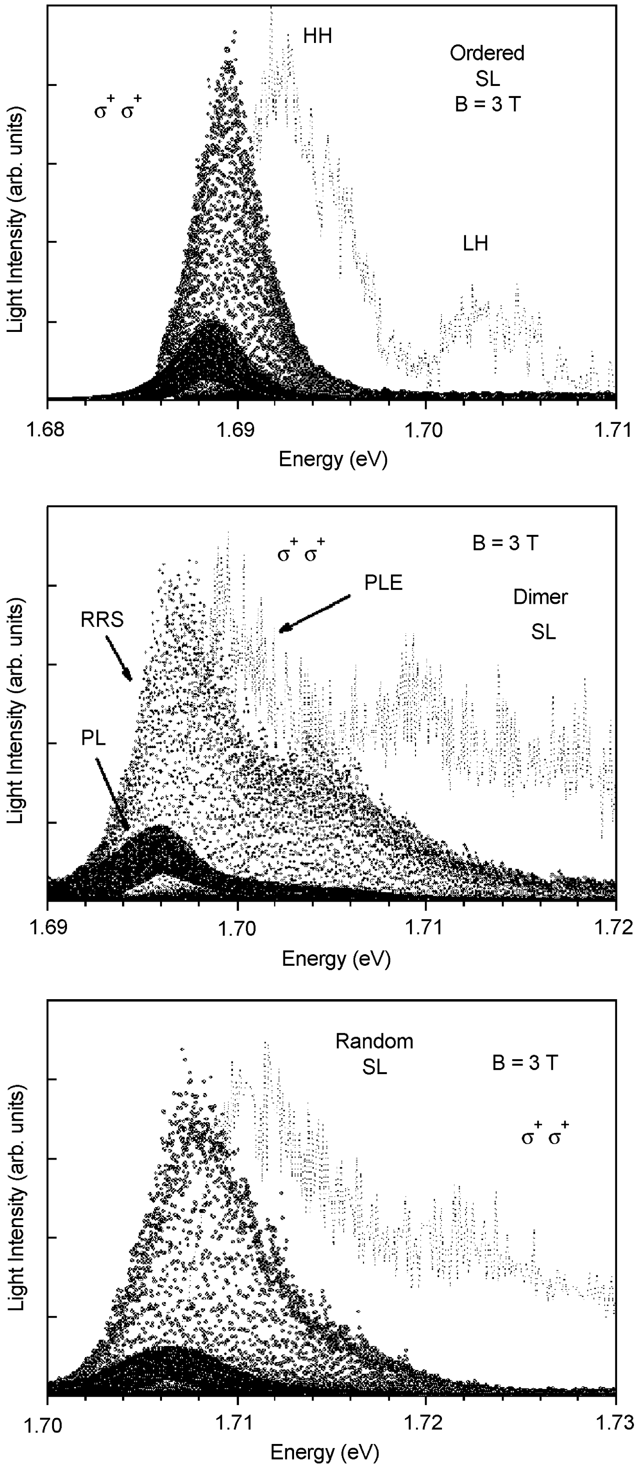

Fig. 1. RRS, PL and PLE spectra of three SL's at a magnetic field of 3 T. The spectra are plotted using small dots to identify two main structures: the RRS and the PL. HH and LH refer to heavy and light hole transitions.

In order to get quantitative information of the exciton dephasing we have calculated the energy dispersion of the homogeneous linewidth using the model of Hegarty and coworkers

$$\Gamma_h(\omega) = \left[\frac{I_s(\omega)}{K[1 - T^2(\omega)]} + \Gamma_x^{-1}\right] - \Gamma_0, \tag{1}$$

where $I_s(\omega)$ is the RRS intensity, Γ_x is the observed linewidth, T the optical transmission of the sample, K is a constant and Γ_0 a fix parameter related to the layer thickness and to the correlation length of the unintentional width fluctuations. Due to experimental reasons we did not measure the optical absorption of the samples but we measured the PLE which is, however, proportional to the absorption.

In Fig. 2 we show $\Gamma_h(\omega)$ at a field of 3 T obtained from Eq. (1). In the figure, for each SL, $\Gamma_h(\omega)$ is normalized to unity at the energy of the maximum of the PLE. For the OSL we see that $\Gamma_h(\omega)$ grows monotonously as observed by Hegarty and coworkers in the case of ordered multiple quantum wells [2,3]. According to theses authors the rapid increase of the homogeneous linewidth can interpreted as due to the presence of a mobility edge between delocalized and localized states and of a phonon dephasing which result in an exponential growth of $\Gamma_h(\omega)$ (Eq. (4) of Ref. [8]).

The $\Gamma_h(\omega)$ of the OSL is well fitted by an exponential function as shown in Fig. 2. Takagahara showed that in a

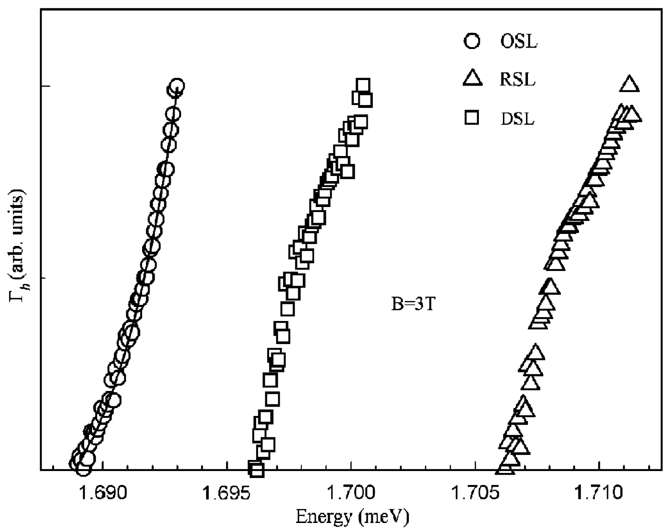

Fig. 2. The energy dispersion of the normalized homogeneous linewidth for the three SL's at a magnetic field of 3 T. The full line is a fit of the dispersion of the OSL with an exponential function.

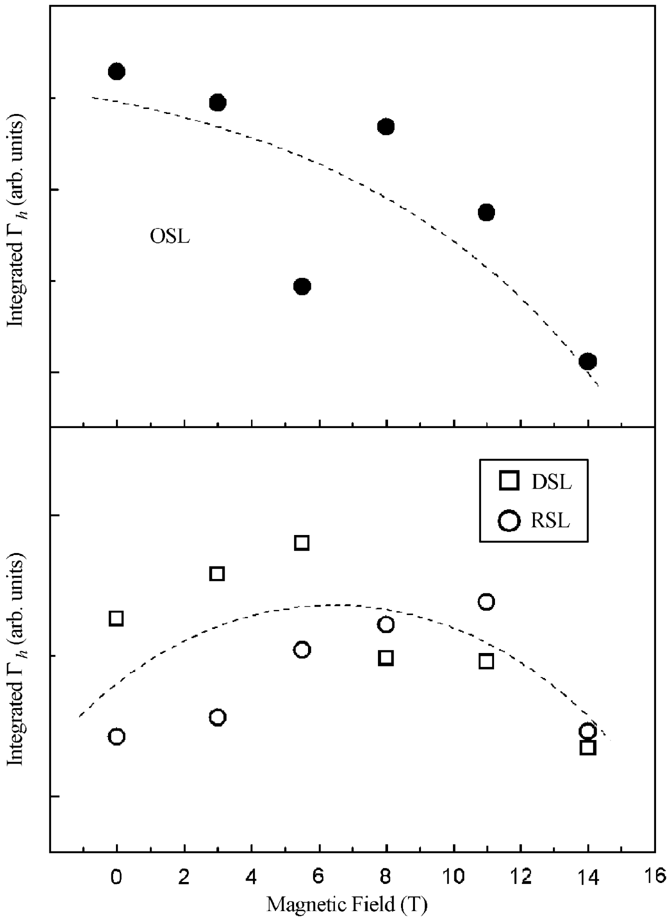

Fig. 3. The integrated homogeneous linewidth for the three SL's as a function of the magnetic field. The lines are guides to the eye.

quantum well heterostructure there is a transition region, few meV wide, between delocalized and localized regimes with a progressive change between the two regimes [7]. In contrast, in the case of the RSL and DSL $\Gamma_h(\omega)$ grows not exponentially, but displays a turndown roughly at the half of energy range, that is related to the intentional disorders along z.

In Fig. 3 we report the value of the integral of $\Gamma_h(\omega)$ over a 4 meV range starting from the energy of the RRS peak, as a function of the external magnetic field. We can observe that for the OSL the integrated $\Gamma_h(\omega)$ diminishes with increasing the magnetic field. This can be understood considering that the field localizes the excitons and that the dephasing mechanisms for a localized exciton are fewer and weaker than for a delocalized one [8]. Instead for the two disordered SL's the integrated $\Gamma_h(\omega)$ does not decrease monotonously. This behavior suggests a more complex interplay between the localization due to the intentional disorder along z and the localization due to the magnetic field.

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