Effect of temperature on exciton trapping on interface defects in GaAs quantum wells

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We present investigations of the temperature dependence of the luminescence and excitation spectra in a GaAs single quantum well grown by metal-organic chemical-vapor deposition. The results support our previous interpretation of the luminescence line at low temperature in terms of exciton trapping on interface defects.

In a previous paper,[1] we have presented experimental evidence for the binding of excitons to interface defects in single GaAs-$Ga_xAl_{1-x}As$ quantum wells grown by metal-organic chemical-vapor deposition (MO-CVD). At low temperatures (2 K), a Stokes shift of a few milli-electron-volts has been found between the luminescence line and the first peak observed in the excitation spectrum.[1,2] This peak is due to transitions involving free excitons corresponding to the $n=1$ electron (E_1) and heavy-hole (HH_1) states, and the luminescence line was attributed to the radiative recombination of excitons trapped on interface defects. A simple calculation of the exciton binding energy on these defects provided values in reasonable agreement with the optical data. This interpretation was based on the assumption that the recombining excitons trapped on interface defects are not thermalized, which was supported by a calculation of the phonon-assisted trapping time τ_{trap} of a free exciton by a trap (i.e., an interface defect) and of the phonon-assisted jumping time τ_{jump} of a bound exciton between traps. In relatively good samples, typical dimensions of the interface defects were two monolayers for the defect depth and 200 Å for their lateral size.[3] The density of these defects was taken to be in the 10^{10}-cm^{-2} range, corresponding to a mean lateral distance between two defects equal to about 1000 Å. This is in accordance with $\tau_{trap} < \tau_{lum} < \tau_{jump}$, where τ_{lum} is the recombination time measured in time-resolved luminescence experiments.[4] For a much lower trap density, a photocreated free exciton has not enough time to be trapped during its lifetime τ_{lum} (i.e., $\tau_{trap} > \tau_{lum}$); for a much larger density, a trapped exciton can jump from one defect to another (i.e., $\tau_{lum} > \tau_{jump}$), which would lead to a luminescence line evidencing a thermalization of the recombining excitons. We wish to show here that the temperature dependence of the luminescence and excitation spectra strongly supports our interpretation.[1]

Figure 1 shows typical luminescence and excitation spectroscopy data obtained at different temperatures in a 70-Å-thick single GaAs-$Ga_{0.48}Al_{0.52}As$ quantum well which was grown by MO-CVD.

The sample was fixed on a cold finger in a variable temperature cryostat and we used, in these experiments, standard cw dye laser and lock-in techniques. The dashed lines correspond to the photoluminescence spectra and the solid ones to the excitation spectra. The low-energy excitation peak corresponds,[1] as already mentioned, to excitons involving heavy holes, and the second one to excitons involving light holes. The energies of the excitation and luminescence peaks are plotted in Fig. 2 as a function of temperature. The red shift of the heavy-hole (curve *b*) and light-hole (curve *a*) peaks when the temperature is increased reflects simply the temperature decrease of the band gap of GaAs (Ref. 5) which is also shown in Fig. 2 (curve *d*). The behavior of the luminescence line (Fig. 1) is actually different: (i) When T is raised, it broadens; (ii) its energy position is found to be temperature independent up to 30 K (curve *c* in Fig. 2) and, then, presents the same variation with temperature as the excitation peaks. We think that these data are consistent with a temperature-induced detrapping of the excitons bound to interface defects.

Since $\tau_{trap} < \tau_{lum}$, there is, in fact, a thermodynamical

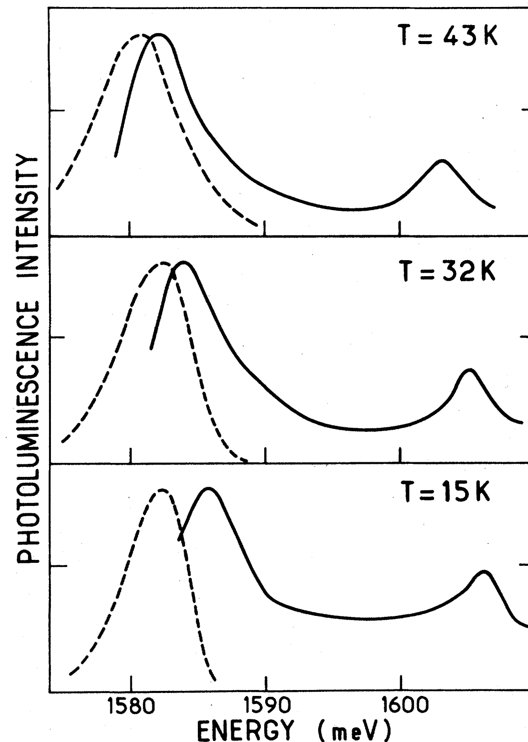

FIG. 1. Excitation (solid line) and luminescence (dashed line) observed at different temperatures in a 70-Å-thick single GaAs quantum well.

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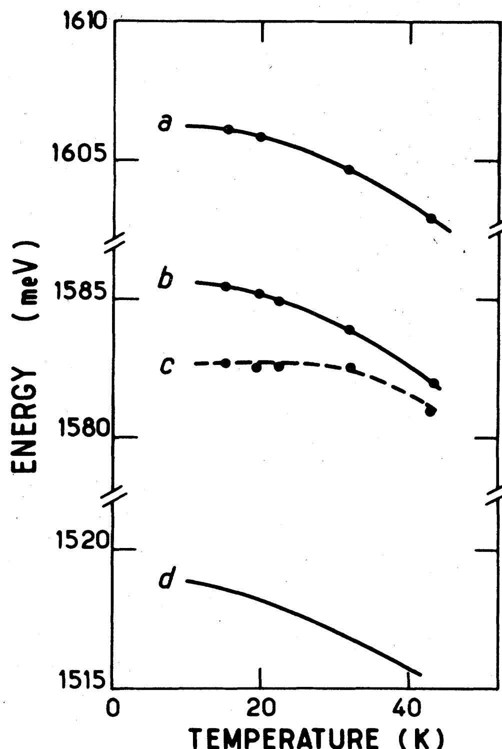

FIG. 2. Temperature dependence of the energies of the excitation (curves *a* and *b*) and luminescence (curve *c*) peaks shown in Fig. 1 and discussed in the text. The variation with temperature of the band gap of GaAs is also shown here (curve *d*).

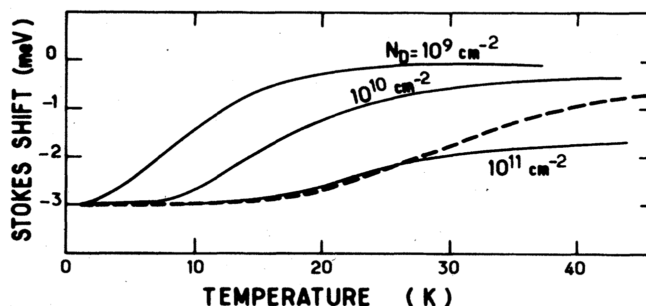

FIG. 3. Calculation, for different values of the trap density N_D, of the Stokes shift between the luminescence and first excitation peaks as a function of temperature (solid lines). The observed Stokes shift is also presented here (dashed line).

equilibrium between the bound- and free-exciton states. This leads in the low-excitation regime to $g_i \exp(-E_i/kT)$ Boltzmann occupation factors in the luminescence intensity associated with each of the recombination processes. Here, g is the degeneracy factor of the ith exciton level with energy E_i and T is the lattice temperature. Thus, the luminescence line involves bound- and free-exciton states and, when the temperature is raised, it broadens on the high-energy side as the free-exciton states are populated; it shifts also towards the heavy-hole exciton peaks in the excitation spectrum because free excitons have a much larger density of states than trapped excitons. From a qualitative point of view, these considerations are in agreement with the experimental results reported here.

A more quantitative understanding of the temperature variation of the luminescence peak can be reached from a crude calculation. If we call E the mean binding energy of excitons to traps and N_D the concentration of interface defects, the occupation numbers of bound and free states are easily found to be, respectively, proportional to $N_D \exp(E/kT)$ and $m_x kT/2\pi\hbar^2$, where m_x is the free-exciton translational mass. If we assume that the recombination matrix element is the same for both free and trapped excitons, the corresponding luminescence intensities are thus proportional to the respective occupation numbers of the involved levels. The position of the resulting luminescence peak can be roughly calculated by a simple averaging between the energies of the bound- and free-exciton levels. The results of such calculations are shown in Fig. 3 for several values of N_D, taking $m_x = 0.54 m_0$ and $E = 3$ meV which is the Stokes shift observed at low temperatures. The experimental Stokes shift, which is also shown in Fig. 3, decreases from 3 to 0.5 meV when the temperature increases. From the results presented in Fig. 3, a value of N_D ranging between 10^{10} and 10^{11} cm^{-2} is found for the sample under consideration here. It is noteworthy that this is in accordance with the order of magnitude taken for N_D in Ref. 1 to calculate the trapping and jumping times.

In conclusion, the temperature dependence of the luminescence and excitation spectra of reasonably good GaAs-$Ga_xAl_{1-x}As$ quantum wells supports qualitatively a model of trapping of excitons on interface defects, as well as the kinetics of this trapping. We would like to emphasize that, in poorer samples, the higher density of defects leads to a partial and complicated thermalization of trapped excitons which is not described here.

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