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HYDROSTATIC PRESSURE DEPENDENCE OF THE PHOTOLUMINESCENCE IN HEAVILY DOPED GaAs

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The photoluminescence at the direct gap E_o of heavily doped p- and n-type GaAs is reported as a function of pressure applied with a diamond anvil cell. The emission in the p-samples is still observed after the material becomes indirect, because of the enhancement of the radiative recombination by the presence of the free holes. The transfer of the free electrons from Γ_1^c to X_1^c determines the pressure dependence of the emission in n-GaAs.

GaAs is a direct gap semiconductor at normal pressure. Due to the different signs of the pressure coefficients of the direct (Γ_1^c-Γ_8^v, E_o gap) and the indirect (X_1^c-Γ_8^v)-energy gap GaAs becomes indirect when the pressure is increased above 40 kbar. Studies of the spontaneous recombination across the direct E_o gap as a function of pressure have shown that the luminescence efficiency decreases when the lowest gap becomes indirect and, in the case of undoped GaAs, the E_o emission completely disappears for pressures beyond 45 kbar [1].

Figure (1) displays typical photoluminescence spectra at the E_o gap of heavily doped p-GaAs as a function of hydrostatic pressure. For pressures in the range between 30 and 45 kbar the intensity of the luminescence decreases exponentially, as shown in Fig.(2), due to the crossing between the Γ_1^c- and X_1^c-conduction band states. However, the emission is still observed for pressures above that at which the material becomes indirect, due to the enhancement of the luminescence by the free holes. The ratio of the intensity above 60 kbar to that at low pressures decreases with decreasing free hole concentration. The solid lines of Fig.(2) represent theoretical fits to the pressure dependence of the intensity for a series of hole concentrations. The fits were performed using the following expression for the intensity [1,2]:

$$I \simeq I_o\{[1+A\exp\frac{(\alpha_\Gamma-\alpha_X)(P-P_o)}{kT}]^{-1}+\frac{\tau_{\Gamma\to X}}{\tau_{rad}}\} \qquad (1)$$

where I_o is a constant, P_o the pressure at which Γ_1^c and X_1^c are degenerate, α_Γ the pressure coefficient of the E_o gap, α_X that of the (X_1^c-Γ_8^v) indirect one and A is related to the density of states of the conduction band at Γ and X [1]. τ_{rad} is the radiative recombination time which depends on hole concentration [3] while $\tau_{\Gamma\to X}$ represents an average scattering time of the photoexcited electrons from the conduction band states near Γ to those near X.

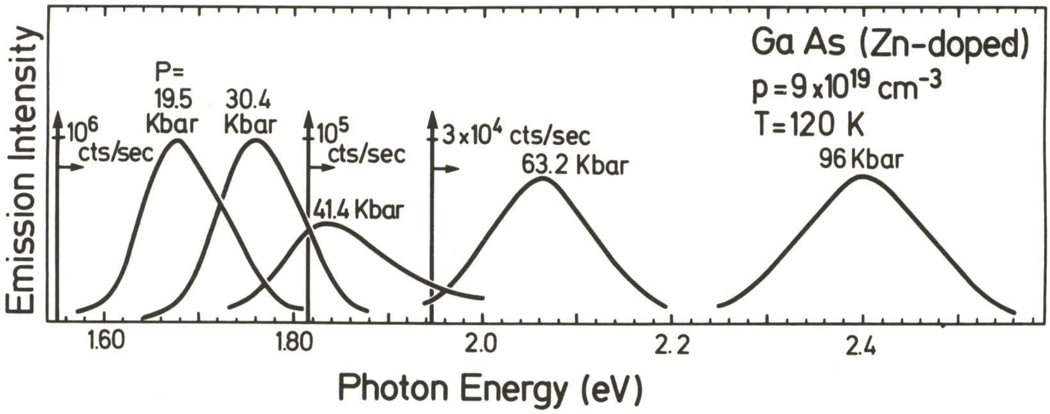

Fig. 1
Photoluminescence spectra at the E_o gap in heavily doped p-GaAs under various pressures

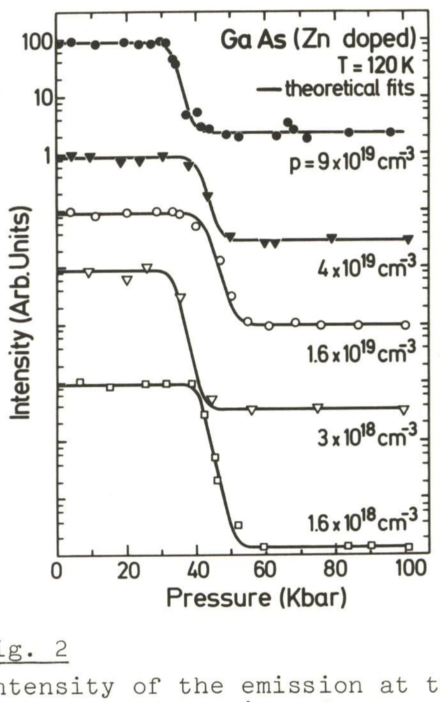

Fig. 2
Intensity of the emission at the E_o gap as a function of pressure for various hole concentrations

The first term on the r.h.s. of Eq. (1) refers to the transfer of photoexcited electrons to the X_1^c states after the "X_1^c, Γ_1^c" crossing, while the second term takes account of the enhancement of the emission by the free holes because τ_{rad} decreases with increasing hole concentration [3]. The parameters obtained from the fits using our own measured values for α_Γ (Ref.2) are listed in Table I. The average value of $\alpha_X = -(1.8\pm0.6)\mathrm{x}10^{-3}$ eV/kbar agrees with previously published ones [1].

Luminescence at the indirect energy gap $X_1^c-\Gamma_8^v$ was observed in samples with $1.6\mathrm{x}10^{18}$ holes cm^{-3} for pressures between 40 and 55 kbar. This new emission line labeled $X_1^c \rightarrow \Gamma_8^v$ in Fig.(3) shifts to lower energies with increasing hydrostatic pressure with $\alpha_X = -(2.8\pm0.8)\mathrm{x}10^{-3}$ eV/kbar in agreement, within experimental error, with the value obtained from the fits of the pressure dependence of the intensities. A value of (1.946±0.02)eV is obtained for the energy difference $X_1^c-\Gamma_8^v$ at normal pressure [2], which agrees with previous measurements [4]. The new line represents to our knowledge the first observation of indirect luminescence when a material becomes indirect upon application of pressure.

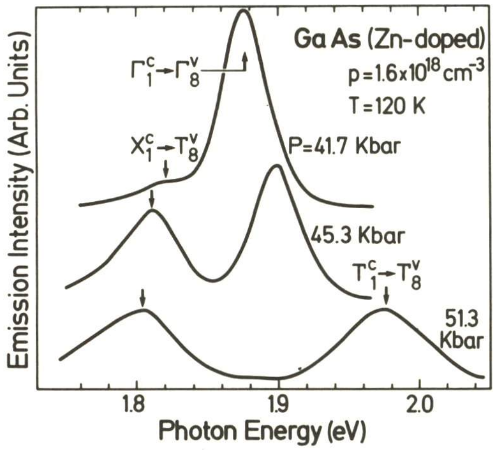

Fig. 3

Pressure dependence of the emission at the indirect X_1^c-Γ_8^v energy gap

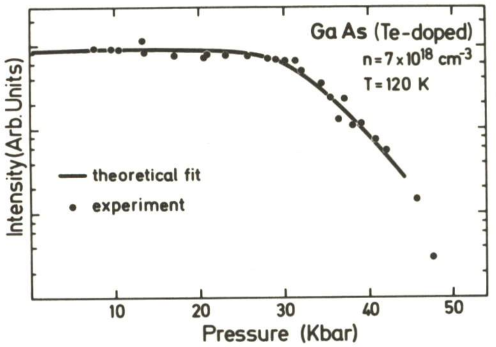

Fig. 4

Pressure dependence of the emission at the E_o gap in n-GaAs

The emission at the E_o gap in heavily doped n-GaAs disappears for values of the pressure above P_o, as displayed in Figure (4). The intensity of the luminescence from the direct gap in heavily doped n-GaAs can be described by [2]:

$$I = I_o n_\Gamma(P)/n_\Gamma(0) \qquad (2)$$

with $n_\Gamma(P)$ the free electron concentration at Γ under pressure P. As pressure is applied $n_\Gamma(P)$ decreases because of the transfer of the free electrons to the X_1^c-states. The solid line of Fig.(4) was calculated taking into account the pressure dependence of n_Γ.

In the case of n-type semiconductors the shape of the luminescence lines at the direct gap is related to the position of the Fermi level relative to the bottom of the conduction band at Γ, in a way described in Ref.5. With increasing pressure the width of the emission lines of n-GaAs decreases. Figure [5]. displays the change of shape of the lines as a function of pressure. This effect can be quantitatively explained by the pressure dependence of the Fermi level with respect to the Γ_1^c-minimum as indicated by the theoretical fit on Fig.(5). A detailed report of this work will appear in [2].

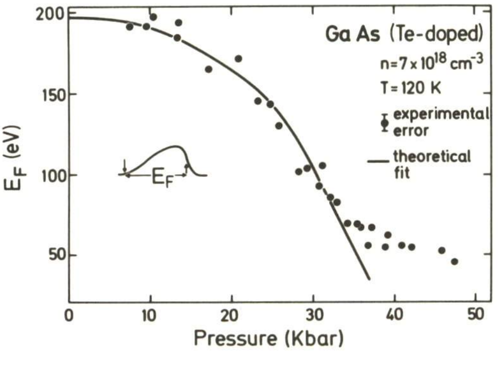

Fig. 5

Pressure dependence of the Fermi level measured from the bottom of Γ_1^c in n-GaAs

Table I. Parameters obtained from the fits with Eq. (1)

$p(cm^{-3})$	A	P_o(kbar)	$\alpha_X/10^{-3}$eV $kbar^{-1}$	$\tau_{\Gamma\to X}/10^{-12}$ sec
$9x10^{19}$	7	36	-2.3	3.5
$4x10^{19}$	7	44	-1	6
$1.6x10^{19}$	7	46	-2.4	3.7
$3x10^{18}$	7	37	-1.4	4
$1.6x10^{18}$	7	43.5	-1.2	2.6

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