HYDROSTATIC PRESSURE SPECTROSCOPY OF THE VANADIUM LUMINESCENCE IN GaAs

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We report luminescence measurements of the intracenter transition $^3T_2 \rightarrow {}^3A_2$ of the $V^{3+}(3d^2)$ charge state in semi-insulating GaAs under hydrostatic pressure up to 0.8 GPa at liquid helium temperature. The hydrostatic pressure coefficient of the zero-phonon line is found to be equal to 6.9 ± 0.2 meV/GPa. This result enables us to determine the Huang–Rhys parameter, which characterizes the coupling to the symmetric mode of vibration, as $S_A = 1.4 \pm 0.1$. Using this parameter, computer simulation leading to a reconstruction of the shape of both luminescence and corresponding absorption spectra were performed.

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1. Introduction

Optical absorption and luminescence bands in GaAs at 0.74 eV corresponding to $^3A_2 \leftrightarrow {}^3T_2$ transitions of the $V^{3+}(3d^2)$ charge state crystals have been investigated for many years (see for example review articles [1, 2]). The results of several experiments were analysed in terms of a dynamical Jahn–Teller effect with the ε-mode existing in the excited $^3T_2$ state [3–7]. The obtained values of the Huang–Rhys parameter $S_E = E_{JT}/\hbar\omega_E$ (where E_{JT} is the Jahn–Teller energy and $\hbar\omega_E$ — the phonon energy) vary between 3.4 and 4. It was also shown [8] that in order to explain the total shape of luminescence and absorption bands, an interaction with the symmetric α-mode of vibrations should also be taken into account.

The lack of any effect of hydrostatic pressure up to 1 GPa on the transport properties of p-type GaAs:V [9] suggests a minor influence of the α-mode on the ground $^3A_2$ state (degenerate with the GaAs valence band). The parameter S_A describing the interaction of the α-mode with the excited $^3T_2$ state can be thus obtained by a moment analysis of the luminescence or absorption bands [8] or from the hydrostatic pressure coefficient of one of these bands. This pressure coefficient is known from a uniaxial stress experiment [3], but with a significant experimental error.

This paper presents hydrostatic pressure measurements of the vanadium luminescence band which gave a much more accurate value of the pressure coefficient and, subsequently the S_A parameter. This result and the ε-mode Jahn–Teller data from literature make it possible to reproduce the shape of both luminescence and absorption spectra

2. Experimental

Vanadium doped, semi-insulating GaAs crystals were prepared by the liquid encapsulated Czochralski (LEC) technique with a vanadium concentration of $7 \div 8 \times 10^{16}$ cm^{-3} [10]. Zero pressure luminescence was measured in a CF1204 (Oxford) cryostat. For pressure investigations samples were placed in a high pressure optical cell with benzine as the transmitting medium. The cell with a sample was mounted in the exchange helium gas cryostat and cooled to low temperatures. Hydrostatic pressure up to 0.8 GPa was measured with a calibrated InSb manometer. Photoluminescence (PL) was excited by the 488 nm line of an Ar ion laser with power density around 1 W/cm^2. PL was analysed with a SPEX 500M monochromator equipped with a North Coast Optics Ge photodiode or cooled PbS detector (Hamamatsu).

3. Results and discussion

A typical low-temperature (4 K) atmospheric pressure photoluminescence spectrum related to the $^3T_2 \rightarrow {}^3A_2$ transition is shown in Fig. 1. It consists of a strong zero-phonon line (ZPL) A with accompanying hot line B (see inset)
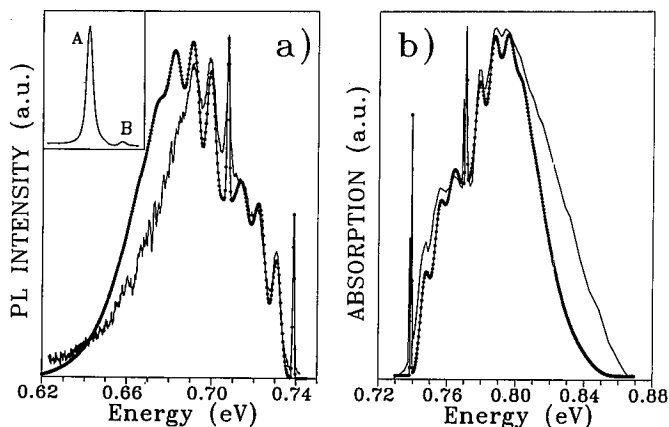

Fig. 1. Luminescence (a) and absorption (b) bands corresponding to $^3A_2 \leftrightarrow {}^3T_2$ transitions of the V^{3+}($3d^2$) charge state in GaAs at about 4 K (solid lines). Theoretical Poisson shapes (star lines) were calculated for the parameters $S_E = 3.9$, $\hbar\omega_E = 8.1$ meV; $S_A = 1.4$, $\hbar\omega_E = 31.5$ meV. Inset — luminescence zero-phonon lines A and B.
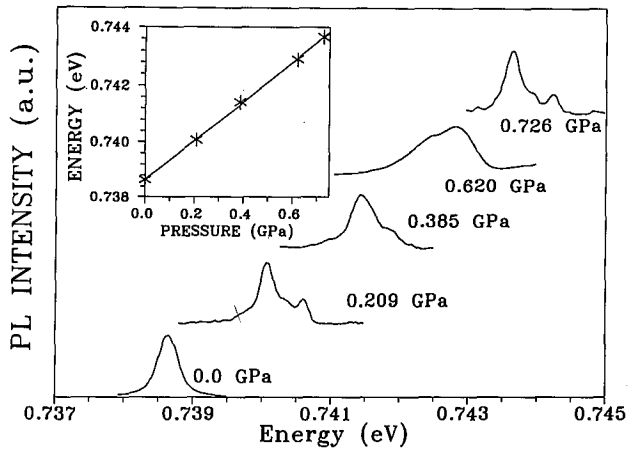
Fig. 2. Shift of the luminescence zero-phonon line A under hydrostatic pressure at about 4 K (10 K for 0.62 GPa). Inset — a linear fit to the experimental data with a pressure coefficient equal to 6.9 ± 0.2 meV/GPa.

followed by phonon replicas. The energy shift of the A line with increasing pressure is presented in Fig. 2. With the exception of the measurements at 0.62 GPa, all photoluminescence data were collected at about 4 K. The low intensity shoulders of the main line are due to axial stresses induced on the GaAs surface by frozen benzene. The measured positions of line A were plotted versus the stress value. A straight line fit to the data gave the hydrostatic pressure coefficient of the ZPL being equal to 6.9 ± 0.2 meV/GPa. From this value it is easy to calculate the symmetric vibration energy $E_A = 43 \pm 3$ meV. Taking the phonon energy $\hbar\omega_A = 31.5$ meV from the experimental spectra one obtains the Huang–Rhys parameter being equal to $S_A = E_A/\hbar\omega_A = 1.4 \pm 0.1$.

Computer simulation taking into account optical transitions involving two phonons ($\hbar\omega_E$ and $\hbar\omega_A$) with the ε-mode Jahn–Teller effect at the $^3T_2$ state known from other experiments [3–7] and the obtained value of the S_A parameter lead to a reconstruction of the shape of both luminescence and absorption bands (see Fig. 1).

Acknowledgment

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