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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  $6.9 \pm 0.2$  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  $\epsilon$ -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  $\alpha$ -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  $\alpha$ -mode on the ground  ${}^3A_2$  state (degenerate with the GaAs valence band). The parameter  $S_A$  describing the interaction of the  $\alpha$ -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  $\epsilon$ -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  $7 \div 8 \times 10^{16} \text{ cm}^{-3}$  [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  $1 \text{ W/cm}^2$ . 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)

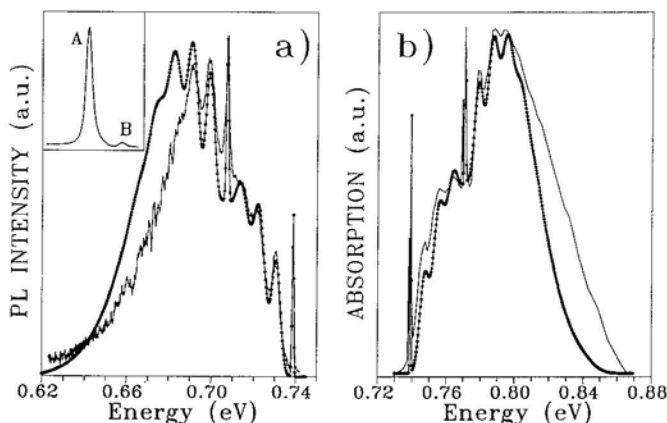


Fig. 1. Luminescence (a) and absorption (b) bands corresponding to  ${}^3A_2 \leftrightarrow {}^3T_2$  transitions of the  $V^{3+}(3d^2)$  charge state in GaAs at about 4 K (solid lines). Theoretical Poisson shapes (star lines) were calculated for the parameters  $S_E = 3.9$ ,  $\hbar\omega_E = 8.1 \text{ meV}$ ;  $S_A = 1.4$ ,  $\hbar\omega_E = 31.5 \text{ meV}$ . Inset — luminescence zero-phonon lines A and B.

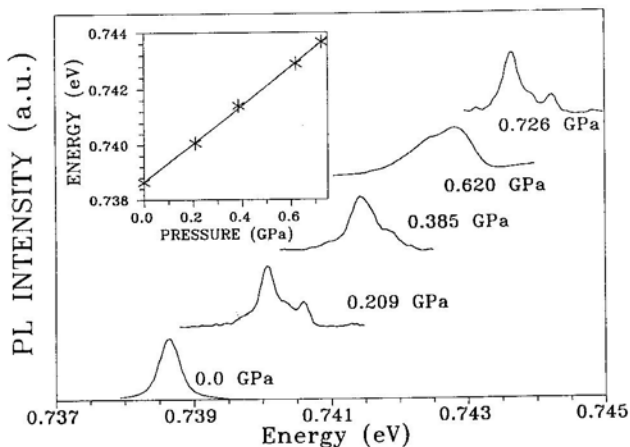


Fig. 2. Shift of the luminescence zero-phonon line A under hydrostatic pressure at about 4 K (10 K for 0.62 GPa). Inset — a linear fit to the experimental data with a pressure coefficient equal to  $6.9 \pm 0.2$  meV/GPa.

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  $6.9 \pm 0.2$  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  $\epsilon$ -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).

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