Vol. 79 (1991) *ACTA PHYSICA POLONICA A* No 2–3

Proc. XIX International School of Semiconducting Compounds, Jaszowiec 1990

EFFECT OF HYDROSTATIC PRESSURE ON InP:Yb LUMINESCENCE*

A. STĄPOR, A. KOZANECKI,

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, Warszawa, Poland

K. REIMANN, K. SYASSEN,

Max-Planck-Institute für Festkörperforschung, Heisenbergstrasse 1, Stuttgart, Germany

J. WEBER, M. MOSER AND F. SCHOLZ

4 Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, Germany

(Received August 8, 1990)

The effects of hydrostatic pressure on the InP:Yb luminescence were explored using a gasketed diamond anvil cell (DAC). The pressure dependence of the Yb^{3+} luminescence shows a small positive shift (0.96 meV/GPa) at low pressures (< 4 GPa) and a negative one (−0.04 meV/GPa) above 4 GPa. The spectra of the Yb^{3+} emission differ markedly in these two pressure ranges. It was concluded that intra-$4f$-shell transitions of the Yb^{3+} on indium substitutional (T_d) site dominate in the spectrum above 4 GPa, whereas at lower pressures the emission has a different nature.

PACS numbers: 71.55.Eq, 78.55.Cr

In spite of improvements in the growth techniques, the quantum efficiencies of the RE-related luminescence in III–V materials are usually poor. The only exception is InP:Yb, which shows strong Yb-related luminescence at 1 μm [1, 2] (see also Fig. 1). In contrast to the behavior usually exhibited by the RE-s dopants which tend to form several different centers, as, e.g. it is true for Er in GaAs [3], all the InP:Yb samples reveal the same Yb-related emission spectrum. For ambient pressure at 4 K, this consists of three relatively sharp zero-phonon lines at 1.230 eV, 1.238 eV, and 1.242 eV. The strongest 1.238 eV line is accompanied by a broad band of local phonon replicas. Zeeman [8], photoluminescence excitation (PLE) [5],

*This work was suported in part by CPBP 01.12.

and electron paramagnetic resonance (EPR) [6] experiments led to the conclusion that the spectrum is due to the $^2F_{5/2} \rightarrow {}^2F_{7/2}$ intra-$4f$-shell transition of an Yb^{3+} ion replacing indium on a substitutional site (T_d symmetry).

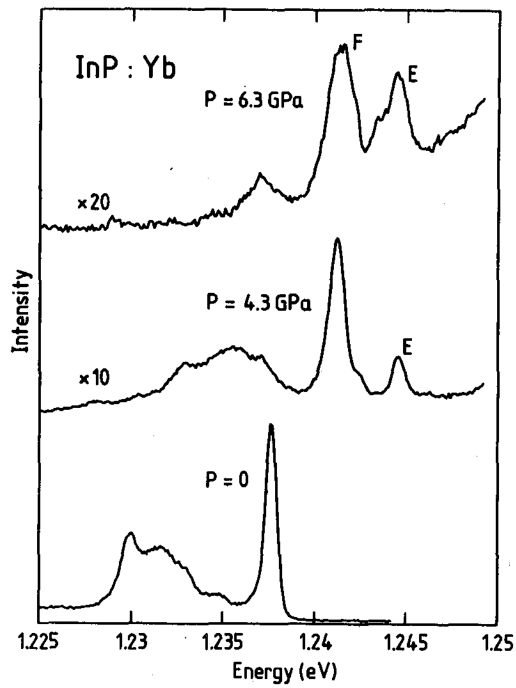

Fig. 1. Spectra of the Yb-induced emission in MOVPE-grown n-type InP:Yb for different pressures, at 6 K.

The pressure dependencies of the Yb-related luminescence are presented in Figs. 1 and 2. In the low pressure range, the 1.238 eV line (ascribed by Aszodi et al. [4] to the $\Gamma_8 \rightarrow \Gamma_8$ transition of the Yb^{3+} cubic center) and its phonon replicas dominate in the spectrum, revealing weak pressure dependence (0.96 meV/GPa). Above 4 GPa, the 1.238 eV line disappears abruptly, and two new lines (E and F), showing very small negative shifts, become dominant. The energy of the F line at ambient pressure, extrapolated from its pressure dependence at high pressures, fits perfectly with the position of the 1.242 eV line, which was assigned to the $\Gamma_8 \rightarrow \Gamma_8$ transition of the cubic Yb^{3+} center. Serious problems are met when one wants to describe the pressure evolution of the Yb-induced luminescence in a picture of a cubic Yb^{3+} center [4]. These are due to very different properties of the emission below and above of 4 GPa (see Figs. 1 and 2). The very simple energy structure of the Yb^{3+} T_d center offers only two possible explanations for these "4 GPa" anomalies : a $\Gamma_8(^2F_{5/2}) - \Gamma_6(^2F_{5/2})$ crossover and an abrupt change of the Yb^{3+} center symmetry that should occur in the vicinity of 4 GPa. We can probably rule out the last possibility, because a solid-state phase transition in InP is not expected till 10.6 GPa [7]. As far as the $\Gamma_8 - \Gamma_6$ crossover is concerned, transitions from the Γ_8 state, which is assumed to be the lower crystal-field state of the $^2F_{5/2}$ spin–orbit level, should dominate in the spectrum at low pressures (< 4 GPa), whereas, at higher pressures the role of the transitions from the Γ_6 state should increase. Therefore, the 1.238 eV line should be assigned to the Γ_8 state, but the E and F lines, whose zero-pressure energies are 1.245 eV and 1.242 eV, respectively, to the Γ_6 state. Unfortunately, this description disagrees totally with the energy structure postulated for the cubic Yb^{3+} center.

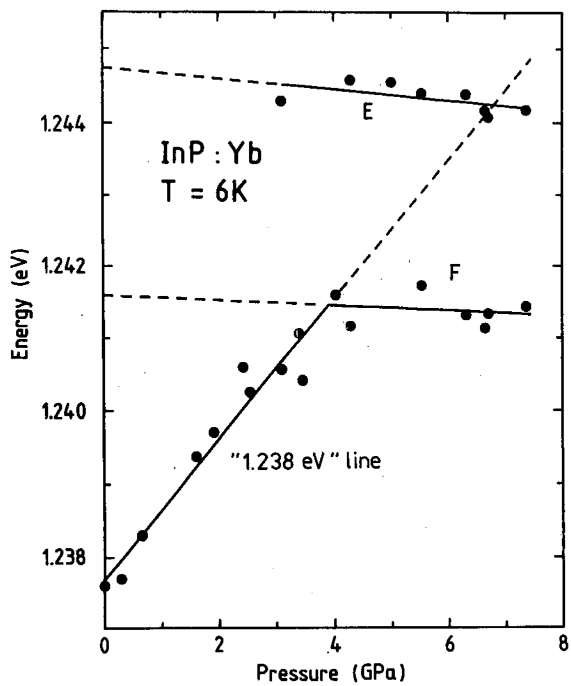

Fig. 2. Pressure dependences of the Yb-related emissions in MOVPE-grown *n*-type InP:Yb, at 6 K; the solid lines represent linear fits to the experimental points.

Hence, we conclude the "4 GPa" anomalies cannot be understood in the simple picture of a single Yb^{3+} cubic center, and we are dealing with two Yb-induced emissions of different origins. In contrast to the postulated energy structure of the Yb^{3+} T_d center in InP, a point-charge model predicts, for Yb^{3+} at a substitutional (T_d) cation site [8], Γ_6 and not Γ_8 to be the lower-lying crystal-field state of the $^2F_{5/2}$ level. Then, according to the symmetry selection rules for MD transitions, only two $\Gamma_6 \rightarrow \Gamma_6$ and $\Gamma_6 \rightarrow \Gamma_8$ transitions are allowed from the Γ_6 state. That would agree nicely with the spectrum observed at high pressures, where lines F and E dominate. Therefore, it is likely that these lines come from the Yb^{3+} cubic center and the 1.238 eV line has a different orgin.

The abrupt change of the Yb-induced luminescence spectrum observed in the vicinity of 4 GPa (see Figs. 1 and 2) seems to be a result of the appearance of the Yb^{2+}/Yb^{3+} level in the InP gap. The level probably moves out of the conduction band at about 4 GPa. In this way, a new, and very efficient, excitation mechanism of Yb^{3+} emission would become active at higher pressures. This consists of electron capture on the Yb^{2+}/Yb^{3+} state, followed by nonradiative electron relaxation, resulting in excitation of the Yb^{3+} $4f$ shell [9].

References

[1] L.F. Zakharenkov, V.A. Kasatkin, F.P. Kesamanly, B.E. Samorukov, M.A. Sokolowa, *Sov. Phys.-Semicond.* **15**, 946 (1981).

[2] K. Uwai, H. Nakagome, K. Takahei, *Appl. Phys. Lett.* **50**, 977 (1987).

[3] H. Nakagome, K. Uwai, K. Takahei, *Appl. Phys. Lett.* **53**, 1726 (1988).

[4] A. Aszodi, J. Weber, Ch. Uihlein, L. Pu-Lin, H. Ennen, U. Kaufmann, J. Schneider, J. Windscheif, *Phys. Rev. B* **31**, 7767 (1985).

[5] J. Wagner, J. Windscheif, H. Ennen, *Phys. Rev. B* **30**, 6230 (1984).

[6] A. Stąpor, J. Raczyńska, H. Przybylińska, K. Fronc, J.M. Langer, in *Material Science Forum*, ed. H.J. von Bardeleben, Trans Tech, Switzerland 1986, Vol. 10-12, p. 633.

[7] S.W. Tozer, D.J. Wolford, J.A. Bradley, D. Bour, G.B. Stringfellow, in *Proc. 19th Internat. Conf. on Physics of Semiconductors, Warsaw 1988,* ed. W. Zawadzki, Vol. 2, Institute of Physics Polish Academy of Sciences, Warsaw 1988, p. 881.

[8] Z.J. Kiss, *Phys. Rev.* **127**, 718 (1962).

[9] A. Stąpor, M. Godlewski, H. Przybylińska, D. Hommel, *J. Lumin.* **40/41**, 625 (1988).