Solid State Communications, Vol. 85, No. 6, pp. 525–527, 1993.
Printed in Great Britain.

0038–1098/93 $6.00 + .00
Pergamon Press Ltd

THE INFLUENCE OF ISOCHRONOUS ANNEALING UPON THE NEAR-BAND-EDGE PHOTOLUMINESCENCE SPECTRA OF THE ELECTRON-IRRADIATED *n*-InP

S.I. Radautsan, I.M. Tiginyanu and V.V. Ursaki

Institute of Applied Physics, Academy of Sciences of the Moldova Republic, 277028 Kishinev, USSR

and

F.P. Korshunov, N.A. Sobolev and E.A. Kudryavtseva

Institute of Solid-State and Semiconductor Physics, Academy of Sciences of Belorussia Republic, 220726 Minsk, USSR

(*Received* 18 *May* 1992 *by R. Fieschi*)

The near-band-edge photoluminescence (PL) bands observed at 1.305 and 1.392 eV ($T = 4.2$ K) in electron-irradiated InP single crystals and epilayers have different behaviour with increasing temperature of isochronous annealing. Moreover, the band at 1.392 eV shows a complex structure, at least in *n*-InP epilayers. On the ground of these new results, an earlier proposed connection between these PL bands and the In_p-antisite defect may require a revision.

RECENTLY [1–3] it has been shown that electron-irradiation ($E = 3.5$–4 MeV) of indium phosphide single crystals and epilayers gives rise to two near-band-edge photoluminescence bands at 1.392 and 1.305 eV ($T = 4.2$ K) as well as to a wide band centered at 0.99 eV. The first two bands have been connected to electron transitions from the conduction band to two states of the In_p acceptor antisite defect. As to the band at 0.99 eV, it has been proved to be caused by V_p-type centers responsible for Fermi-level pinning effect in In_p under a high dose ($D > 2 \times 10^{17}$ cm^{-2}) of electron irradiation [3]. In this paper new results concerning the behaviour under isochronous heat treatment of these near-edge PL bands are presented.

(1 0 0)-Oriented wafers sawed from undoped LEC-*n*-In_p ingots have been investigated. Electron concentrations and carrier mobilities at 300 K in as-grown single crystals were 2×10^{16} cm^{-3} and 3550 cm^2 V sec^{-1}, respectively. For the purpose of comparison some vapour-phase-grown *n*-In_p epilayers [2], with a comparatively low density of residual impurities, have been measured as well. The electrical parameters at 77 K of the as-grown epilayers were the following: $n = 2 \times 10^{14}$ cm^{-3}, $\mu_n = 7.8 \times 10^4$ cm^2 V sec^{-1}. The irradiation by electrons ($E = 3.5$–4 MeV, $D = 2 \times 10^{17}$ cm^{-2}) was carried out at sample temperatures of about 30°C. Isochronous annealings were performed in a hydrogen atmosphere for 15 min at 50–400°C. PL was excited by argon laser ($\lambda_{exc} = 514$ nm) at $T = 4.2$ K, spectral resolution was better than 1 meV.

Figure 1 illustrates the near-band-edge PL spectra of electron-irradiated *n*-In_p crystals after annealing at different temperatures. One can distinguish up to seven PL bands in these spectra. According to the literature [4], the band with the maximum at 1.416 eV is due to exciton recombination, while the one at 1.376 eV corresponds to donor–acceptor (DA) recombination. The latter band is accompanied by LO-phonon replicas at 1.333 and 1.290 eV. One can observe also PL bands at 1.392 and 1.305 eV, attributed earlier to the In_p-defect. It has to be noted that the exciton and DA bands are observed in the as-grown and in the electron-irradiated samples, while the PL bands related to In_p-centers are observed only after the electron beam treatment of the crystals. A weak PL peak at 1.348 eV has been also observed in the electron-irradiated *n*-In_p crystals after annealing at 300–400°C. Taking into consideration the energy of LO-phonon in In_p ($\hbar\omega_{LO} = 42.8$ meV [5]) the above mentioned peak can be attributed to the LO-phonon replica of the 1.392 eV PhL band.

Isochronous annealing of the crystals results in a monotonous recovery of the PL band intensity (reduced by the electron irradiation) with the exception of the band at 1.305 eV. In the last case an enhancement of the band intensity with T_{ann} occurs in the interval 50°C $< T_{ann} <$ 150°C, followed

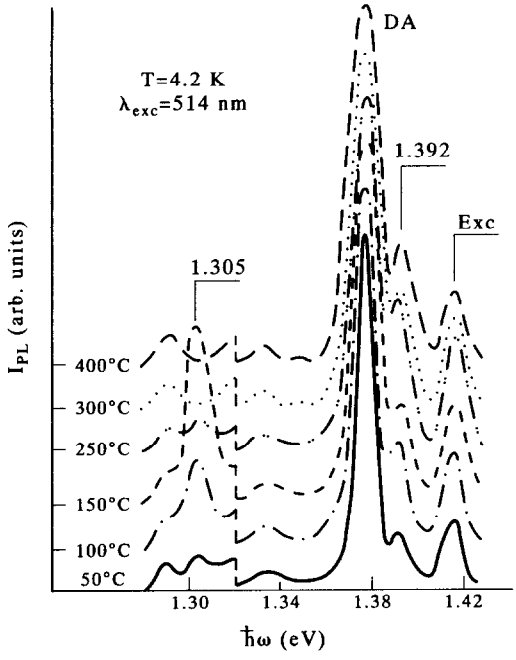

Fig. 1. Normalized PL spectra of electron-irradiated *n*-InP crystals after annealing at different temperatures. T_{ann}, °C: 1, 50; 2, 100; 3, 150; 4, 250; 5, 300; 6, 400.

by a decrease at higher temperatures. This is clearly seen in Fig. 2, where the dependence of the ratio $I_{1.305}/I_{DA}$ ($I_{1.305}$ and I_{DA} denote the intensity of PL bands at 1.305 and 1.376 eV respectively) upon T_{ann} is illustrated. The decrease of the 1.305 eV PL band intensity could be caused by the annealing of the acceptor In_p-centers. Indeed, at temperatures $T_{ann} >$ 120–150° a significant recovery of free electron concentration has been observed by us in preliminary irradiated In_p crystals, thus proving the occurrence of the acceptor-type defect annealing.

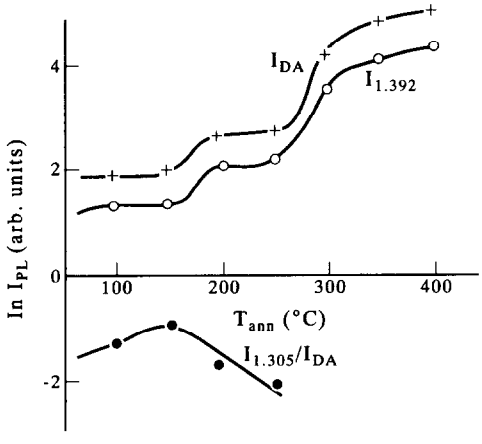

Fig. 2. The intensity of *n*-InP PL bands vs. the annealing temperature of single crystals.

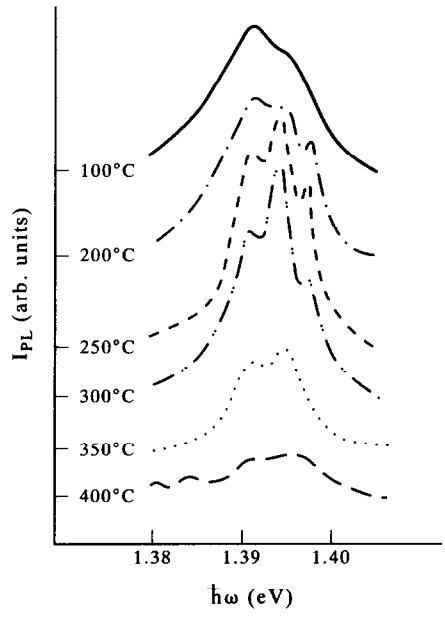

Fig. 3. PL spectra of electron-irradiated *n*-InP epilayers after annealing. T_{ann}, °C: 1, 100; 2, 200; 3, 250; 4, 300; 5, 350; 6, 400.

Let us now discuss the unexpected dependence upon the T_{ann} of the intensity of 1.392 eV PL band (see Fig. 2), which has been previously connected to the same In_p-center [1]. In order to get a better understanding of this band, we have thoroughly analysed the PL spectra of *n*-In_p electron-irradiated epilayers after annealing. It is important to note that *n*-In_p epilayers do not show a DA-band and its LO-phonon replicas [2]. In these In_p epilayers, the 1.392 eV band has a complex structure with several narrow PL bands (Fig. 3) unresolved in *n*-In_p single crystals. Therefore, this band results to be more complicated than it had been suggested earlier and additional investigations have to be performed to clarify the nature of all the narrow bands observed in the *n*-In_p epilayers. The complexity of the 1.392 eV band might explain its monotonous increase with T_{ann} up to 400°C without, however, excluding that the In_p-defect may contribute to the formation of a definite narrow PL band.

In summary, the isochronous heat treatment of electron-irradiated *n*-In_p single crystals and epilayers leads to the annealing of some point defects, including probably In_p, with an ensuing decrease of the intensity of the 1.305 eV PL band for $T_{ann} > 150$°C. It has also been shown that the band at 1.392 eV has a very reach structure which has to be further investigated in order to elucidate the nature of this band previously attributed to In_p-antisite defect.

REFERENCES

1. F.P. Korshunov, S.I. Radautsan, N.A. Sobolev, I.M. Tiginyanu, V.V. Ursaki & E.A. Kudryavtseva, *Fiz. Tekh. Poluprovodn.* **23,** 1581 (1989).
2. F.P. Korshunov, S.I. Radautsan, N.A. Sobolev, I.M. Tiginyanu, E.A. Kudryavtseva, V.A. Ursu, I.N. Tsyplenkov, V.N. Lamm & V.A. Sherauhov, *Fiz. Tekh. Poluprovodn.* **24,** 2034 (1990).
3. N.B. Pyshnaya, S.I. Radautsan, I.M. Tiginyanu, V.V. Ursaki, N.A. Ursu, I.M. Aliev & H.A. Halilov, *Cryst. Res. Technol.* **26,** K129 (1991).
4. A.M. White, P.J. Dean, K.M. Fairhurst, W. Bardsley, E.W. Williams & B. Day, *Solid State Commun.* **11,** 1099 (1972).
5. C. Hilsum, S. Fray & C. Smith, *Solid State Commun.* **7,** 1057 (1969).