Revista Brasileira de Aplicações de Vácuo, Vol. 13, n. 1 e 2, 1994

PHOTOLUMINESCENCE OF IRRADIATED InP SUBSTRATES AND EPITAXIAL LAYERS

J. V. Bellini[1], P. R. Ribas[1,2], P. L. Souza[3], and W. M. Mendes[4]

[1]DEMM/IME, Praça Gen. Tiburcio, 80, Rio de Janeiro
[2]EEIMVR/UFF/RJ, Av. dos Trabalhadores, 420, Volta Redonda
[3]CETUC/PUC/RJ, Rua Marquês de São Vicente, 222, Rio de Janeiro
[4]CBPF, Rua Xavier Sigaud, 150, Rio de Janeiro

ABSTRACT:

InP substrates and epitaxial layers of different carrier concentrations were exposed to electron (3.8 MeV) and gamma (up to 3.8 MeV) radiation in distinct experiments. Photoluminescence (PL) measurements showed that highly doped substrates presented large full width at half maximum of PL peak due to overlapping of donor impurity levels with the conduction band, a phenomenon which was not observed in undoped layers. Both highly doped substrates and undoped epitaxial layers showed a significant decrease in PL intensity after irradiation. This drop was most likely caused by the introduction of deep nonradiative recombination centers within the bandgap. Room temperature aging for 48 hours led to band-to-band PL intensity partial recovery, while annealing at 473K caused an almost complete recovery.

1. INTRODUCTION

Evaluation of the properties of compound semiconductors exposed to radiation is relevant since high energy photons and electrons trigger degradation mechanisms. The irradiation mimics usual degradation processes which are responsible for a decrease in the lifetime of optoelectronic devices. High energy particles and eletromagnetic radiation may cause two main processes to develop [1,2]: (i) electron excitation and consequent excess carriers; (ii) atom removal from its site creating a interstitial-vacancy pair.

The presence of these pairs introduces energy levels within the bandgap creating strong nonradiative recombination centers. Since PL efficiency is a function of the radiative recombination rate, PL peak intensity and shape are an appropriate way of monitoring structural defects introduced by radiation.

In this work, the effect of high energy radiation and subsequent heat treatments on InP substrates and epitaxial layers was investigated through PL assessments.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

Three n-type materials were studied: (i) Sn-doped ($3x10^{18}$ cm^{-3}) InP substrate grown by LEC; (ii) S-doped ($7x10^{18}$ cm^{-3}) InP substrate grown by LEC; (iii) 1.4 μm-thick undoped InP epitaxial layer, grown by MOCVD on a semi-insulating InP substrate.

2.2 Irradiation

The materials were irradiated with electrons and gamma-rays in distinct experiments. A 3.8 MeV electron accelerator with a 30 μA beam current provided an electron fluence of $3x10^{16}cm^{-2}$ on the sample surfaces, at room temperature. For γ-ray irradiation, a 0.3 mm-thick electron-bombarded Ta target provided a continuous spectrum with 2 MeV peak intensity (0-4 MeV range). γ-irradiated LN_2-cooled samples were exposed to a 10^5 Rad total dose and analysed before heating to room temperature.

2.3 Heat treatments

After irradiation, the γ-irradiated materials were aged at room temperature for 48 hours and all samples were heat treated at 473K for 10 min, under a N_2:H_2 (85:15) continuous flux, to anneal out the defects introduced during radiation. The InP epitaxial layer was heat treated additionaly at 673K.

2.4 Characterization

Photoluminescence of the samples was excited using the 4880 Å line of an Ar^+ laser and detected by a LN_2-cooled Ge photodetector after going through a 250 mm monochromator. The sample temperature was maintained at 77K during all PL measurements. In the spectra to be presented the multiplying factor signifies an increase in the lock-in amplifier sensitivity and corresponds to a decrease in the PL intensity. The PL spectra were obtained before irradiation, after irradiation, and after heat treatments.

3. RESULTS AND DISCUSSION

3.1 InP:Sn substrates

Before irradiation, the InP:Sn sample showed a PL peak at 8780 Å which corresponded to the material bandgap at 77K (1.41 eV). The large full width at half maximum (FWHM) was due to overlapping of donor impurity bands with the conduction band, which is present in highly doped materials. After electron irradiation, the PL intensity decreased by a factor of six, as can be seen in figure 1. The PL intensity drop was probably caused by the introduction of deep nonradiative recombination centers within the bandgap, which reduced the radiative recombination rate. A 473K anneal led to an almost complete PL signal recovery, thus indicating that most defects were eliminated at this temperature.

The InP:Sn exposed to γ-ray irradiation at 77K showed a significant PL intensity drop of about five times as compared to the non-irradiated material. The PL spectrum presented in figure 2 indicates that the originally broad near-edge PL peak involved more than one emission. The low-energy emission can be due to a donor-to-valence band transition with the donor level located at 12 meV below the conduction band. The high energy transition was detected quite systematically at 1.42 eV due to high Sn doping which is related to the Burstein-Moss effect [3]. There was some evidence that the high energy emission was more affected than the donor-to-valence band transition. Aging at 300K for 48 hours led to a PL intensity partial recovery due to the high mobility of defects yet at this temperature, which is in good agreement with previous works [4,5]. Annealing at a higher temperature (473K) led to a complete recovery of the PL signal.

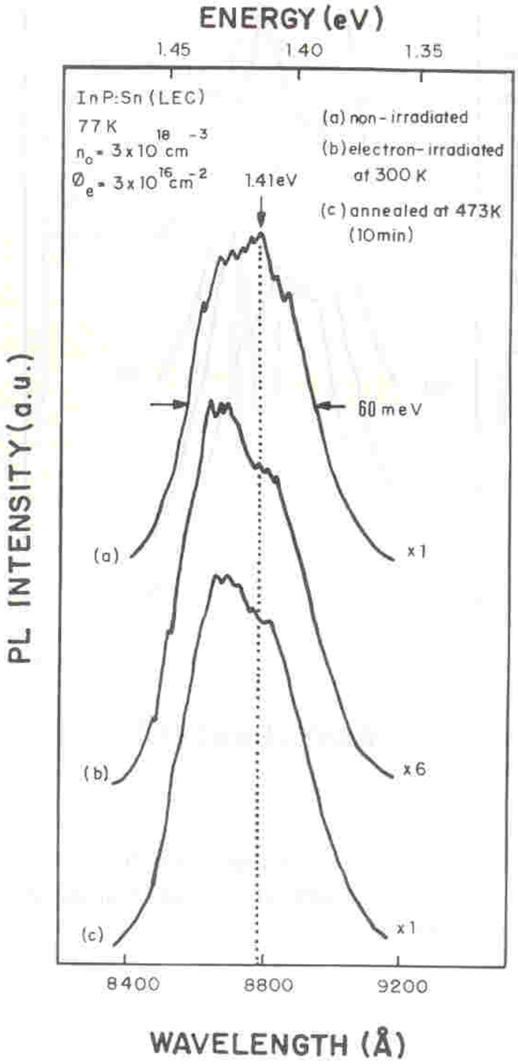

Fig. 1 - Photoluminescence spectra of InP:Sn before and after room temperature electron irradiation and after heat treatment.

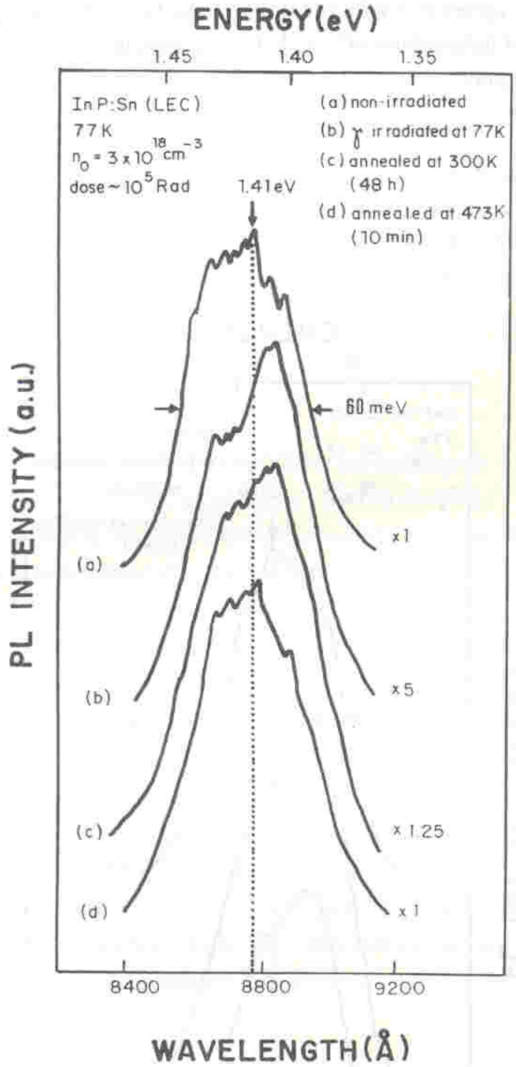

Fig. 2 - Photoluminescence spectra of InP:Sn before and after low temperature γ-irradiation and after heat treatments.

3.2 InP:S substrates

This material showed a broader PL line around the band gap when compared to the Sn-doped substrate. Furthermore, the high emission line was found to be located at a higher energy level which is consistent with the fact that this material was more doped than the InP:Sn substrate.

After electron irradiation, the PL intensity decreased by a factor of four, as observed in figure 3. A 473K anneal led to an almost complete PL signal recovery. This drop was most likely caused by the introduction of nonradiative recombination centers which are removed after heat treatment.

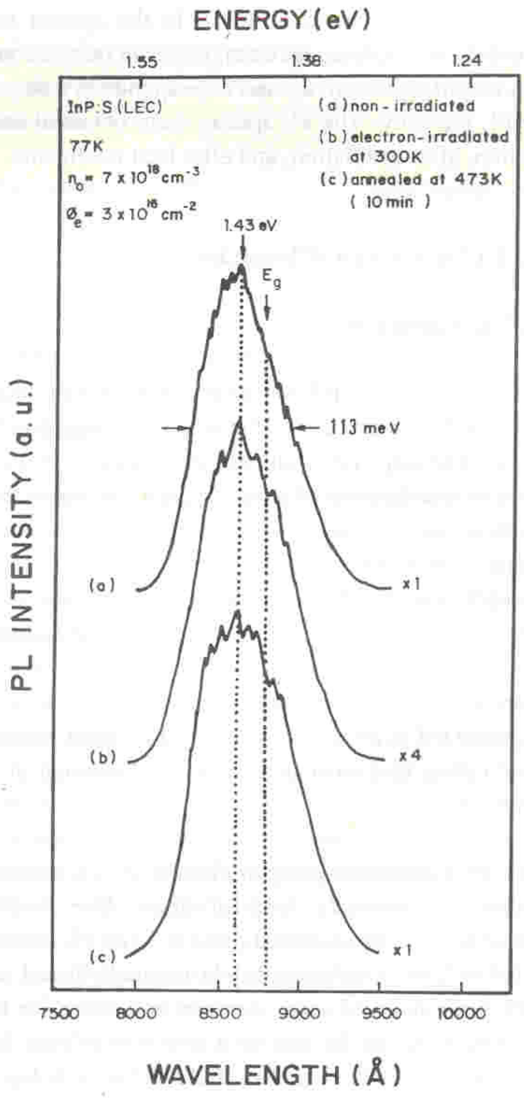

Fig. 3 - Photoluminescence spectra of InP:S before and after room temperature electron irradiation and after heat treatment.

γ-ray irradiation at 77K caused a PL intensity drop of about six times, although this intensity was completely recovered after aging at room temperature for 48 hours.

The different effects on the line shapes of the irradiated substrates doped with Sn_{In} and S_P (figures 1 and 3) led to the conclusion that the lattice sites occupied by the dopants should play an important role in the formation of the radiation-induced defects.

3.3 Undoped InP epitaxial layer

Before irradiation, the InP epitaxial layer showed a PL peak at 1.41 eV which corresponded to the bandgap emission. The sharpness of the curve is characteristic of an undoped layer. After electron irradiation, no PL signal was detected. Only after a 473K annealing a very faint PL signal could be observed, as can be seen in figure 4. Heat treating the sample at a higher temperature (673K) led to a partial PL recovery. These results indicated the undoped InP layer was more sensitive to electron irradiation than the highly doped substrates. In addition, this material showed a PL peak at 1.37 eV which was relatively enhanced after the pos-irradiation 673K annealing and was attributed to an emission from an acceptor level [6].

The InP epitaxial layer showed a PL intensity decrease of about fifteen times after γ-ray irradiation at 77K. The PL line shape was completely recovered after aging the material for 48 hours at room temperature.

4. CONCLUSIONS

Photoluminescence measurements were performed before and after electron and γ-ray irradiation on InP substrates and epitaxial layers in order to assess their optoelectronic properties. Both substrates and the epitaxial layer presented important PL spectra modifications which were related to the introduction of irradiation-induced structural defects.

Electron irradiation caused major changes in PL efficiency of all materials, although heat treatments at 473K for 10 minutes were usually sufficient to recover the original PL line shapes and intensities.

Contrary to the electron-irradiated materials, the samples subjected to γ-rays showed already a significant recovery at room temperature, which indicates that the γ-ray induced defects are less stable and probably not responsible for the degradation of optoelectronic devices operating at room-temperature.

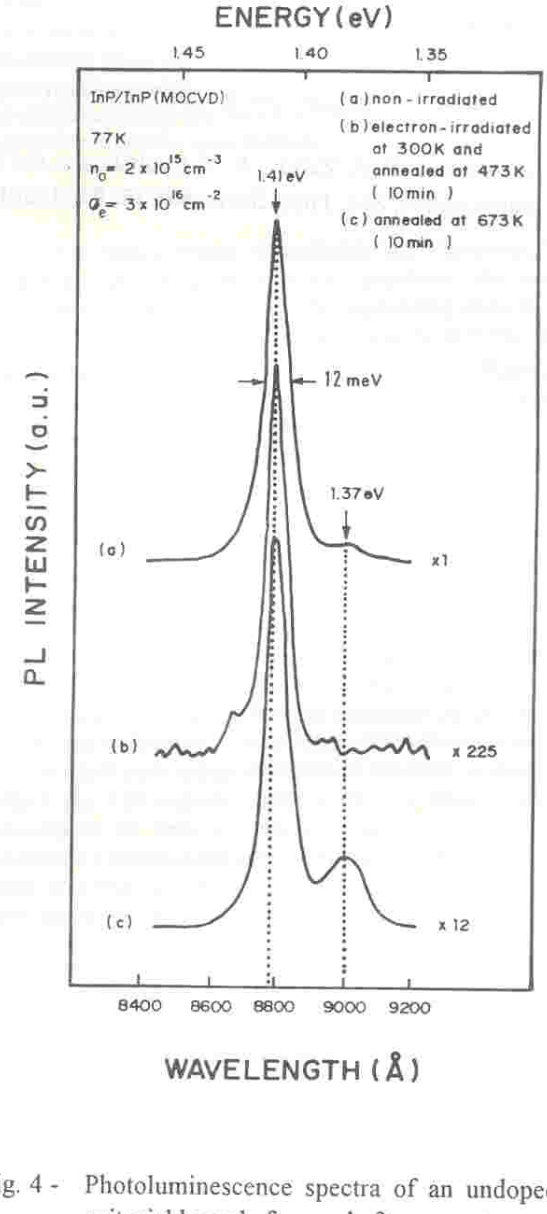

Fig. 4 - Photoluminescence spectra of an undoped InP epitaxial layer before and after room temperature electron irradiation and after heat treatments.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Centro Brasileiro de Pesquisas Físicas, Brazilian Army, Conselho Nacional de Desenvolvimento Científico e Tecnológico, and Pontifícia Universidade Católica. We thank Prof. Argus (CBPF) and L. Demenicis (PUC) for their support during experimental work.

6. REFERENCES

1. C. A. Londos, Phys. Stat. Sol. a **113**, 503 (1989).

2. A. Z. Abasova, F. A. Zaitov, A. V. Lyubchenko and S. Sultanmuradov, Sov. Phys. Semicond. **17**, 93 (1989).

3. E. W. Williams, W. Elder, M. G. Astles, M. Webb, J. B. Mullin, B. Straughan and P. J. Tufton, J. Electrochem. Soc.: Solid-State Science and Technology **120**, 1741 (1973).

4. M. Yamaguchi, K. Ando, A. Yamamoto, and C. Uemura, Appl. Phys. Lett. **44**, 432 (1984).

5. M. Yamaguchi, Y. Itoh, and K. Ando, Appl. Phys. Lett. **45**, 1206 (1984).

6. N. Duhamel, E. V. K. Rao, M. Gauneau, H. Thibierge, and A. Mircea, J. Crystal Growth **64**, 186 (1983).