Sci. Annals. Fac. Phys. & Mathem., Univ. Thessaloniki, **20b**, 157 (1980)

PHOTOCAPACITANCE STUDIES ON P-I-N InP: Fe STRUCTURES

By

A. S. POPOV and A. Y. BAHNEV

Semiconductor Physics and Technology Research Laboratory
University of Sofia

Previous investigations on P-I-N structures formed on iron doped InP substrates [1] showed that iron impurities form deep traps resulting in the appearence of S-shaped regions in the current-voltage characteristics of forward biased diodes. This is explained by double injection of current carriers through deep levels but their accurate identification is impossible, especially in the case when several levels of close energies are involved. In the present paper we simplify and apply the photocapacitance method proposed by Okumura and Ikoma [2] for the investigation of several deep levels simultaneously present in the energy bandgap of a P-I-N structure.

P-I-N structures are formed on InP: Fe substrates cut from cylindrical ingots synthesized from stoichiometric melt homogeneously doped with iron. The P-side of the structure is obtained by fast Zn-diffusion and after that one side of the substrate is lapped. Samples $1 \times 1mm^2$ are scribed and on the lapped surface In + 5% Sn pearls are alloyed to form the N side. This way on the two sides of the compensated I-region assymetric junctions are made and we can use the inverse square relation of the junction capacitance and reverse bias.

When the reverse-biased P-I-N structure is irradiated with monochromatic light, the photoionisation of the deep impurities in the compensated region lead to an increase of the static space charge in the depletion region and respectively to an alteration of the barrier capacitance.

When there are several discrete deep levels in the band gap, each of them will contribute to the whole change of the barrier capacitance, when we illuminate with light within a definite energy interval. If the wavelength decrease slowly at a definite speed, successive ionisation of deep levels occurs; shallower impurities are first ionised. Consequently the initial capacitance of the structure -C(0) has two components: the first due to the photoionisation of shallower impurities and the second to the partial ionisation of the deep level reached at the moment:

$$C(0)_i = \sum_i C(0)_{ti} + C(0)_{tj} \qquad (1)$$

$C(0)_{ti}$ = capacitance due to the photoionisation of shallower levels

$C(0)_{tj}$ = capacitance due to the partial photoionisation of the reached deep level.

The photocapacitance reach different values for the same wavelength of the incident light in account to different speeds of scanning, and we shall use this futher. This is shown on Fig. 1.

We express the change of capacitance over time from the concentration of ionised impurities and from the speed of scanning — $\beta = \frac{d(h\nu)}{dt}$. In this note we don't go into details but if this is interesting, the results after that may be shown. The change of capacitance is given by:

$$\frac{d_{\Delta}C_j}{dt} = \frac{\Phi\sigma_j}{2}\left(\frac{C^2_{jmax} - C_j^2}{C_j}\right) \qquad (2)$$

where Φ = is photon flow density; σ_j = photoionisation cross-section of deep centers with energy level E_{t_j}, ${}_{\Delta}C_{jmax}$ = the maximal change of capacitance at the total ionisation of all impurities giving the same deep level E_{t_j}.

Than we can determine the cross-section of the photoionisation through the derivative of the capacitance with respect to the photon energy ($\beta = \frac{d(h\nu)}{dt}$) and the maximal and momento values of the capacitance:

$$\sigma_j = \frac{2\beta C_j}{\Phi(C_j{}^2{}_{max} - C_j{}^2)} \cdot \frac{d({}_{\Delta}C_j)}{d(h\nu)} \qquad (3)$$

The total concentration of the ionised impurities with an energy

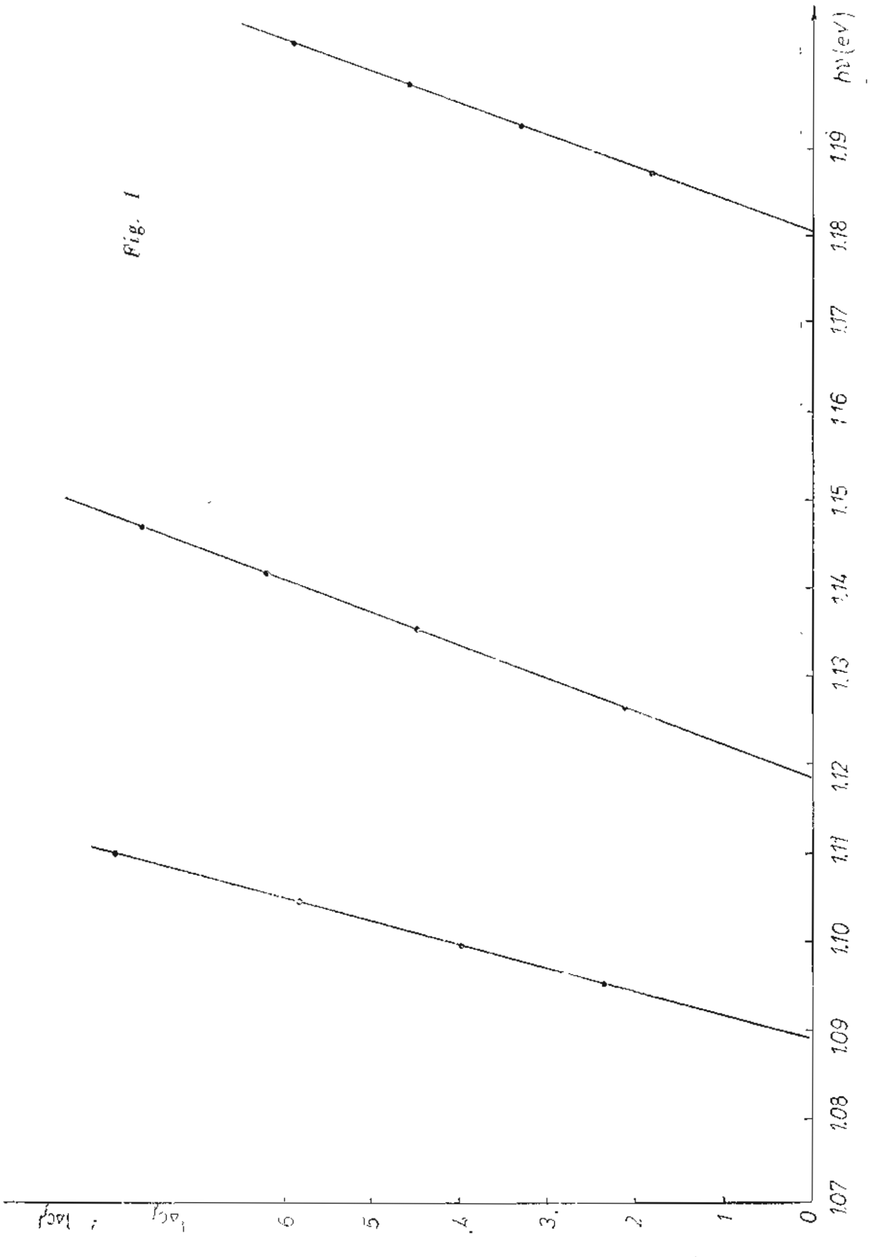
hν (eV)
1.07
1.08
1.09
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
1.18
1.19
0
1
2
3
4
5
6

Fig. 1

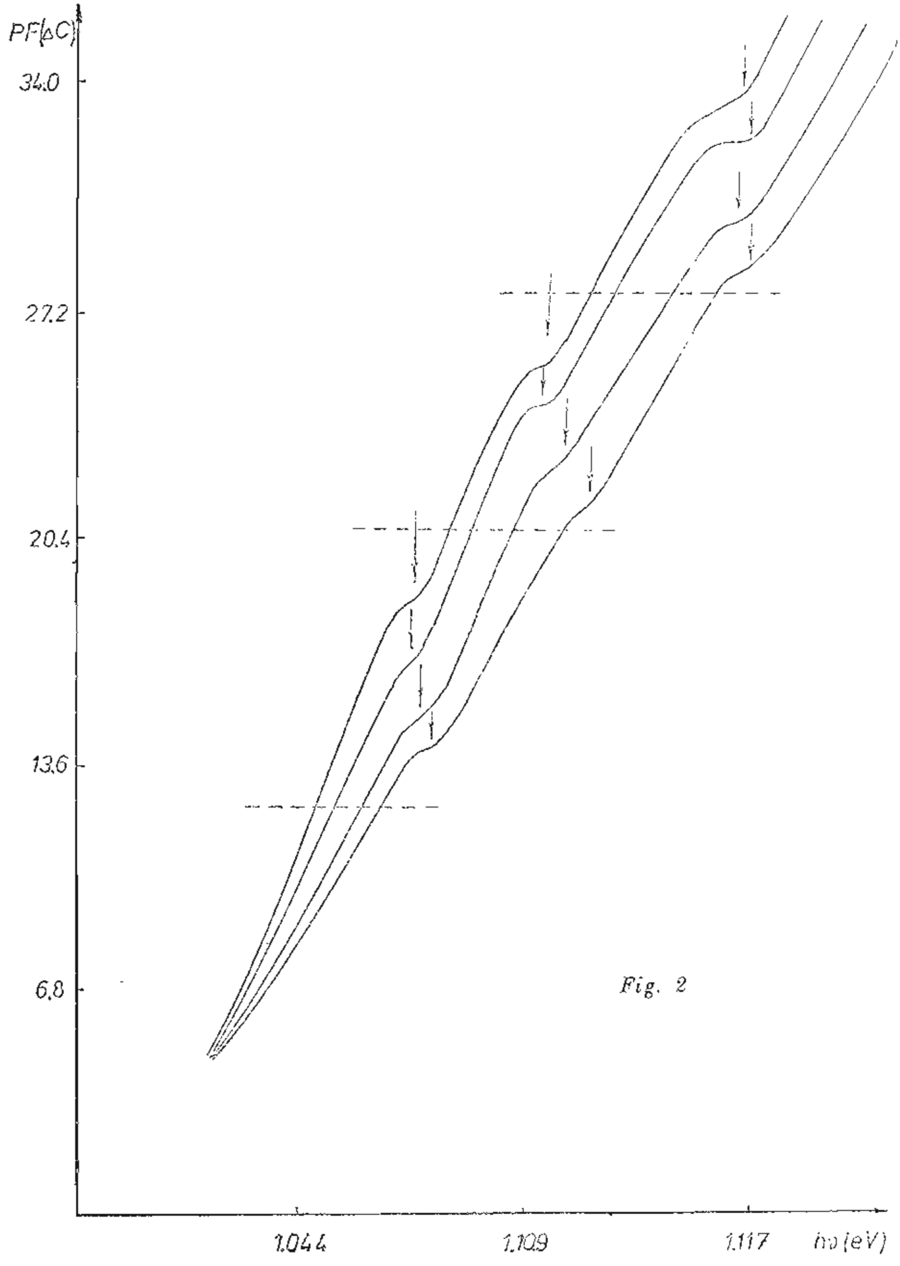

Fig. 2

level E_{tj}, N_{tj} is:

$$N_{t_j} = \frac{C^2_{j\,max} - C^2_j}{A} \quad (4)$$

A — a constant including the parameters of the material and the structure (E, S, U_k).

As it was done by Okumura and Ikoma, we use the Lucovsky model, in which the ion potential is approximated by δ-function and the photoionisation cross-section is expressed by:

$$\sigma = \frac{1}{\bar{n}} \left(\frac{E_{ef}}{E_0} \right) \frac{8he^2}{3mc} \cdot \frac{E^{1/2}_{t_j}(h\nu - E_{t_j})^{3/2}}{(h\nu)^3} = B \cdot \frac{(h\nu - E_{t_j})^{3/2}}{(h\nu)^3} \quad (5)$$

Equating (5) and (3) we obtain:

$$h\nu - E_{t_j} = \text{const} \left[\beta \left. \frac{d_1 C_j}{d(h\nu)} \right|_{\Delta C} \cdot \frac{(h\nu)^3_{\Delta C} \cdot C_{j/\Delta C}}{C^2_{jmax} - C^2_{j/\Delta C}} \right]^{2/3} \quad (6)$$

from which one can determine the ionisation threshold energy for each deep level E_{t_j}. For this purpose it is necessary to investigate the dependence of the photocapacitance on the speed of the light scanning. On Fig. 1 we can see that the same change of the photocapacitance can be reached for different wavelengths. The expression in the square brackets is a linear function of $(h\nu)_{\Delta C}$ (the energy at which equal ΔC are reached) and E_{t_j} is determined by the cross point on the abciss. We have plotted these relations for three characteristic points about 1,08eV, 1,11eV, 1,17eV (Fig. 2). The so obtained accurate values are 1,09eV, 1,12eV, 1,18eV. For the first two we suppose they are related to the Fe^{1+} and Fe^{2+} states of the iron impurity in InP. For the third level we assume that it is due to electrically active structural defects in the crystal induced in the process of recrystallization.

For the above discussed levels, the calculated photoionisation cross-sections for a fixed energy of the photons of the incident light was about 10^{-16}cm^2.

REFERENCES

1. L. A. Demberel, A. S. Popov, D. B. Kushev, N. N. Zheleva. Phys. Stat. Sol. (a) **52**, 314(1979).
2. T. Okumura, I. Ikoma. Appl. Phys. Lett. **25**(10), 572(1974).

ΠΕΡΙΛΗΨΗ

ΜΕΛΕΤΗ ΦΩΤΟΧΩΡΗΤΙΚΟΤΗΤΑΣ ΣΕ P-I-N InP: Fe ΔΟΜΕΣ

Ὑπὸ

A. S. POPOV ΚΑΙ A. Y. BAHNEV

(Ἐργαστήριο Φυσικῆς Ἡμιαγωγῶν καὶ Τεχνολογικῶν Ἐρευνῶν Πανεπιστήμιο Σόφιας).

Προηγούμενη ἐξέταση τῶν δομῶν P-I-N ποὺ σχηματίζονται ἀπὸ InP ὑπόβαθρο μὲ προσμείξεις σιδήρου ἔχει δείξει ὅτι οἱ ἀκαθαρσίες σιδήρου σχηματίζουν βαθειὲς παγίδες μὲ ἀποτέλεσμα τὴν ἐμφάνιση περιοχῶν S στὴ τάση ρεύματος. Στὴν ἐργασία αὐτὴ ἐφαρμόζουμε τὴ μέθοδο φωτοχωρητικότητας ποὺ προτάθηκε ἀπὸ τοὺς Okumura καὶ Ikoma γιὰ τὴ μελέτη διαφόρων βαθειῶν σταθμῶν ποὺ ἐμφανίζονται στὸ ἐνεργειακὸ χάσμα τῶν P-I-N δομῶν.