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INFRARED PHOTOCONDUCTIVITY IN HEAVILY DOPED AND HIGHLY COMPENSATED GALLIUM ARSENIDE

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1. INTRODUCTION

In the recent years, as a result of intensive theoretical and experimental work, much of the peculiarity in the physical nature of the properties of heavily doped, highly compensated III-V semiconductors was revealed. Nevertheless, experimental data on photoconductivity, due to shallow impurity — band transitions in highly doped and compensated GaAs is practically absent. The further reported experiments deal with millisecond photoconductivity relaxation and spectral dependence of photoconductivity in the visible and near IR energy bands.

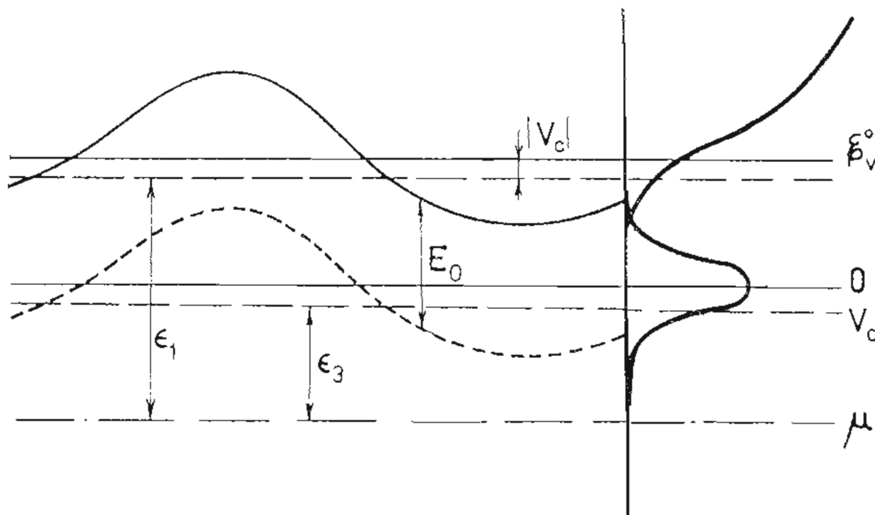

Fig. 1

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Ge-doped and Te-compensated LPE GaAs was investigated, with a total impurity concentration $1{,}3 \times 10^{19}cm^{-3}$ and a presumable degree of compensation $K = 0{,}95$. Some previons electric measurements on this material resulted in experimental evaluation of the activation energy, which was reported by Arnaudov et al. (1) to be about 85meV. The present widely accepted model for an energy band structure, modulated by a random potential is shown on Fig. 1. Here E_0 is the isolated impurity ionization energy, for the case of GaAs : Ge found by Ashen et al. to be 40,4meV (2), Vc is the impurity band percolation level. A preliminary theoretical study showed a deep-lying Fermi-level at about 120meV below E_0. On the figure e_1 and e_3 denote the activation energies for the conduction and impurity bands respectively. It is reasonable to expect, that an appropriate choice of the excitation photon energy could unravel the activation mechanisms, kinetics of photoconductivity and recombination processes in the above discussed case.

2. EXPERIMENTAL SETUP

Two different experimental arrangements for measuring both, spectral dependence of photoconductivity (Fig. 2) and photoconductivity

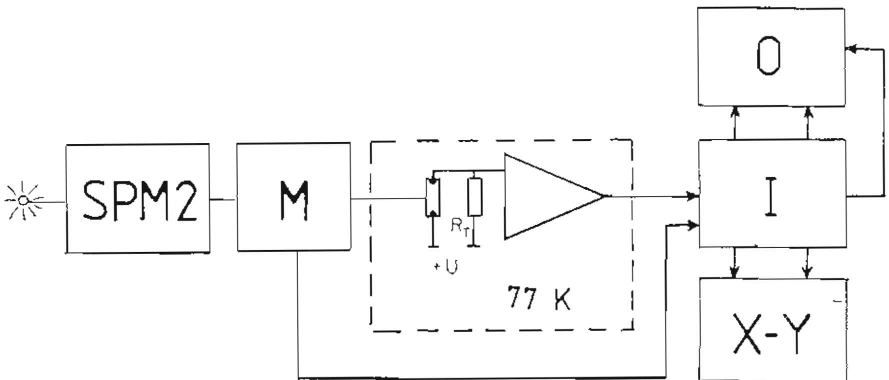

Fig. 2

decay time (Fig. 3), were used. In the first case, a monochromator with appropriately selected prisms and sources served as a tunable light source in the region 0,15-2,5eV. In the second case, the requirement for a high intensity photon flux with a photon energy of approximately 0,1eV, necessitated the application of a carbon dioxide laser, opera-

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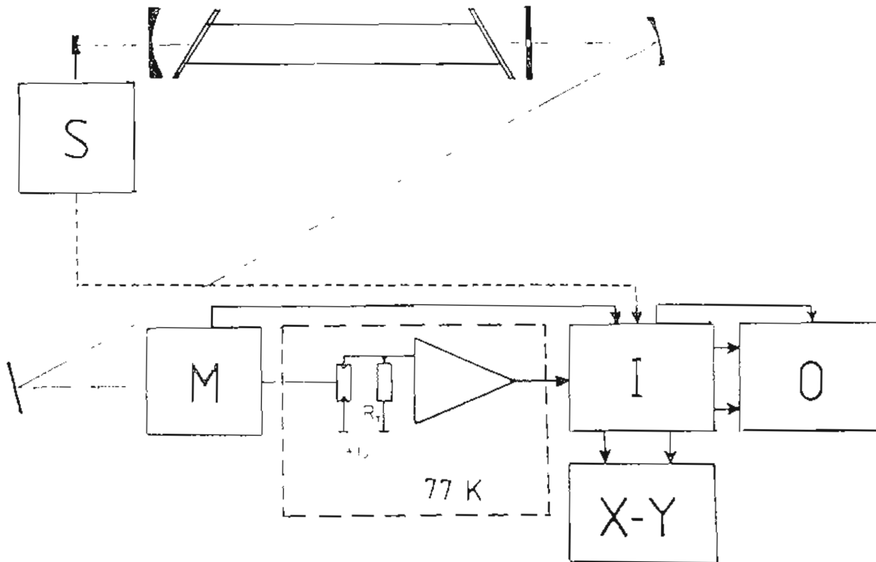

Fig. 3

ting in the continuous-wave mode. The intensity of the photon flux was varied within an order of magnitude by means of calibrated Ge-filters.

All the measuremeuts were performed at liquid nitrogen temperatures ($kT << e_1, e_3$). After being chopped at a 20 Hz repetition rate, the photon flux was led into a cryostat. In order to improve the signal-to-noise ratio, the load resistance and a FET-preamplifier were built into the cryostat and cooled down to 77°K. The registration techniques was based on a "Boxcar" integrator principle, the replica being taken directly on an X-Y plotter.

3. EXPERIMENTAL RESULTS

The photocondnctivity decay curves, shown on Fig. 5, were plotted down at four different intensities of the photon flux:

$$I_1 = 2{,}1 \times 10^{17} cm^{-2}s^{-1},\ I_2 = 6 \times 10^{17} cm^{-2}s^{-1},\ I_3 = 1{,}5 \times 10^{18} cm^{-2}s^{-1},$$

$I_4 = 4 \times 10^{18} cm^{-2}s^{-1}$ and 30V biasing voltage. A replica is a result of 14 times signal-to-noise ratio improvement and optimum scanning mode of the sampling gate.

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The observed spectral dependence of photoconductivity, shown on Fig. 4, has an initial energy resolution better than 20meV, which however is cosiderably worsened by the procedure of normalisation with respect to the incident radiation spectrum. Under the same conditions, as the sample of interest, a chromium-doped semiinsulating GaAs substrate was also investigated.

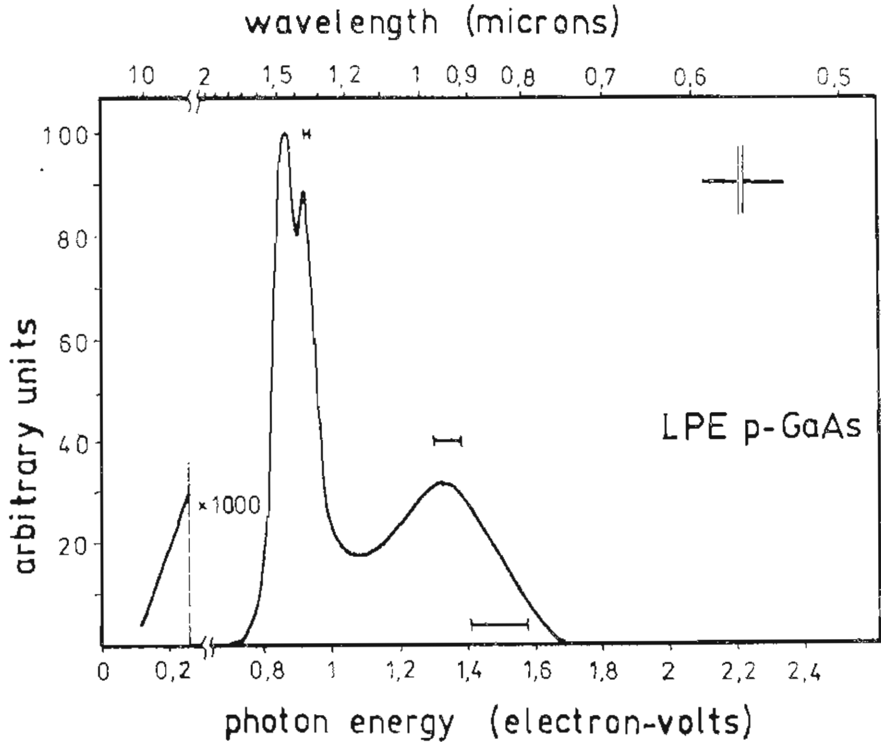

Fig. 4

4. DISCUSSION

The spectral dependence of photoconductivity, as presented in Fig. 4, can be divided into three parts: The first part is the high energy region, where interband absorption is present. In the next part, the peaks labelled at 0,86 and 0,92eV obviously originate from deep-lying levels. A previous private communication with Arnaudov (3) marked, that the photoconductivity peak at 0,86eV coincides with an energetic

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level, observed by means of photoluminiscence experiments. The results obtained by Allen (4) suggest, that it can be ascribed to chromium atoms, present in the layer as a result of doping in the process of epitaxial growth. However, the peak at 0,86eV was not observed in the photoconductivity spectrum of the substrate, which the layer was grown upon. This may be considered as an argument against the assignment of the above mentioned peak to chromium, despite of partial energetic coincidence. These facts make us consider the possibility of further detailed investigations on samples, grown on different substrates (for example p^+-type) and with different degrees of doping and compensation, which could reveal a possible relation between the intensity of these peaks and impurity concentration. The third part of the spectrum is the region, where free carriers are activated to the impurity band percolation level. It is clearly seen, that photoconductivity is monotonously decreasing in this region, which is to be expected in the case of extremely low intesities.

From the initial slopes of the rise and decay curves (Fig. 5), the characteristic relaxation times were found to be $\tau_1 = 2,7 \times 10^{-3}$s and

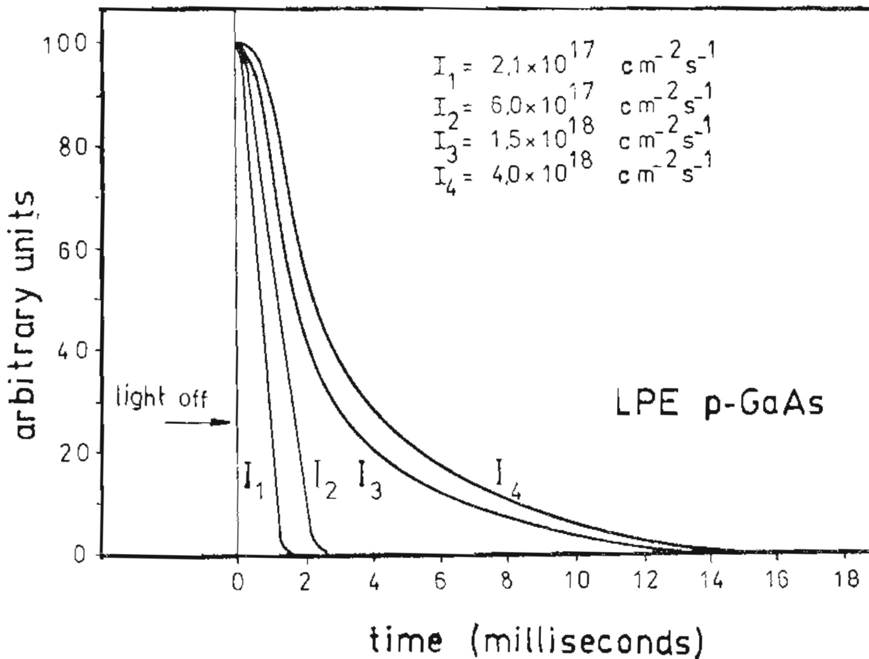

Fig. 5

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$\tau_d = 3{,}1 \times 10^{-3}$s. The comparatively precise measurements of these quantities enabled us to evaluate, in the standard manner, the effective photon capture cross-section $q \propto 10^{-17}cm^2$. This result is obviously in agreement with the observed millisecond relaxation times. The decay time dependence upon the intensity of the photon flux shows the significant role, played by the energy levels, lying in the density -of-states tail in the generation-recombination processes.

The summing-up of the data about the Fermi-level position, the photon energy, the value of the RMS potential and the small capture cross-section implies, that hopping conductivity is the main transport mechanism when radiation is absent. Upon illumination, a small percolation component is added to it, whose relaxation after the cut-off of the photon flux is hindered by the small recombination cross-section of the deep-lying localized electrons.

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ΠΕΡΙΛΗΨΗ

ΥΠΕΡΥΘΡΗ ΦΩΤΟΑΓΩΓΙΜΟΤΗΤΑ ΣΤΟ GaAs ΜΕ ΙΣΧΥΡΗ ΠΡΟΣΜΕΙΞΗ ΚΑΙ ΜΕΓΑΛΗ ΑΠΟΚΑΤΑΣΤΑΣΗ

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(Ἐργαστήριον Φυσικῆς Ἡμιαγωγῶν καὶ Τεχνολογικῶν Ἐρευνῶν Πανεπιστήμιο Σόφιας).

Τὰ τελευταῖα χρόνια πολλὲς ἀπὸ τὶς ἰδιομορφίες στὶς φυσικὲς ἰδιότητες τῶν ἡμιαγωγῶν ἰσχυρῆς προσμείξεως καὶ μεγάλης ἀντισταθμίσεως ἔχουν ἑρμηνευτεῖ μὲ ἀκριβῆ πειραματικὰ καὶ θεωρητικὰ ἀποτελέσματα. Στὸ χῶρο αὐτὸ πρέπει νὰ παρατηρήσουμε ὅτι πειραματικὰ ἀποτελέσματα φωτοαγωγιμότητας ἀπὸ μεταπτώσεις ρηχῶν ἀκαθαρσιῶν στὸ GaAs δὲν ἔχουν ἀναφερθεῖ. Ἔτσι παρουσιάζουμε ἐδῶ πειραματικὰ ἀποτελέσματα φωτοαγωγιμότητας ἀπὸ GaAs στὸ ὁρατὸ φάσμα καὶ κοντὰ στὴ IR ἐνεργειακὴ ταινία.

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