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MAGNETOTRANSMISSION MEASUREMENTS OF INTRA-SHALLOW-DONOR TRANSITIONS IN SEMI-INSULATING GaAs*

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In this paper we present the results of an investigation of the $1s$–$2p_+$ intra-shallow-donor transition by means of an extremely difficult magnetotransmission experiment performed on semi-insulating GaAs. We report the temperature dependence of the transition intensity. We noticed the absence in the absorbance spectra of a well-pronounced structure which is observed at low magnetic fields in photoconductivity measurements. The results are discussed in terms of a fluctuating potential from ionized centres in semi-insulating GaAs.

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Shallow donors in semi-insulating (SI) GaAs are subjected to strong local electric fields due to compensation and weak screening [1]. At liquid helium temperatures, these centres are not occupied by electrons due to the pinning of the Fermi level on the deep native donor EL2 [2, 3]. Applying a previously reported method [2] — external infrared illumination (with wavelength $\lambda = 0.86$ μm) — we are able to create a measurable, steady population of neutral shallow donor states. The samples† are then additionally illuminated with far infrared (FIR) light in order to obtain intra-shallow-donor transitions. The transmission of FIR light ($\lambda = 119$ μm) was measured by a homemade, very sensitive bolometer as a function of applied magnetic field. The experimental set-up allows us to measure the transmission through the sample and its photoconductivity simultaneously. All experiments were made at low temperatures — near 4.2 K.

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†The sample was a rectangular slab (3.0 × 1.0 × 0.5 mm) of bulk SI GaAs (grown by the LEC technique in the (100) direction) with a concentration of the EL2 defect about 10^{16} cm^{-3}. The dark resistance at 4.2 K was of the order of 10^{12} Ω. Two non-rectifying (down to 4.2 K) Au–Ge–Ni contacts were alloyed by Dr. Kamińska and Dr. Piotrowska from the Institute of Electron Technology in Warsaw.

Previous photoconductivity experiments [2, 4] showed a significant difference in the behaviour of intra-shallow-donor transitions in the SI material with respect to n-type GaAs (see Fig. 1b). In this paper a typical absorbance spectrum (derived from transmission) for a SI sample is presented on Fig. 1a (upper curve). It is practically the same as in n-type GaAs (lower curve). The well-pronounced peak corresponds to the $1s$–$2p_+$ transition in the hydrogen-like [5] shallow-donor system, split by an external magnetic field. For magnetic fields outside of the peak

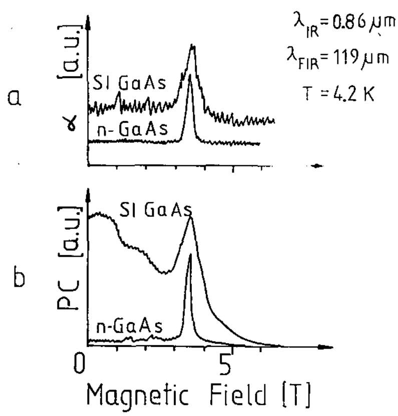

Fig. 1. a) Absorbance of FIR radiation in n-type and SI GaAs samples versus magnetic field. Both curves have different vertical scales. b) Photoconductivity of n-type and SI GaAs samples due to FIR illumination versus magnetic field. Vertical scales for both curves are not the same.

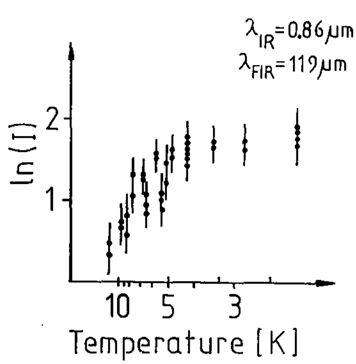

Fig. 2. Temperature dependence of the $1s$–$2p_+$ intra-shallow-donor transiton intensity for SI GaAs.

region no comparable absorbance was visible. Figure 2 shows the results of temperature investigations in the $1s$–$2p_+$ transiton intensity. With increasing temperature we observe a decrease in the transition intensity due to the temperature depopulation of shallow-donor ground state. From the saturation value for the lowest temperatures we are able to determine the concentration of neutral (i.e. populated by electrons) shallow-donor centres. It is of the order of 10^{13} cm^{-3}. Comparing this value with a typical concentration of shallow-donor centres (a few times 10^{15} cm^{-3}) we find that about every thousandth shallow centre is occupied by an electron. Matching this ratio with information that samples were illuminated by low intensity infrared light coming from a monochromator we see a relatively huge metastability. We attribute this result to the influence of a fluctuating potential on the lifetime of electrons in the shallow-donor ground state.

Introducing a probability P_α of transferring an electron from the ground state of a shallow-donor to the excited state and a probability P of transferring an electron from the excited state of the shallow-donor to the continuum of Landau levels, we can describe the photoconductivity (PC) and transmission (T) signals as follows [2]:

$$\mathrm{PC} \propto P_\alpha P, \tag{1}$$

$$\mathrm{T} \propto P_\alpha. \tag{2}$$

Comparing the upper and lower curves in Fig. 1a we see that for both materials the absorbance spectra (derived from transmission) are similar — the fluctuating potential does not affect P_α very strongly. However, the PC spectra are completely different from each other. For lower magnetic fields there is an enhanced PC signal in SI GaAs (comparable with the $1s$–$2p_+$ transition) which does not appear in the n-type. The stronger photoconductive signal must come from a larger value of the probability P. The only difference between the two samples is the presence of local electric fields in the SI material. Therefore, we conclude that the fluctuating potential strongly influences the probability P.

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