Vol. 82 (1992) *ACTA PHYSICA POLONICA A* No 5

Proceedings of the XXI International School of Semiconducting Compounds, Jaszowiec 1992

DEEP DEFECTS IN LOW-TEMPERATURE GaAs

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Conductivity of GaAs layers grown by molecular beam epitaxy at low substrate temperature (190–200°C) and then annealed at few different temperatures (between 300 and 600°C) were studied. It was confirmed that electron transport is due to hopping between arsenic antisite defects. Parameters describing hopping conductivity and their dependence on temperature of annealing are discussed. Other deep defects with activation energies of 0.105, 0.30, 0.31, 0.47, 0.55 eV were found using photoinduced current transient spectroscopy measurements.

PACS numbers: 71.55.–i, 72.80.Ey

Molecular beam epitaxy (MBE) GaAs layers grown at low substrate temperatures (about 200°C, so-called low-temperature (LT) GaAs) demonstrate very interesting properties from both application and scientific points of view. They were successfully used for improvement of electric insulation in GaAs integrated circuits. In science, they attract much attention because of their off-stoichiometry, significant concentration of arsenic antisite defect and hopping conductivity between deep defect centers [1].

In the present paper systematic transport studies of LT GaAs were performed. Layers numbered 3-1871, 3-1872, 3-2088 were grown on a semi-insulating substrate under As rich condition at 190°C at MIT Lincoln Laboratory. LT GaAs layers of the 3-1871 and 3-1872 samples were 2.5 μm thick. The 3-2088 sample had a 2.0 μm of LT GaAs layer insulated from the substrate with a thin 0.5 μm layer of AlAs. All samples were divided into parts which were annealed in MBE system at different temperatures.

Optical absorption measurements were done on 3-1872 samples. Concentrations of EL2-like defects were obtained using Martins calibration curve [2].

Temperature-depending conductivity measurements were carried out in the range 12–300 K. It was found that in temperature below 300 K the conductivity had a hopping character. For each sample an equilibrium ("dark") current was registered. Then, the sample was illuminated with the light $\lambda = 0.95$ μm for ten minutes at low temperature (about 12 K) and then during heating up to room temperature the current was measured again. Illumination was done in order to quench EL2 to the metastable state but it should also cause a nonequilibrium occupancy of the other centers.

Typical results of the measurements are shown in Fig. 1. For the as grown samples the conductivity after illumination increased, for the samples annealed at high (higher than 300°C) temperature a reverse relation was observed. All illumination induced changes disappeared when the sample was heated up to 120 K. For few samples a small peak at low temperature of thermally stimulated current (TSC) was observed. Absence of other TSC peaks is astonishing because high concentrations of defects were expected. It could be explained by a high carrier recombination rate in LT GaAs.

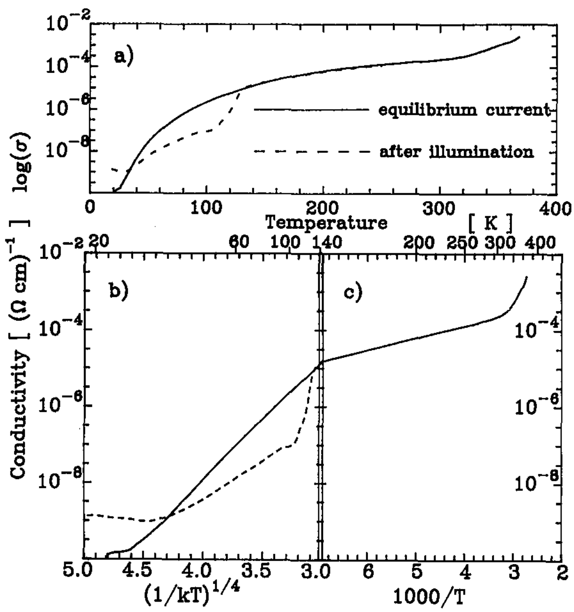

Fig. 1. Typical conductivity versus temperature dependence for LT GaAs layer. The same curve was shown in three different temperatures scales to visualize different characters of the $\sigma(T)$ dependence in low and high temperature ranges.

The hopping conductivity was analyzed basing on percolation theory, taking into account two ranges of temperature. For higher temperature the conductivity σ should be

$$\sigma = \sigma_{03} \exp\left(\frac{\varepsilon_3}{kT}\right), \tag{1}$$

where

$$\sigma_{03} = \sigma \exp\left(1.73 \frac{2}{aN^{1/3}}\right), \tag{2}$$

N is a concentration of hopping centers, a is a localization parameter of the defect wave function and ε_3 is an average energy of Coulomb interaction between two impurities. In Fig. 1c logarithm of conductivity versus $1000/T$ was shown. Fitting the relation (1) to the experimental data, it was possible to determine ε_3 for all samples. For annealed samples ε_3 decreased with annealing temperature. According to Shklovskii's theory developed for shallow impurities ε_3 should increase with $N^{-1/3}$ [3]. Basing on EL2 concentration known for some samples from optical absorption measurements, concentrations in the rest of samples were calculated. It was found that concentration of EL2 centers was still high (about 10^{18} cm^{-3}) even in annealed samples (up to 600°C). Following Eq. (2), the conductivity σ_{03} was examined. From the slope it was found that the wave function localization parameter a was equal to 5.2 Å. It is important to notice that such small value of this parameter is characteristic of deep centers.

For lower temperature hopping is characterized by Mott's law

$$\sigma = \sigma_0 \exp\left(-(T/T_0)^{1/4}\right) \tag{3}$$

($T_0 = 21.2/(g(\mu)a)$, $g(\mu)$ is density of states at the Fermi level), which was confirmed by experiment (see Fig. 1b). Fitting the above relation to the experimental data, parameter T_0 could be determined for all samples. Using the previously found parameter a, it was possible to estimate $g(\mu)$ and determine an experimental dependence between the concentration of hopping centers N and the density of states $g(\mu)$. This dependence was used to calculate the concentration of defects after illumination. As a result, it was obtained that in all the samples the concentration of hopping centers decreased after illumination.

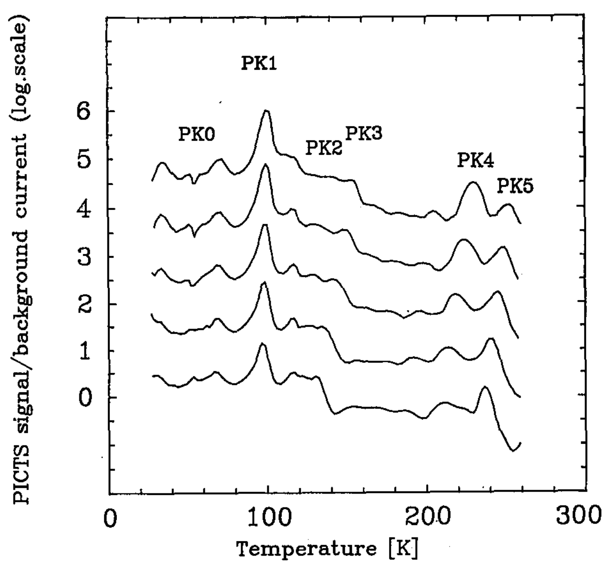

Fig. 2. PICTS spectra of 3-2088 LT GaAs layer annealed at 600°C. Spectra were measured with different rate windows, every next spectrum was shifted by factor 1. Each spectrum was divided by the background current.

In order to find deep defects other than EL2, photoinduced current transient spectroscopy (PICTS) was used. The example of PICTS spectrum is shown in Fig. 2. Both as grown and annealed samples were measured in the temperature range 20–270 K. Current transients observed in as grown samples were strongly nonexponential and thus worthless for further analysis. Nevertheless, the presence of broad peak at about 60 K was obvious. In annealed samples six PICTS peaks (named PK0...PK5) were registered. First, PK0 peak with activation energy $E_a = 0.105 \pm 0.02$ eV at temperature about 60 K could be observed only in samples annealed at temperatures lower than 450°C. For the rest of samples persistent photocurrent existing in the range 40–100 K disabled us from observing this peak. The PK1 peak, $E_a = 0.47 \pm 0.07$ eV, at $T = 90$–100 K was exactly at the point of disappearance of the persistent photocurrent. Because of its abnormally high activation energy PK1 was not probably connected with electron emission from any point defect. The PK2 and PK3 peaks with E_a of about 0.30 and 0.31 eV observed at 130–150 K most probably originated from EL6 and EL7 centers known from standard GaAs [4]. The peaks PK4 and PK5 ($E_a = 0.55 \pm 0.05$ eV) observed at temperatures 220–260 K were probably due to emission from deep acceptors. Activation energy of these defects could not be calculated accurately because of quick increase in background current at that temperature.

In summary, hopping conductivity in LT GaAs was examined. Small value of localization parameter a indicated that hopping was via some deep centers. Taking into account that concentration of this center decreased after illumination at $T = 12$ K and increased back after annealing at 120 K, the statement that hopping conductivity was due to EL2 centers was confirmed. Other than EL2 defects were found by photoinduced current transient spectroscopy.

Acknowledgments

Authors are deeply indebted to F.W. Smith and R. Calawa, MIT Lincoln Laboratory, for supplying us with the LT GaAs layers.

Numerical coefficients in Eqs. (2) and (3) were found by Shklovskii [3].

The work was supported by the Committee for Scientific Research grant number 2 0179 91 01.

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