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DETECTION OF PERSISTING PHOTOELECTRONS IN AlGaAs DOUBLE HETEROSTRUCTURE LASER DIODES BY DLTS*

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LPE-made AlGaAs double heterostructure laser diodes having a Sn-doped n-type confinement layer were investigated. A significant change of the low--temperature part of DLTS spectra and $C(T)$ curves was observed after applying forward or higher reverse voltage. Relaxation of the curves took several hours. This persistent photoconductivity phenomenon is explained by photoionization of the DX centres.

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Introduction

$Al_xGa_{1-x}As$ reveals the presence of dopant-related deep electron traps for $x > 0.2$ partly in a concentration higher than the concentration of shallow donors. These so-called DX levels [1] show peculiar features such as coupling of emission and capture processes to higher bands direct material ($x < 0.43$) and strongly thermally activated capture behaviour [2]. The latter property leads to persistent photoconductivity (PPC) at lower temperatures since the recapture of photoemitted electrons by empty traps takes several hours [3].

Samples

Double heterostructure laser diodes (DH LD) were made by liquid phase epitaxy (LPE). The layers have been the following ones: n-type GaAs:Si (substrate, 100 μm), n-type GaAs:Si (buffer layer), n-type $Al_{0.35}Ga_{0.45}As$:Sn (cladding layer, 2 μm), p-type $Al_{0.05}Ga_{0.95}As$, partly Ge-doped (active layer, 0.15 μm), p-type $Al_{0.35}Ga_{0.65}As$:Mg,Ge (cladding layer, 2 μm), p-type GaAs:Ge (contact layer).

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Results

In the DLTS spectra two Sn-related DX centres called DX1 and DX2 here were always found independently of the p-side dopant (Fig. 1, spectrum (a)). The localization of DX1, DX2 in the n-type cladding layer was confirmed by profile measurements (DDLTS).

$E_{t,2} = 0.33 \pm 0.03$ eV was found for DX2. The DX1 should be the main Sn-related DX centre ($E_{t,1} = 0.19 \ldots 0.21$ eV, e.g. [4]). The low-temperature part of spectrum (a) was recorded under non-saturation conditions.

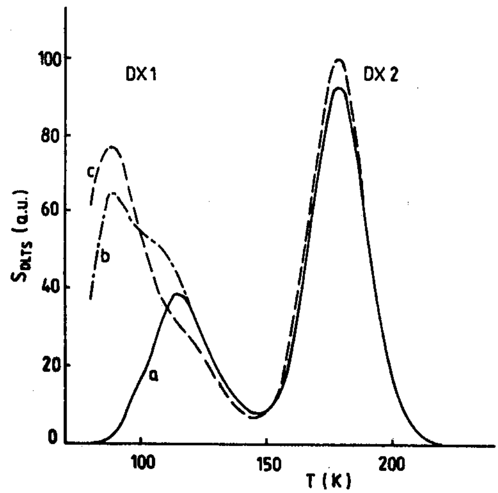

Fig. 1. DLTS spectra recorded under heating conditions. The rate window was 1180 s^{-1}, the bias was –5 V. Spectrum (a) (———), pulse duration $t_p = 100\ \mu s$. Spectrum (b) (— - —), as (a), but after a current pulse at T_{LN}. Spectrum (c) (— —), the first pulse was a current pulse (10 μs). After 5 μs delay a majority carrier pulse as in (a), (b) was applied (90 μs).

The DX1-related signal was strongly increased in spectra (b) (as (a), but after current injection at T_{LN}) and (c) (double pulse excitation: the first pulse — current injection, the second pulse — majority carrier pulse). Similar results were obtained after applying higher reverse bias ($-9 \ldots -14$ V) to the samples for some minutes instead of forward bias.

The relaxation of the sample capacity C_o and of the DLTS signal at T_{LN} after current injection is shown in Fig. 3. In the first 10 s not shown here there were a quick and strong decay of C_o (comp. [5]) which corresponds to the difference between records C and D in Fig. 2.

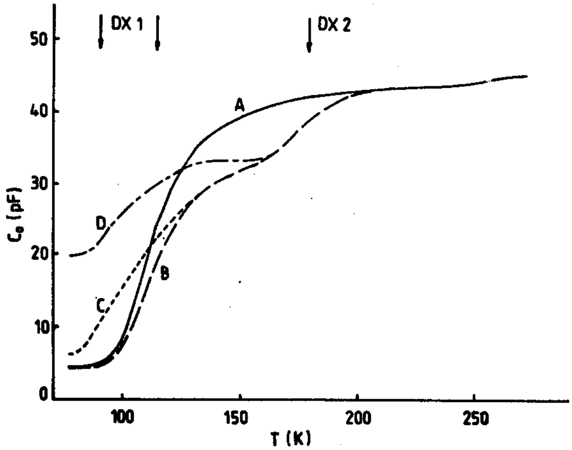

Fig. 2. C–T records at a bias of –5 V. Tracks B (—), C(– – – –) and D(— - —) were records during the DLTS measurements of Fig. 1: tracks B, C, D correspond to spectra (a), (b), (c), respectively. Arrows indicate the positions of the DLTS peaks.

Interpretation

The increase of the DX1-related DLTS signal after current injection is caused by a better electron filling degree of the trap at the end of the excitation pulse:

$$f_n = 1 - \exp(-c_n t_p) \tag{1}$$

with

$$c_n = n\sigma_n \overline{v}_n \tag{2}$$

and n — the free electron concentration, σ_n — the electron capture cross section, $\overline{v}_n$ — the mean thermal electron velocity.

The concentration of free electrons in the n-type cladding layer is rather low at T_{LN} due to freezing effects. During the current flow through the DH LD light is generated ($h\nu \approx 1.5$ eV) which is well able to photoionize the DX centres [6, 7]. Because of the PPC effect a strong increase of the free electron concentration is caused.

The persisting photoelectrons also reduce the serial resistance contribution from the n-type cladding layer as observed in the I–V characteristics for forward bias at T_{LN}.

The cause of the increased free electron density after applying higher reverse bias could be avalanche process-related light emission. It is well known that avalanche processes in GaAs can produce light emission phenomena, e.g. [8].

The slow component of the decay curves (Fig. 3) is related to DX2, the quick initial decay to the main trap DX1. This is supported by photoconductivity and DLTS measurements [7] and by capture data reported, e.g. [4]. That means the

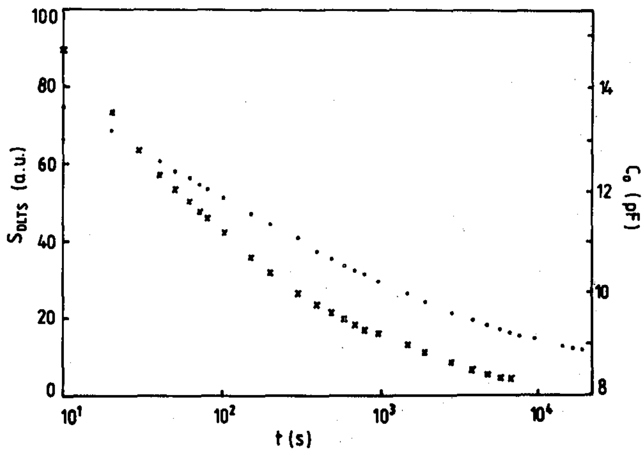

Fig. 3. Decay of the DLTS signal (•, left ordinate) and of the sample capacity (×, right ordinate) at T_{LN} after a current pulse. The conditions of the DLTS measurement were: rate window 11.8 s^{-1}, pulse length 10 ms, bias −5 V, pulse height 5 V.

PPC effect in n-type $Al_{0.35}Ga_{0.65}As$:Sn at and above T_{LN} is mainly related to DX2 and not to the dominant trap DX1.

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