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ACOUSTIC - DLTS INVESTIGATION OF GaAs MIS STRUCTURES [1]

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The acoustic deep-level transient spectroscopy (A-DLTS) is used to determine the parameters of deep levels in GaAs metal-insulator-semiconductor (MIS) structures. A principle description of the A-DLTS technique the basic idea of which coincide with original DLTS is outlined. MIS structures were fabricated on n-type GaAs substrates by plazmatic deposition of SiN insulating lager. A-DLTS spectra for zero-bias as well as forward filling pulses are observed to determine energy levels and capture cross-sections of the deep traps of the interface region.

I. INTRODUCTION

For practical metal-insulator-semiconductor (MIS) devices, interface traps play an important role because they influence the electrical, optical, thermal and mechanical properties of the materials as well as the properties of the devices made from these materials. The determination of traps parameters as activation energy, capture and emission rates and traps density is important for semiconductor device technology and many useful experimental methods have been reported. Among the very important and widely used techniques belong several modifications of deep-level transient spectroscopy (DLTS) [1-5].

Recently two acoustic modifications of DLTS were developed to determine the parameters of trap levels and so extended a number of DLTS techniques. Both the surface acoustic wave (SAW) technique using tranverse acoustoelectric voltage measurement [6] and the longitudinal acoustic wave technique using acoustoelectric response signal [7] can be used also in the cases, which are not easily accesible to previous DLTS ones.

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In this paper we present the study of n-type GaAs MIS structure by the latter mentioned acoustic technique that has already been succesfully used for the determination of the Si MIS structure deep levels parameters. However, the principle of here presented version of acoustic deep-level transient spectroscopy (A-DLTS) more closely coincides with the idea of original DLTS proposed by Lang [1]. The present as well as former A-DLTS technique is based on the fact that the response of the acoustoelectric signal produced by MIS structure is very sensitive to the ralative changes of the structure capacitance and accumulated charge of interface region.

II. EXPERIMENTAL PROCEDURE

The A-DLTS technique used in our study is conected, similarly to original Lang's DLTS, with the fact that the time development of the capacitance of the MIS structure after an injection bias pulse applied to the structure reflects relaxation processes associated with the thermally activated emision of injected carriers. The reciprocal value of the ralaxation time characterized the return to the thermodynamic equilibrium state determines the emission rate that for electrons is given by the relation

$$e_n = \frac{1}{\tau_n} = \sigma_n v_n N_c e^{-\frac{\Delta E}{kT}} \tag{1}$$

where σ_n is the electron capture cross-section, v_n is the thermal velocity of electrons, N_c is the effective density of states at bottom of the conduction band and ΔE is the trap activation energes.

Acoustoelectric responce signal poduced by the MIS structure traversed by a longitudinal acoustic wave is proportional to the voltage and relative change of capacitance induced by the acoustic wave and for the thin planar structure ($d \ll \lambda$) can he expressed by [7]

$$U_{ac} = U_i \frac{p_0}{K_i} + U_s \frac{p_0}{K_s} = \frac{Q}{C_i}\frac{p_0}{K_i} + \frac{Q}{C_s}\frac{p_0}{K_s} \tag{2}$$

where U_i and U_s are the voltages acros the insulator and the equivalent semiconductor capacitance, respectively, p_0 is the acoustic pressure, K_i, K_s and C_i, C_s are the elastic moduli and capacitances of the insulator and semiconductor, respectively, Q is the accumulated charge. If we suppose for the signification $K_i = K_s = K$, that is of course not necessary, the relation

$$U_{ac} = Q\left(\frac{1}{C_i} + \frac{1}{C_s}\right)\frac{p_0}{K} = \frac{Q}{C}\frac{p_0}{K} \tag{3}$$

shows on the direct correlation between the acoustoelectric response signal and the total structure capacitance C.

The principle of our A-DLTS measurements consist then in the special analysis of the acoustoelectric transient signal after infection pulse using a set of emission rate windows similarly as in the case of DLTS technique developed for the capacitance transient. The ralaxation times of exponential transient signal are displayed

using selected rate windows and a response peak occurs at the temperature where the traps emission rate is within the window. The emission rate windows are precisely determined by setting of gates at times t_1 and t_2 after bias injection pulse and the difference of acoustoelectric response signals $\Delta U_{ac} = U_{ac}(t_1) - U_{ac}(t_2)$ can be monitored as function af temperature. The sign of the acoustoelectric signal difference ΔU_{ac} depends on whether the electron occupation had been increased or decreased by the bias pulse. The peaks with the maxima at temperatures when the emission rate is the same as adjusted window given by

$$\tau_m = \frac{t_2 - t_1}{\ln t_2 - \ln t_1} \tag{4}$$

are then as a result of measurement. The experimental arrangement is illustrated in Fig. 1. A $LiNbO_3$ transducer acousticaly bonded to the quartz rod buffer was

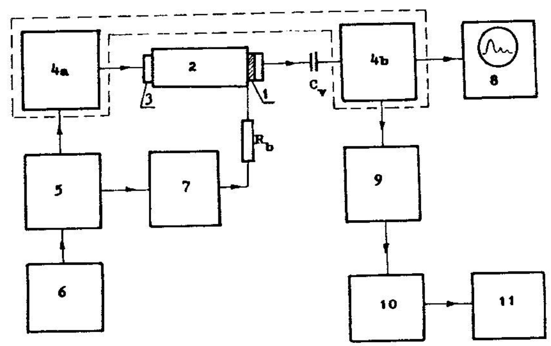

Fig. 1. Experimental arrangement in block diagram: 1 GaAs MIS structure, 2 buffer, 3 transducer, 4 Matec pulse modulator and recceiver, 5 double pulse generator, 6 synthetyser, 7 bias voltage pulse-generator, 8 osciloscope, 9 box-car integrator, 10 computer with analogous-digital converter, 11 printer. f=4.6 MHz $P_{ac} \approx 0.1$ to $1.0 W cm^{-2}$.

used to generate a longitudinal acoustic wave of frequency 4.6 MHz by applying a double rf pulse. The inreceiver transducer. The double acoustoelectric signal from the structure then after detection in the receiver was selected by the box-car integrator and conseqently evaluated by anlogous-digital convertor and computer, that recorded directly acoustoelectric signal defference as function of temperature. The injection bias pulse was applied to the investigated structure through the resistor R_b. The capacitor C_v protected the receiver input against dc voltage. The investigated MIS structure together with buffer and transducer was situated in the brass holder placed in the nitrogen cryostat, which enabled the measurement of the temperature dependence of the acoustoelectric response signal difference. The Al-SiN-GaAs MIS structure were fabricated on n-type GaAs: substrate plates with (100) surface orientation and $0.76 - 1.86 \times 10^{-18} cm^{-3}$ Te concentration. The insulator SiN layers of thickness 115 nm were prepared by plazmatic deposition at temperature 300 °C and presure of 450μbar from the mixture of following gases:

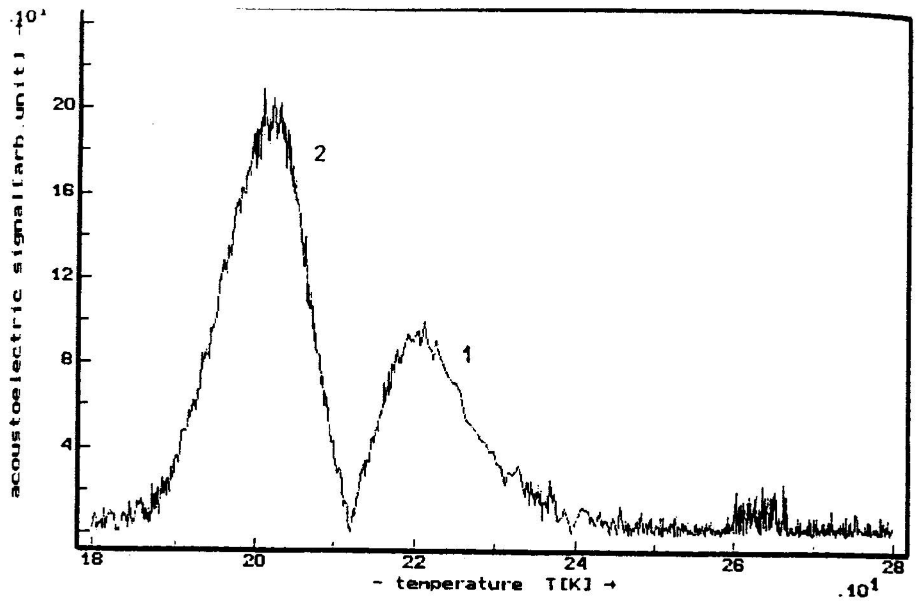

Fig. 2. Typical A-DLTS spectrum of GaAs MIS structure with an n-type substrate directly registered by computer. Acoustoelectric signal represents the difference of the acousstoelectric response at times t_1 and t_2.

$NH_3(25\%) + SiH_3(17\%) + Ar(58\%)$. The capacitors of $10 \times 10mm^2$ were then cut for experimental investigation.

III. RESULTS AND DISCUSSION

Following the above described procedure the Al-SiN-GaAs MIS structure was investigated. Fig. 2 shows a typical A-DLTS spectrum obtained under a normal zero bias filling pulse conditions with steady-state bias -3V. On each such spectrum observed at various rate windows two different peaks, labeled 1 and 2 can be seen. Another two A-DLTS peaks (3 and 4) are observed if a forward bias filling pulse is applied.

The important feature to note in Fig. 2 is that the acoustoelectric response defference ΔU_{ac} representing A-DLTS signal at temperatures between peaks decreases to zero value becouse of the change of the character of the acoustoelectric transient minority and majority carrier traps, respectively. Our A-DLTS apparatus is able to register namely only the absolute value of the A-DLTS signal ΔU_{ac} although it enables to follow the progress of individual acoustoelectric response signals $U_{ac}(t_1)$ and $U_{ac}(t_2)$, respectively.

It should be also noted that A-DLTS measurement of our GaAs MIS structures could not be realized in the temperature region below 180 K up to liquid nitrogen temperature. The decrease of the n-type GaAs substrate conductivity due to the

Table 1
Summary of the traps parameters detected by the A-DLTS in GaAs MIS structure

Number (Fig.3)	ΔE[eV]	σ[cm^2]
1	0.32	2.8×10^{-15}
2	0.35	6.0×10^{-14}
3	0.41	8.0×10^{-20}
4	0.16	4.3×10^{-18}

temperature decrease entails the rise of its piezoactivity and so the strong background signal overlaped the acoustoelectric signal produced by the interface region of MIS structure and some interference peaks of unknown origin occured. The Arrhenius plots for the individual peaks constructed from the A-DLTS spectra are in Fig. 3. Replaicing v_n and N_c in (1) by the adequate formulae [7], the relax-

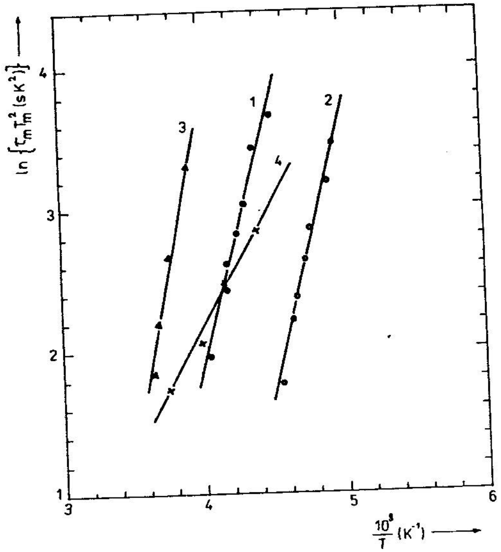

Fig. 3. Arrhenius plots constructed for A-DLTS spectra for a zero bias filling pulse (o,•) and for forward filling pulse (Δ,∗). The trap activation energies are shown in Table 1.

ation time charactering the acoustoelectric transient has the following temperature dependence

$$\frac{1}{\tau_m} = \gamma_n \tau_n T^2 e^{\frac{-\Delta E}{kT}} \quad (5)$$

where $\gamma_n = 2.28 \times 10^{20} cm^{-2} s^{-1} K^{-2}$ for electron traps in GaAs [6]. The resulting acivation energies determined from these plots using (5) and correspounding calculated capture cross-sections are summarezed in Table 1. The most of the obtained energy levels are in good agreement with the values found by other techniques in the bulk GaAs or in the GaAs heterostructures. The obtained deep level near 0.32 eV was observed both by DLTS and other methods as bulk level [6,8,9] with very close value of cross-section. The energy level position at 0.35 eV was found and determined also as the bulk traps level with slightly defferent cross-section [10] but also as defect observed after high energy electron irradiation [8]. The energy level at 0.41 eV observed for forward bias filling pulse coincides with the impurity traps levels found in V.P.E. GaAs [10] and also in the AlGaAs/GaAs heterostructures by SAW acoustoelectric voltage measurement [6]. However, its cross-section detected here is several orders of magnitude smaller than its cross-section reported in [6,10]. The last energy level at 0.16 eV which is very close to the conduction band was found for the forward bias filling pulse, too. The close level at 0.14 eV was found by similar way in DLTS measurement of the Al-nGaAs Schotky diode [8]. Although the traps levels at 0.12 eV to 0.17 eV are mostly reported as relults abtained after irradation or illuminitation, some of then are found also at dark [6,8,10].

In spite of the fact that the same or very close traps levels have been found by others methods that confirmes the further study possibilities of deep levels in MIS structures by acoustoelectric investigations, the additional exteriments at various injection filling pulses and lower temperatures using a light beckground should be done for GaAs MIS structures.

In summary, the presented results clearly demonstrate that A-DLTS technique based on the acoustoelectric response signal provoked by ultrasound wave in MIS structure can be succesfully used for deep-level investigation. The A-DLTS measurements have been performed on n-type GaAs MIS structure ans four trap levels have been observed. The activation energies of these levels and also two of calculated cross-sections are in good agreement with some values determined by other methods. However, processes associated with the piezoactivity of n-GaAs substrate occured at lower temperatures have to be suppressed to make possible the measurements at wider temperature range.

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