phys. stat. sol. (a) **139**, K35 (1993)

Subject classification: 71.55 and 73.40; 72.50; S5.11

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Acoustic Version of Lang's DLTS for MIS Structure Investigation

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Introduction Deep-level transient spectroscopy (DLTS) in several modifications is widely applied to determine the trap parameters as activation energy, capture cross-section, and trap density in metal–insulator–semiconductor (MIS) structures [1 to 3]. DLTS techniques are used to obtain information about a trap level mostly by observing the capacitance transient associated with the return to thermal equilibrium of the occupation of the trap level following an initial condition.

Recently two modifications of acoustic transient spectroscopy were developed: the surface acoustic wave (SAW) technique using a transverse acoustoelectric voltage measurement [4] and longitudinal acoustic wave technique using an acoustoelectric response signal [5].

In this note we present a new version of acoustic deep-level transient spectroscopy (A-DLTS), the principle of which closely coincides with the idea of the original DLTS technique [6]. The method is verified by the investigation of a GaAs MIS structure and some A-DLTS results are presented.

Experimental principle and details The presented A-DLTS technique is connected, similarly to Lang's original DLTS, with the fact that the time development of the capacitance of the MIS structure after an injection bias pulse has been applied to the structure reflects relaxation processes associated with the thermally activated emission of injected carriers. The acoustoelectric response signal produced by the MIS structures when a high frequency longitudinal acoustic wave traverses them is proportional to the voltage and relative change of capacitance induced by the acoustic wave and for a thin planar structure ($d \ll \lambda$) can be expressed [5] by

$$U_{ac} = U_i \frac{p_0}{K_i} + U_s \frac{p_0}{K_s} = \frac{Q}{C_i} \frac{p_0}{K_i} + \frac{Q}{C_s} \frac{p_0}{K_s}, \tag{1}$$

where U_i and U_s are the voltage across 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 insulator and semiconductor, respectively, Q is the accumulated charge and the parameters d and λ are the insulator thickness and the acoustic wavelength, respectively. If we suppose, for simplicity, $K_i = K_s = K$, that is of course not necessary, (1) becomes

$$U_{ac} = Q\left(\frac{1}{C_i} + \frac{1}{C_s}\right)\frac{p_0}{K} = \frac{Q}{C}\frac{p_0}{K}, \tag{2}$$

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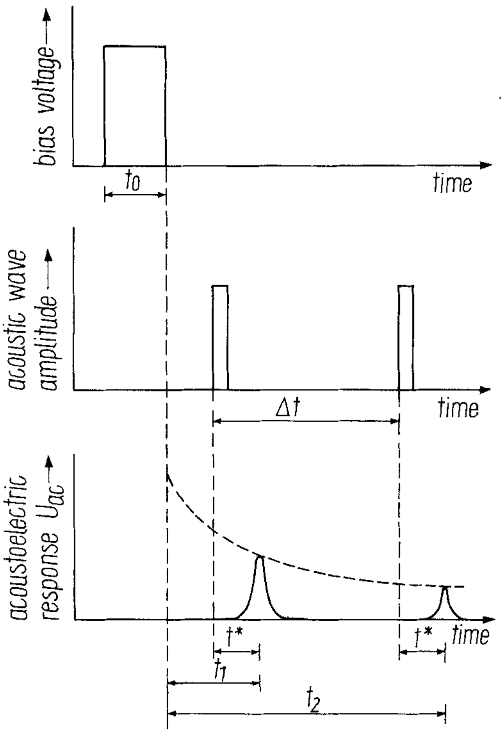

Fig. 1. Schematic illustration of the time arrangement of some experimental parameters; t_0 is the bias pulse width, Δt the double pulse separation, and t^* the traverse time through the buffer rod

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

The principle of our A-DLTS measurements consists then in the special analysis of the acoustoelectric transient signal after an injection pulse using a set of emission rate windows similarly as in the case of the DLTS technique developed for the capacitance transient. The relaxation times of an exponential transient signal are displayed using selected rate windows and a response peak occurs at the temperature where the trap 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 the 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 a function of temperature. The peaks with the maxima at the temperature for which the emission rate is the same as the adjusted window given by

$$\tau_m = \frac{t_2 - t_1}{\ln \dfrac{t_2}{t_1}}, \tag{3}$$

are then the result of the measurement. The schematic illustration of the time arrangement of some experimental parameters is given in Fig. 1.

The experimental set-up is illustrated in Fig. 2. A $LiNbO_3$ transducer acoustically bonded to the quartz rod buffer was used to generate a longitudinal acoustic wave by applying a double rf pulse. The investigated MIS structure was bonded to the other side of the rod buffer and worked as a receiver transducer. The double acoustoelectric signal from the structure after detection in the receiver was selected by the box-car integrator and consequently evaluated by an analogous–digital converter and the computer, that recorded the acoustoelectric signal difference as a function of temperature. The sampling times t_1 and t_2 were selected as $t_2 = 10t_1$ and varied from 0.2 to 2 ms. The thermal extension of the quartz rod buffer as well as the temperature dependence of ultrasound velocity did not influence the time t^* so significantly as to disturb the measurement in the used temperature range.

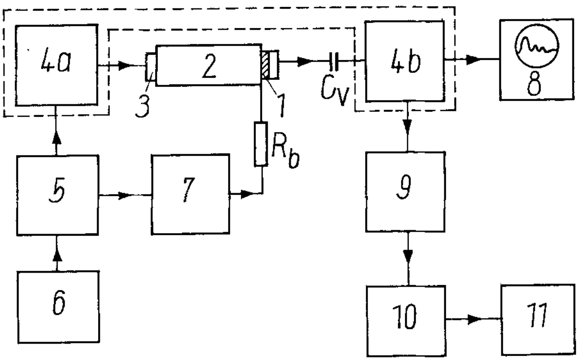

Fig. 2. Experimental arrangement in block diagram: 1 GaAs MIS structure, 2 buffer, 3 transducer, 4 Matec pulse modulator and receiver, 5 double pulse generator, 6 synthesyzer, 7 bias voltage pulse-generator, 8 oscilloscope, 9 box-integrator, 10 computer with analogous-digital converter, 11 printer. $f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

Results and discussion The above-described procedure was verified by GaAs MIS structure investigations. The Al–SiN–GaAs MIS structures were fabricated on n-type GaAs:Te substrate plates. The insulating SiN layers of thickness 115 nm were prepared by plasma deposition [7]. Capacitors of 10×10 mm^2 were cut for experimental purpose. On a typical A-DLTS spectrum under normal zero bias filling pulse conditions at various rate windows two different peaks can be seen (Fig. 3). Another two A-DLTS peaks are observed if a forward bias filling pulse is applied.

The Arrhenius plots for the individual peaks constructed from the A-DLTS spectra are shown in Fig. 4. Using the well-known relation expressing the temperature dependence of the relaxation time characterizing the acoustoelectric transient [4, 5] the activation energies and corresponding capture cross-sections were determined. The obtained energy levels 0.32 (1) and 0.35 eV (2) for zero bias filling pulses, 0.41 (3) and 0.16 eV (4) for forward bias filling pulses as well as the corresponding cross-sections 2.8×10^{-15} (1), 6.0×10^{-14} (2), 8.0×10^{-20} (3), and 4.3×10^{-18} cm^2 (4) are mostly in good agreement with the values found by DLTS or other techniques [7].

The present acoustic modification of the DLTS technique can be compared with the capacitance or conductance technique used also in case of a thick insulator layer. In such case, a small charge distribution causes large potential changes on the small

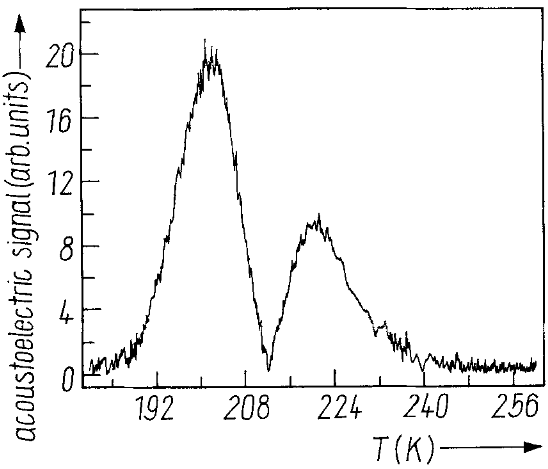

Fig. 3. A-DLTS spectrum of GaAs MIS structure directly registered by the computer for $t_1 = 0.2$ ms and $t_2 = 2.0$ ms. The acoustoelectric signal here represents the difference of acoustoelectric response at times t_1 and t_2

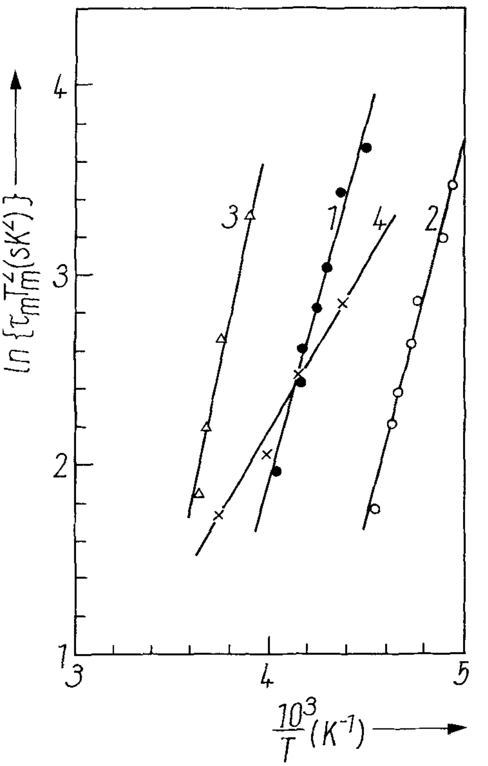

Fig. 4. Arrhenius plots constructed for A-DLTS spectra for a zero bias filling pulse (○, ●) and forward filling pulse (△, ×)

capacitance of the insulator layer. The fact that the whole acoustoelectric response signal is created in the interface region is the reason that generally a larger response of any change in the space charge distribution of the interface region due to the varying external conditions can be expected. Also the preparation of ohmic contacts does not appear so important. Some disadvantages of our technique consist in the geometrical arrangement and relatively large used samples. However, some sample minimization can be realized.

In summary, the presented A-DLTS technique based on the acoustoelectric response signal provoked by an ultrasound wave in a MIS structure can be successfully used for deep-level investigations.

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(Received January 4, 1993; in revised form April 14, 1993)