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Acoustic spectroscopy of deep centres in GaAs/AlGaAs heterostructures

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Abstract

Two versions of the acoustic deep-level transient spectroscopy (A-DLTS) technique based on the acoustoelectric effect resulting from the interaction between an acoustic wave and heterostructure interfaces have been used to study deep centres in GaAs/AlGaAs heterostructures. The former uses the high frequency transverse acoustoelectric signal (TAS) arrising from the interaction of surface acoustic wave electric field and free carriers at the heterostructure interfaces. The latter uses an acoustoelectric response signal (ARS) produced by the heterostructure interface when a longitudinal acoustic wave propagates through the heterostructure. Planar GaAs/AlGaAs heterostructure capacitors with electrodes in a field effect transistor configuration were investigated by these versions of the A-DLTS technique. Several deep centres were found and their activation energies and corresponding cross-sections determinated. Both the appearance of some A-DLTS peaks and the shift of practically all peaks of the A-DLTS spectrum with increasing bias voltage can be considered to be the characteristic features of interface states.

Keywords: Acoustic spectroscopy; Deep centres

1. Introduction

Characterization of deep centers in GaAs/AlGaAs heterostructures based high mobility devices is extremely important since the presence of defects significantly affects device performance. Recently, the acoustoelectric effect in semiconductor structures has been shown to be a useful tool for the experimental study of deep centres and two basic modifications of acoustic deep-level transient spectroscopy (A-DLTS) were introduced. The surface acoustic wave (SAW) technique uses a nonlinear acoustoelectric interaction between the SAW electric field and the free carriers in an interface region which generates a transverse acoustoelectric signal (TAS) across the structure. Transient measurements of the rise or fall times of the resulting dc and hf part of the TAS have been used to study charged traps [1,2]. The longitudinal acoustic wave (LAW) technique which has already been used for MIS structure investigations uses an acoustoelectric response signal (ARS) observed at the interface of the semiconductor structure when a longitudinal acoustic wave propagates through the structure [3].

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Both ARS and TAS are extremely sensitive to any changes in the space charge distribution in the interface region due to the trapped charge after an injection bias pulse has been applied, so that their time development represents acoustoelectric transients which reflect relaxation processes associated with the thermal recombination of excited carriers moving towards their equilibrium state. By

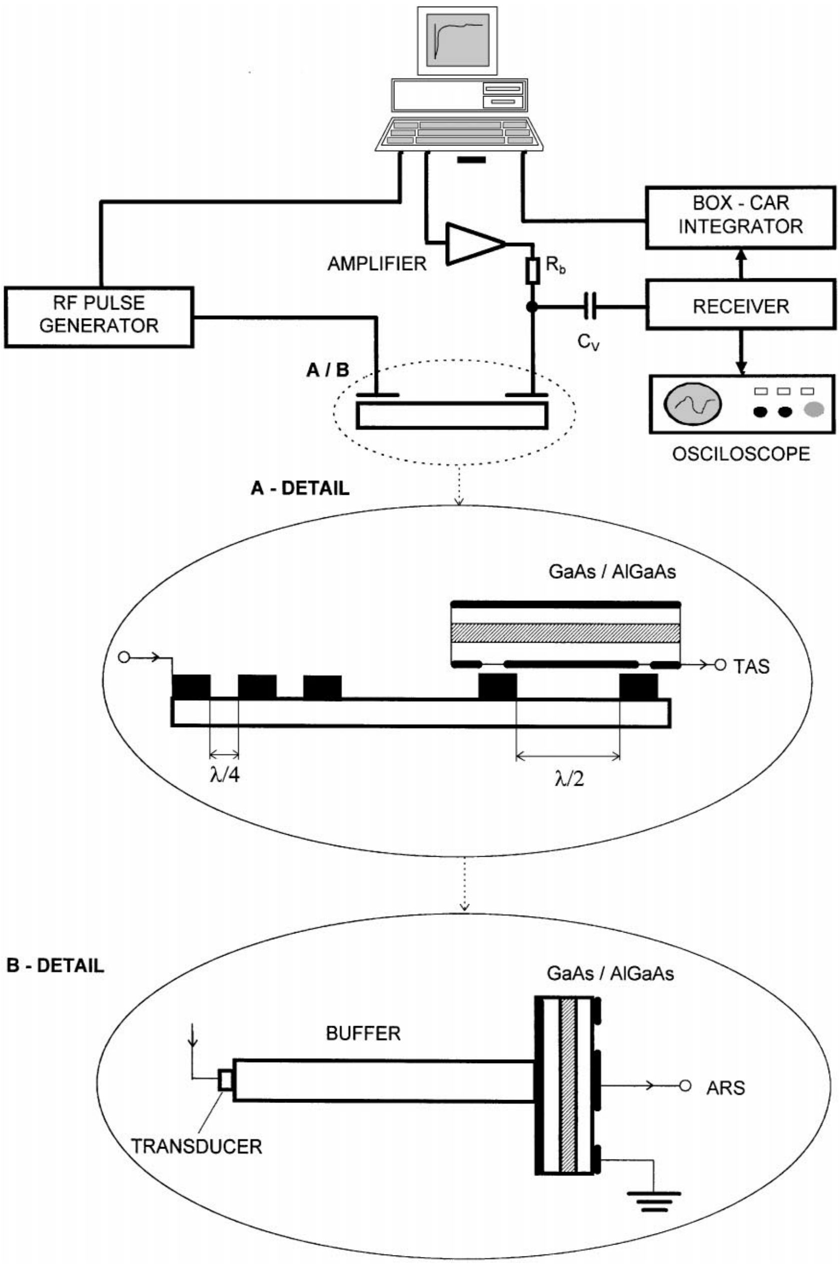

Fig. 1. Block diagram of the experimental arrangement for A-DLTS measurements. The detailed sample configuration is illustrated in A-detail (TAS measurement) and B-detail (RAS measurement).

investigating the temperature dependence of the acoustoelectric transients characterizing the return to thermodynamic equilibrium, the activation energies and corresponding cross-sections can be determined [4].

Here we present the A-DLTS results obtained on GaAs/AlGaAs heterostructures utilizing both a SAW nondestructive technique using the hf part of the TAS and a LAW technique using the ARS.

2. Experimental procedures and results

The A-DLTS techniques we used are based on the fact that the time development of the amplitude of the measured acoustoelectric signal (both TAS and ARS) after an injection bias pulse has been applied to the heterostructure is proportion to the nonequilibrium carrier density, so that the decay time constant associated with the relaxation of the acoustoelectric signal amplitude is a direct measure of the time constant associated with the relaxation processes of injected carriers. Using a method of computer evaluation of isothermal acoustoelectric transients by applying a data compression algorithm [5] and also including, in some cases, a method of digital filtering by convolution [6] in connection with the well known relation expressing the temperature dependence of the relaxation time which characterises the return to thermodynamic equilibrium [3,4], the activation energies and corresponding capture cross-sections can be determined from transient measurements of TAS and ARS, respectively.

A block diagram of the experimental arrangement of both A-DLTS techniques is shown in Fig. 1. The computer system was used to trigger the apparatus, to generate excitation bias pulses as well as to record and evaluate the isothermal transient of the acoustoelectric signals. A SAW of frequency 10 MHz was generated using an interdigital transducer evaporated on the $LiNbO_3$ delay line and the structure to be investigated was placed on the top of the $LiNbO_3$ and pressed against the window (A-detail). A LAW of frequency 13.2 MHz was generated using an $LiNbO_3$ transducer in the arrangement illustrated in B-detail. The acoustoelectric signal produced by the structure after detection in the receiver was selected by the box-car integrator and then recorded and stored by computer. Our GaAs/AlGaAs MBE grown heterostructures were fabricated on standard semiinsulating (SI) substrates and prepared in planar field effect transistor configuration and consisted of the layers which have been already described [7].

Representative A-DLTS spectra recorded by applying an injection bias pulse of − 3, − 5 and − 7 V for the LAW arrangement and − 5 V for the SAW technique are illustrated in Fig. 2. Two basic features of the observed spectra can be recognized. The considerable influence of the gate voltage on the A-DLTS spectrum and an observed shift of practically all the peaks of the A-DLTS spectrum with increasing bias voltage to lower or higher temperatures depending on the type of deep centre can be regarded as the characteristic feature of interface states. The appearance or disappearance of some A-DLTS peaks with decreasing bias voltage corresponds to the quantum well no longer being within the depletion layer and to the transition between depletion and inversion conditions, respectively. Comparing the A-DLTS spectrum obtained at an applied bias voltage of − 5 V by the LAW and SAW technique, respectively, we can see the energy levels shift because of a dc TAV added in the SAW experiments to the excitation bias voltage.

Using Arrhenius plots constructed from the positions of the maxima of the A-DLTS spectra, the activation energies, E, and corresponding capture

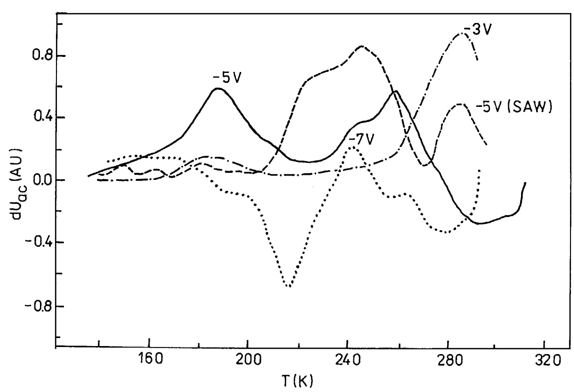

Fig. 2. A-DLTS spectra of GaAs/AlGaAs heterostructures obtained from ARS and TAS transients as a function of bias gate voltage for a relaxation time $\tau = 43.6$ ms.

Table 1
Summary of deep centres detected by A-DLTS techniques on GaAs/AlGaAs heterostructures

Level ($-U_g$ [V])	E [eV]	σ [cm^2]	Character
1(3)	0.24	1.5×10^{-17}	Donor
2(3)	0.48	6.7×10^{-12}	Acceptor
3(3)	0.37	6.1×10^{-15}	Acceptor
4(3)	0.32	1.1×10^{-18}	Donor
5(3)	0.24	4.1×10^{-20}	Donor
1(5)	0.24	2.6×10^{-17}	Donor
2(5)	0.30	8.3×10^{-16}	Donor
3(5)	0.24	1.4×10^{-18}	Acceptor
4(5)	0.34	2.3×10^{-16}	Acceptor
5(5)	1.03	4.2×10^{-4}	Donor
6(5)	0.66	7.9×10^{-12}	Donor
7(5)	0.68	1.5×10^{-12}	Acceptor
8(5)	0.28	2.9×10^{-20}	Acceptor
1(7)	0.33	1.1×10^{-13}	Donor
2(7)	0.37	3.3×10^{-14}	Donor
3(7)	0.38	3.4×10^{-15}	Acceptor
4(7)	1.27	2.1×10^{-4}	Acceptor
5(7)	0.62	5.8×10^{-13}	Acceptor
1(5-SAW)	0.44	1.4×10^{-16}	Donor
2(5-SAW)	0.47	1.3×10^{-14}	Donor
3(5-SAW)	0.39	6.6×10^{-16}	Donor

cross-sections, σ, summarized in Table 1, were determined. The values obtained are mostly in good agreement with the values found by DLTS or other techniques [1,8–10], however, some features still remain unclear. Therefore further study of GaAs/AlGaAs heterostructures is necessary, especially photo-induced acoustic transient spectroscopy can give a qualitative improvement in A-DLTS investigation.

In conclusion, the versions of acoustic transient spectroscopy we present here and which employ both longitudinal and surface acoustic waves, can be successfully used to study deep centres in semiconductor heterostructures. Several deep centres attributed to the interface states in GaAs/AlGaAs heterostructures were discovered and their parameters were determined.

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