

NEW IMPROVED TECHNIQUE FOR MOS INTERFACE STATES INVESTIGATION

Štefan Hardoň, Jozef Kúdelčík, Igor Jamnický, Ivan Bellan

*Department of Physics, Faculty of Electrical Engineering, University of Žilina,
Univerzitná 8215/1, 010 01 Žilina, Slovakia
E-mail: hardon@fyzika.uniza.sk*

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1. Introduction

Semiconductors are fundamental materials of the electronic industry. New technology, however require smaller devices, sharper transitions and higher number of preparation steps. Narrower transitions require sharper doping profiles and subsequently lower temperatures during the preparation processes. The study of deep centre in semiconductor and the interface states properties including their activation energy, cross-section, concentration and interface states distribution are important. In the contribution is presented one version of deep-level transient Fourier spectroscopy (DLTFS) method – Surface Acoustic Wave (SAW) technique. This 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. The contribution is focused on the new method of measurement of TAS with utilization of LABVIEW system and LOCK-IN amplifier.

Interface states at semiconductor-insulator in MOS (Metal-Oxide-Semiconductor) structures play an important role in determining their electrical characteristics important for practical use in semiconductor devices. Research and investigation of semiconductor or MOS structure properties are basic steps, which lead to the development of stable and high quality integrated circuits. Research is focused on the study of the interface states properties: activation energy, cross-section, concentration and interface states distribution. The methods of acoustic transient spectroscopy to study of deep centers in semiconductors are used. On our department we used two version of the acoustic (acoustoelectric) deep-level transient spectroscopy (A-DLTS). The first version is based on the longitudinal acoustic wave (LAW) technique and technique uses an acoustoelectric response signal (ARS) observed at the interface of the semiconductor structure when a longitudinal acoustic wave propagates through the structure. The second version uses SAW technique and her 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. Both TAS and ARS are extremely sensitive to any change in the space charge distribution in the interface region due to the trapped charge after an injection bias pulse has been applied [1].

Nondestructive SAW technique is based on the fact that the SAW electric field on a piezoelectric substrate can affect the free carriers charge in the interface of the semiconductor structure. They produce the transversal acoustoelectric signal (TAS) which reflects changes in the space charge distribution in the interface region their time development after an injection pulse has been applied to the structure. This nonlinear interaction is induced by dc voltage (acoustoelectric effect) and also to a voltage at the voltage at the second harmonic of the wave frequency which appears when there are two counter-propagating excitations waves. DC transverse acoustoelectric voltage (TAV) is produced by the space charge in the semiconductor structure. The resulting electric field across the structure calculates dc acoustoelectric effect and HF wave propagation properties and can be expressed by the relation [2]

$$E = E_0 + E_1 e^{-i(\omega t - kz)} \quad (1)$$

where E_0 is the dc part and E_1 is HF part of TAS, respectively. The direction of SAW wave vector is taken as z and y axis is perpendicular to the semiconductor interface. The corresponding carrier density follows the relation [2]

$$n = n^0 + n_0 + n_1 e^{i(\omega t - kz)} \quad (2)$$

where n^0 is concentration of the carrier without applied field and n_0 and n_1 are the acoustoelectric term and term proportional to the amplitude of exciting wave, respectively. The quantity of transversal acoustoelectric current density is defined as [2]

$$J_{AEy} = \mu e \langle n_1 E_{1y} \rangle \quad (3)$$

where μ is the mobility of electron and e is the charge of the electron. Transversal HF acoustoelectric response signal can be given by the relation [2]

$$U_{ac} = \int_0^d E_1^y \sin(\omega t - ky) dy \quad (4)$$

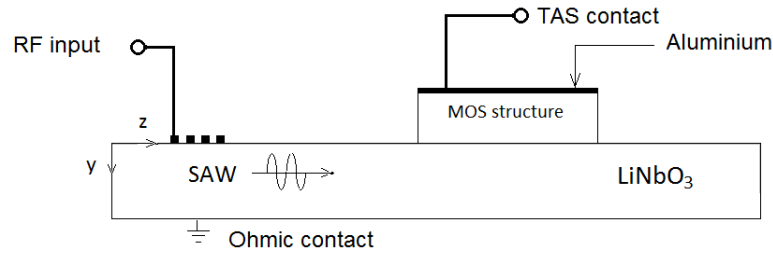


Fig. 1: $LiNbO_3$ delay line, A-DETAIL in fig.4 [4]

The experimental set-up, the SAW measurement arrangement is shown in Fig.1 [3]. An RF pulse of dc voltage is applied to the input interdigital transducer propagating $LiNbO_3$ delay line to launch the surface acoustic wave which is associated with the electric field. RF pulses are typically 4 MHz, their duration is from μs to ms and repetitions are some ms (Fig. 2). The semiconductor sample is placed at the surface of the lithium niobate delay line and using a mechanical probe the semiconductor is slightly pressed against $LiNbO_3$.

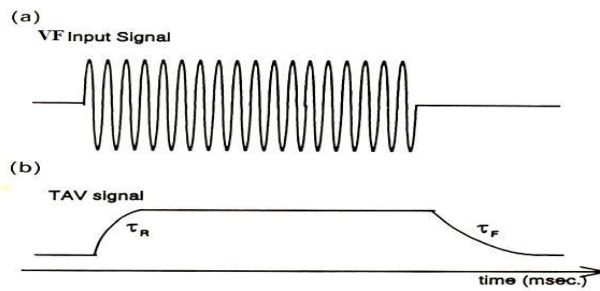


Fig. 2: a) SAW RF input signal, b) results TAS signal

Principle SAW DLTFs is based on the fact, that the amplitude of measurement TAS is proportional to the non-equilibrium density of conditions, $TAS(t) \approx \Delta n(t)$. Relaxation of the carrier from the interface states leading to a new thermal equilibrium steady state. $TAS(t)$ can be expressed by the relation

$$TAS(t) = U_0 + U_1 \exp(-t/\tau) \quad (5)$$

where U_0 represents TAS due to acoustoelectric interaction, U_1 represents growth of TAS which is cause of injection pulse, τ is time constant associated with release electron carrier from deep centers after injection pulse. Time constant is function of temperature

$$\tau^{-1}(T) = \gamma \sigma T^2 \exp\left\{-\frac{E_a}{k_B T}\right\} \quad (6)$$

where γ is constant, k_B is the Boltzmann's constant, E_a is the interface state activation energy related to the bottom of conduction band, σ is the capture cross section and T is the thermodynamic temperature [1, 5]. Analyze of time dependence of TAS(t) at different temperature allows us to determine activation energy and cross section from Arrhenius plot.

In this paper we describe a new version of the SAW technique utilizing the LABVIEW system, LOCK-IN amplifier and analyze of isothermal transients by DLTFs.

2. Experimental

Principle of the measurement of TAS A-DLTS is presented in works [1, 2]. The new version of measurement TAS A-DLTFs is illustrated in Fig. 3. The whole is managed by Labview system. The output signal of TAS from MOS structure is shown in Fig. 4a. For next processing of this signal is important only exponential decrease. Signal conditioning is done electronically using by special electronic circuit (shaver) which removes start-up edge of signal (Fig. 4a). Clock generator signal from LabView determines which part of signal is supplied to the LOCK-IN amplifier. In front panel of our program (Fig. 4b) we can select which parameter will be measurement together with the number of harmonics members. Stored data are next evaluated in other programs where is determine activation energy and cross-section on measurement semiconductor sample.

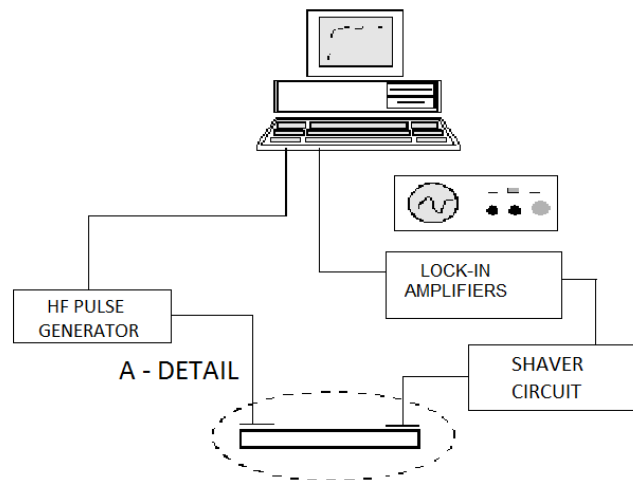


Fig. 3: NEW experimental arrangement of SAW (TAS measurement)

Stored parameters X_n and Y_n represent coefficients a_n and b_n of discrete Fourier coefficients calculated by LOCK-IN (Fourier transformation)

$$a_n(T) = \frac{1}{T_W} \int_0^{T_W} TAS(t, T) \cos\left(n \frac{2\pi}{T_W} t\right) dt = \frac{1}{T_W} \int_0^{T_W} U_1 \exp\left\{-\frac{t}{\tau(T)}\right\} \cos\left(n \frac{2\pi}{T_W} t\right) dt \quad (7)$$

$$b_n(T) = \frac{1}{T_W} \int_0^{T_W} TAS(t, T) \sin\left(n \frac{2\pi}{T_W} t\right) dt$$

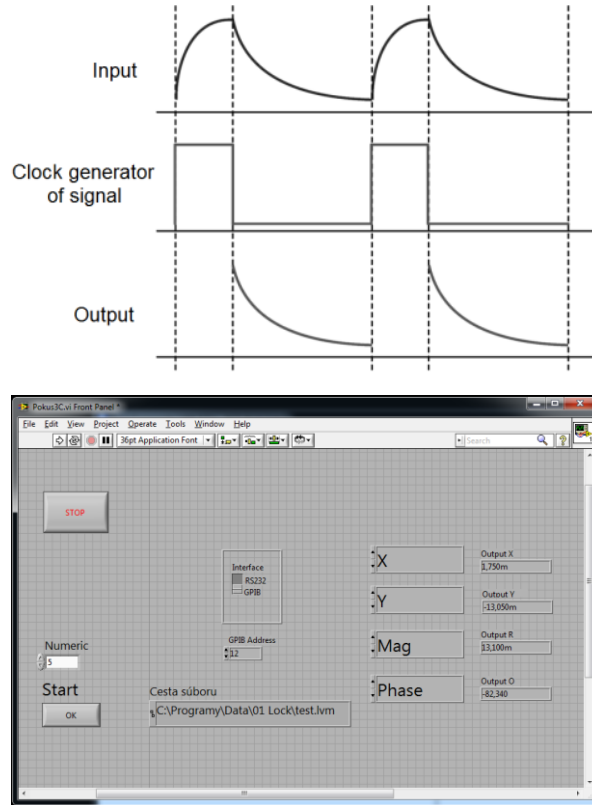


Fig. 4: Trimming (cutting) of TAS signal and front panel of measurement SAW A-DLTS

Discrete Fourier coefficients are function of temperature, so our LabView system can measure selected parameter at various temperatures. Temperature development of the firsts Fourier coefficients are presented on Fig. 5. The numerical simulation was calculated for $E_a = 0,45 \text{ eV}$ and $\sigma = 5 \cdot 10^{-14} \text{ cm}^2$. From this simulation it can be seen that Fourier coefficients have maximum at various temperatures. These maxima are shifter to higher temperatures for higher Fourier coefficients.

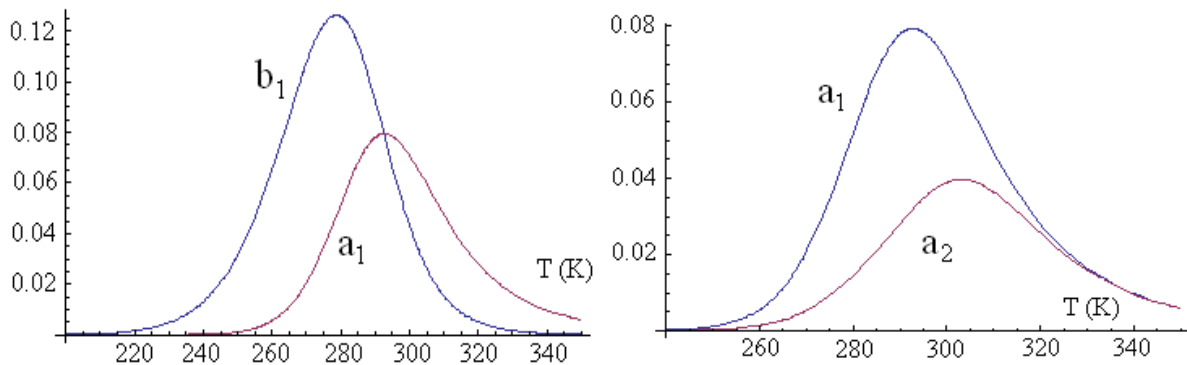


Fig.5: Temperature dependence of Fourier coefficients (a) a_1 , b_1 and (b) a_1 , a_2 .

The time constant can be obtained from ratio of two coefficients. There exist three principally different possibilities [6]. One of them is

$$\tau(a_n, b_n) = \frac{1}{n \omega} \frac{b_n}{a_n} \quad (8)$$

The real results are not always clearly consistent with the theory because not all measured voltage waveforms have pure exponential decay. Selection only suitable coefficient for

calculating the parameters are realized using relations, which give information whether the transient is exponential, for example $2(b_1/a_1)(a_2/b_2) \approx 1$.

On the basis of measured parameters (X_n , Y_n) using LOCK-IN at various temperatures can be calculated temperature dependence of time constant by Eq. (8) (Fig. 6a). From these values and by Arrhenius graph then can be determined activation energy and cross section of studied process in MOS structure. Numerical simulation of Arrhenius plot for $\tau(a_1, b_1)$ is drawn on Fig. 6b.

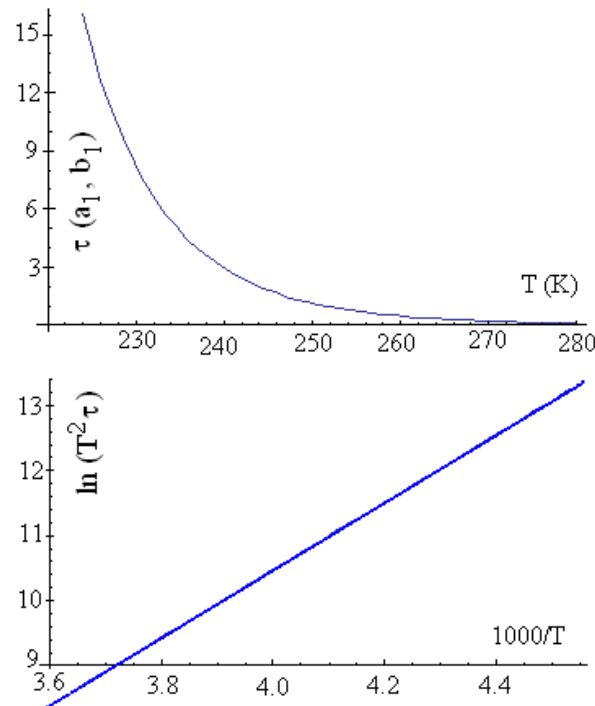


Fig.6: Temperature development of $\tau(a_1, b_1)$ (8) and Arrhenius plot.

3. Conclusions

This new method is non-destructive method which uses nonlinear interaction between surface acoustic wave and semiconductor interface. This method is appear useful tool to determinate interface states. On evaluating of the parameters of interface states is used DLTFs method.

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