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INVESTIGATION OF ACOUSTOELECTRIC RESPONSE OF Si MOS STRUCTURES[1]

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The acoustoelectric response of MOS structures reflects the potential distribution condition inside the structure. In this paper the acoustoelectric response of Si MOS structures as a function of external bias voltage and temperature is studied. The role of space charge in a semiconductor, surface potential and insulator capacity are discussed.

I. INTRODUCTION

In our previous work [1, 2] we have studied the question of the piezoactivity of the SiO_2—Si structure discussed earlier in connection with the mechanical vibrations by Misawa, Moritani and Nakai [3, 4] and theoretically analysed by Grendel [5]. We have found that the structure shows piezoactivity also for high frequency longitudinal acoustic waves and acoustoelectric response is linearly dependent on the external bias voltage applied to the structure. We have also shown an interesting time development of the acoustoelectric response signal after a rapid change of the bias voltage. Because it was evident that this time development reflects the changes inside the structure we have investigated it further.

II. EXPERIMENTAL METHOD AND RESULTS

To investigate the MOS structures we used a simple arrangement with time recording of the acoustoelectric signal development after the bias voltage step had been applied (Fig. 1). The investigated structure was acoustically bonded to the quartz buffer rod and the longitudinal acoustic wave of frequency 4.6 MHz was excited by $LiNbO_3$ transducers driven by a Matec Attennation Comparator

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(4a). The SiO_2-Si structure worked as a receiver transducer, the signal of which after detection in the receiver (4b) was averaged by the box car integrator and recorder as a time function. The repetition frequency of the pulses was 1 kHz and the integrator time constant was 0.1 s. The external bias voltage could be applied to the investigated structures.

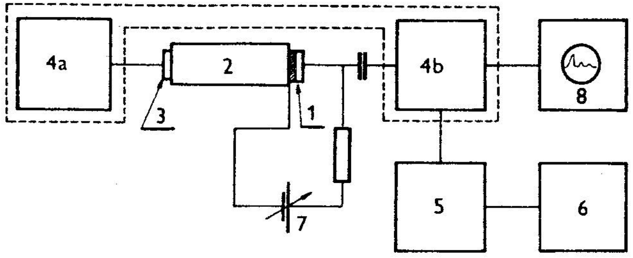

Fig. 1. Experimental arrangements. 1—investigated structure, 2—buffer, 3—transducer, 4—Matec Attenuation Comparator, 5—box car integrator, 6—recorder, 7—bias voltage supply, 8—oscilloscope.

The dependence of the acoustoelectric response of the structure on the external bias voltage measured immediately after its application is schematically illustrated in Fig. 2. The amplitude of the acoustoelectric signal δU_a at constant acoustic power is a linear function of the applied voltage but at a certain value U_{bc}, which we shall call the compensating voltage, the acoustoelectric signal vanishes. When a bias voltage step $\Delta U_b(1)$ which is smaller than U_{bc}, is applied, the acoustoelectric signal $\delta U_a(0)$ drops practically immediately to the value $\delta U_a(1)$ and then gradually returns to the now equilibrium state that is close to the state corresponding to $U_b = 0$. After removal of the bias voltage step $\Delta U_b(1)$ the acoustoelectric response is equivalent to the situation when the same bias voltage step but of a different polarity is applied, thus the acoustoelectric signal increases rapidly to $\delta U_a'(1)$ value. This process is illustrated in Fig. 3 for a SiO_2-Si structure with an oxide layer 1.35 µm thick prepared by thermal oxidation on the 400 Ω cm n-type silicon substrate. The applied bias voltage step was $\Delta U_b(1) = 0.8$ V with the positive polarity on the Si side and the measurement was made at room temperature.

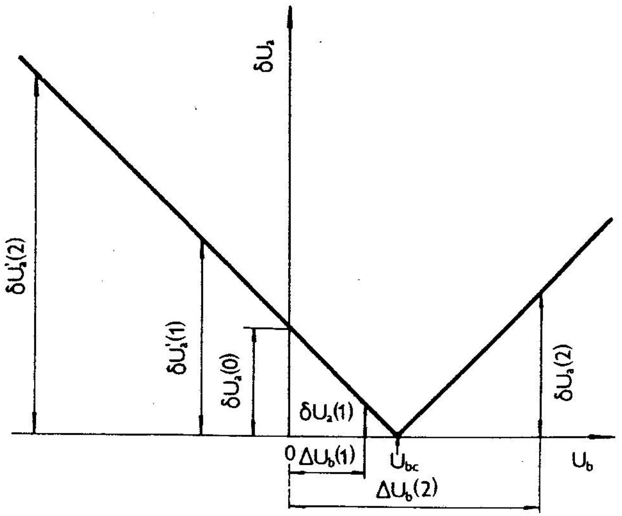

Fig. 2. Schematic diagram of acoustoelectric response signal dependence of a Si MOS structure on external bias voltage.

If the bias voltage step $\Delta U_b(2)$ is higher, than the compensating voltage U_{bc}, the signal is developed in a quite different way. The acoustoelectric signal after the achievement of the $\delta U_a(2)$ value (see Fig. 2) first decreases to the value corresponding to U_{bc} and then increases to the equilibrium state again close to that corresponding to $U_b = 0$. Such a situation is illustrated for the same sample and bias voltage step $\Delta U_b(2) = 2.0$ V in Fig. 4.

After an interruption of this developing process at any time the acoustoelectric signal increases as if the external bias voltage U_b of an opposite polarity were applied.

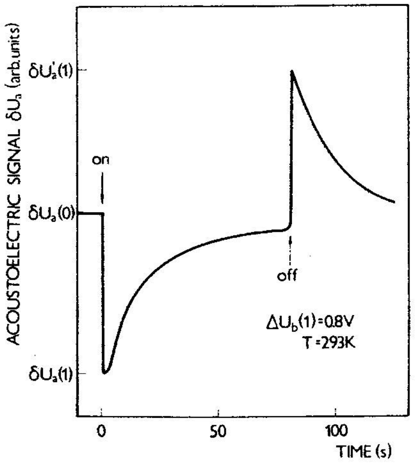

Fig. 3. Time development of acoustoelectric response after bias voltage step $\Delta U_b(1) = 0.8$ V has been applied and after its removal.

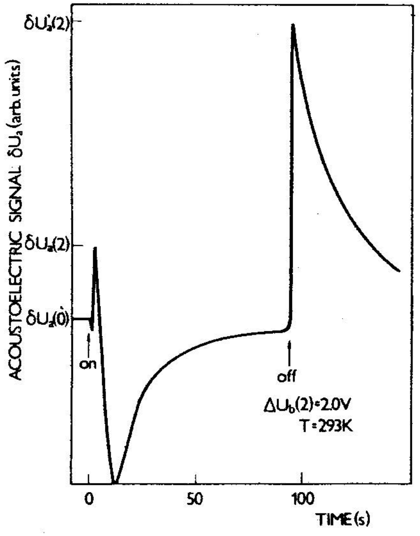

Fig. 4. Time development of acoustoelectric response after bias voltage step $\Delta U_b(2) = 2.0$ V has been applied and after its removal.

III. DISCUSSION

In case of one kind of traps with density N_T and occupancy distribution function f, the generation and time development of the high frequency acoustoelectric signal can be explained using the equation for bias voltage in the form

$$U_b = -[Q_s + eN_T f]/C_0 + \varphi_s + \varphi_{ms} \qquad (1)$$

where φ_{ms} is the contact potential difference between metal and semiconductor, φ_s is the surface potential, Q_s is the space charge in the semiconductor and C_0 is insulator capacity.

The contribution to the acoustoelectric signal δU_a is represented by the changes in C_0, Q_s and φ_s due to the mechanical deformation caused by the acoustic wave. While the acoustoelectric signal measured immediately after the superposition of the external bias voltage is proportional to the U_b value (Fig. 2), in the steady state the signal achieves practically the same value independent of U_b (Fig. 3 and Fig. 4) because of the screening. After the rapid U_b change the screening field development is shifted in time and the acoustoelectric response is proportional to the superposition of a new external field and the previous screening field. Using the appropriate external field a zero response can be achieved. The zero response can occur also during the screening field development so that the time development of the acoustoelectric response after the bias voltage step ΔU_b has been applied depends on the internal field development.

The acoustoelectric signal creation can also be explained by using an equivalent capacity scheme of the structure, which is usually used in electronics. This scheme is based on equivalent capacities of the semiconductor and the insulator, respectively. The frequency dependence of the MOS structure capacity is caused by the same mechanism and we can obtain the same description of the signal time development.

The time development of the signal after the U_b change depends upon the speed at which the potential φ_s and the charge Q_s change. These changes are connected with the kinetic equation for the distribution function f that can be written after Grendel [6] near the thermodynamic equilibrium in the following form

$$\frac{\partial f}{\partial t} = -(c_n n_0 e^{-v} + c_p p_0 e^{v} + e_n + e_p)f + c_n n_0 e^{-v} + e_p \qquad (2)$$

where t is time, e_n, c_n, n_0 and e_p, c_p, p_0 are the emission rate, the capture coefficient and the equilibrium bulk density of electrons and holes, respectively, $v = e\varphi_s/kT$.

Grendel has shown that after a small bias voltage step ΔU_b is applied, the current and consequently also the voltage on the capacity C_0 develop exponentially and this can be used also to explain the acoustoelectric response signal behaviour. However, the introduced equation suppose one kind of traps and a perfect dielectric layer. In the case of several trap levels the acoustoelectric response, generally non-exponential, can be represented by the superposition of several exponential functions. Of course, in the SiO_2 layer, there can occur polarization processes [9] that can also cause a gradual transition of the investigated system to the equilibrium state.

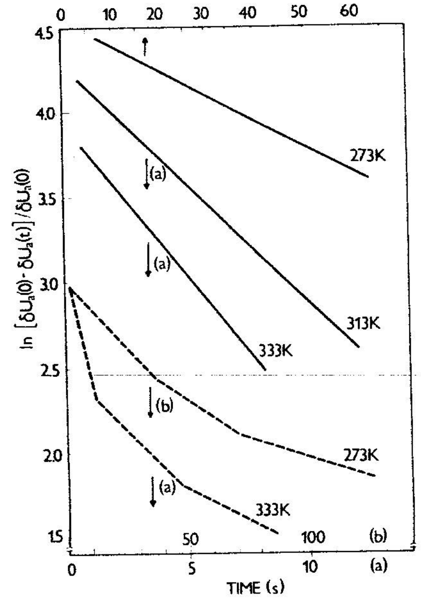

Fig. 5. $\ln\{[\delta U_a(0) - \delta U_a(t)]/\delta U_a(0)\}$ plotted against time for $U_b(1) = 0.8$ V (full lines) and $U_b(2) = 2.0$ V (dotted lines) at various temperatures.

Layer polarization by light ions, such as Na^+ or injected electrons, which can be captured by the traps present in the layer are often considered. Such processes are intensively investigated in connection with memory devices [7, 8]. These processes usually have relaxation times of hundreds to thousands of seconds.

To be able to make some assumptions about the micro-mechanism of the exponential development we have plotted the measured dependences at various temperatures and bias voltages using an exponential scale considering

$$\ln\{[\delta U_a(0) - \delta U_a(t)]/\delta U_a(0)\}$$

as a time function.

The dependences for $\Delta U_b = 0.8$ V are plotted in Fig. 5 (full lines). It can be seen that relatively small temperature changes cause very strong changes of the time constant. We must note that the internal circuit has a time constant much larger so that it cannot influence the measurement.

The occurrence of the strong temperature dependence indicates that the dominant influence on the time development of the accoustoelectric signal is probably the semiconductor properties. Since we plot the same dependences for the bias voltage step $\Delta U_b = 2.0$ as illustrated in Fig. 5 (dotted lines), we can see the various process kinetics for ΔU_b larger than U_{bc}, near U_{bc} and for ΔU_b smaller than U_{bc}. This fact also could support the supposition about the role of the surface potential because it is known from the capacity measurements that the dependence φ_s on U_b changes their slope near $U_b = \varphi_{ms}$. It means that if the acoustoelectric signal time development is controlled by the change in the surface potential, then its progress and slope change can be explained.

IV. CONCLUSION

In spite of the fact that we cannot exactly determine the reason for the dynamic changes in the structure from the present state of our investigation, it is evident that the acoustoelectric investigation can provide valuable information about the kinetics of the processes in the MOS type semiconductor structures.

In a further investigation the influence of the surface potential φ_s and the space charge Q_s on the acoustoelectric response signal will be verified by other independent methods and the observed results will be compared.

REFERENCES

[1] Bury, P., Ďurček, J., Sakalauskas, K.: Phys. Stat. Solidi (a) *95* (1986), 207.

[2] Ďurček, J., Bury, P., Turcková, I.: in *Proc. Conf. Ultrasound 86*, Bratislava 1986.

[3] Misawa, K., Moritani, A., Nakai, J.: Japan. J. Appl. Phys. *15* (1976), 1309.

[4] Misawa, K., Moritani, A., Nakai, J.: *Proc Internal. Topical Conf. The Physics of SiO_2 and Its Interface*, Yorktown Heigths (New York) 1978, 144.

[5] Grendel, M.: Acta Phys. Slovaca *34* (1984), 342.

[6] Grendel, M.: *Physics of Solid Surfaces: Studies in Surface Science and Catalysis*, Vol. 23, Elsevier 1985.

[7] Yong, D. R., Irene, E. A., Di Maria, D. J., De Keersmaecker, R. F.: J. Appl. Phys. *50* (1979), 6366.

[8] Young, D. R.: *Inst. Phys. Conf. Ser.* No 50: Chapter 1 p. 28 (1980).

[9] Hrobár, M., Grendel, M., Turzo I.: Phys. Stat Solidi (a) *82* (1984), 519.

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ИССЛЕДОВАНИЕ ЭЛЕКТРОАКУСТИЧЕСКОГО ОТКЛИКА КРЕМНИЕВЫХ МОП-СТРУКТУР

Электроакустический отклик МОП-структур отражает состояние распределения потенциала в структуре. Б данной работе изучается электроакустический отклик кремниевых МОП-структур как функция внешнего напряжения и температуры. Обсуждается также поль пространственного заряда в полупроводнике, поверхностного потенциала и емкости изоляционного материала.