The Simulation of Electret Effect in $Zn_{0.7}Cd_{0.3}S$ Layers

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Abstract. The regularities of the dark discharge in ionic contact mode as well as of the thermoelectret effect have been investigated for $Zn_{0.7}Cd_{0.3}S$ layers. The peculiarities of electret charge formation as well as the electret voltage dependences on poling electric field, polarisation time and temperature have been analysed in $Zn_{0.7}Cd_{0.3}S$ layers during the present work. The model of space charge accumulation have been proposed.

Keywords: thermoelectret, polarisation, modelling.

1 Introduction

The electret effect has been obtained in the very broad variety of semiconductors as well as dielectrics. The effect can be observed while the space-charge or oriented permanent dipoles are frozen [1]. It has been shown that photoconductive polycrystal solid solutions layers of $Zn_{0.7}Cd_{0.3}S$ possesses well-defined space-charge polarisation [2], the origin of which remains unclear up to now. This polarisation causes the long-time memory, which can be used in the space-time modulators of light when constructing the $Zn_{0.7}Cd_{0.3}S$ layers in composition with liquid crystals.

The goal of present paper is to study the peculiarities of electret voltage dependencies on temperature and layer thickness in $Zn_{0.7}Cd_{0.3}S$ layers and to

simulate the dependencies of electret voltage decay, caused by depolarisation, on temperature.

2 Model background

In the very large scale of semiconductor layers, in which the prevailing factors of the depolarisation are the space charge extraction or/and neutralisation of this charge by equilibrium conductivity, the spontaneous discharge effects can be explained by the Gorokhovatsky model [1].

The case of blocking electrodes (proper for ion contact mode) as well as the experimentally observed concentration of space charge in near-electrode regions have been encountered in this model. When surface density of heterocharge σ_t and homocharge σ_n has been introduced, the temperature dependence of charge redistribution can be written as follows [1]:

$$d\sigma_n(T)/d(T) + (\lambda T/\varepsilon\beta)\sigma_n(T) = (\lambda T/\varepsilon\beta)\sigma_t(T), \qquad (1)$$

where $\sigma_t = (1/2)en_t(T)L$, $\lambda(T) = e\mu n(T)$ – equilibrium conductivity, e – electron charge, μ – mobility, $n_t(T)$ and $n(T)$ – trapped and free charge carrier concentration, L – layer thickness, ε – dielectric permittivity, β – heating rate. According to this model, the depolarisation current density would be:

$$j(x) = d\sigma_n/dt = \lambda\big[E(x) + E_n(x)\big], \qquad (2)$$

where $E(x)$ and $E_n(x) = -\sigma_n(T)/\varepsilon$ are the heterocharge and the shielding homocharge electric fields, respectively.

It is obviously, that charge carrier concentration n and n_t in the TSD processes are determined by the trapping and recombination mechanism.

3 Experimental

The $Zn_{0.7}Cd_{0.3}S$ layers has been deposited by means of thermal evaporation under the vacuum, $\sim 5 \cdot 10^{-4}$ Pa, at the condensation temperature $T = 450$ K onto the glass substrate, which has been previously coated by SnO_2 layer. The thickness of photoconductive layer ($L = 0.3$–$10\,\mu$m) has been chosen by changing the deposition time, when the velocity of the flow has been held to be constant.

The samples of $Zn_{0.7}Cd_{0.3}S$ have been investigated in the ion contact mode, i.e., SnO_2 layer has been grounded and the free surface of semiconducting layer has been charged in the air ambience by the corona discharge. The electret voltage has been ascertained by cooling the layer after it partial free dark discharge, the subsequent discharging by force down to zero surface electrical potential, heating the discharged layer and measuring simultaneously the revealed surface electrical potential of the same polarity, as the initial charge was [3]. The rate of surface electrical potential change, due to the thermostimulated depolarisation, can be treated to be strictly proportional to the electrical current of shortened electret, when, during the depolarisation, layer under investigation has been discharged recurrentively with the aim to maintain zero voltage between SnO_2 contact and free surface of $Zn_{0.7}Cd_{0.3}S$ layer.

4   Results and discussion

It has been established, that the electret voltage U_e grows-up monotonically superlinearly with the increasing temperature and reaches saturation at aproximally $320\,K$. The dependencies of the electret voltage on the polarisation temperature in $Zn_{0.7}Cd_{0.3}S$ layer have been shown in Fig. 1. The saturation bend point shifts
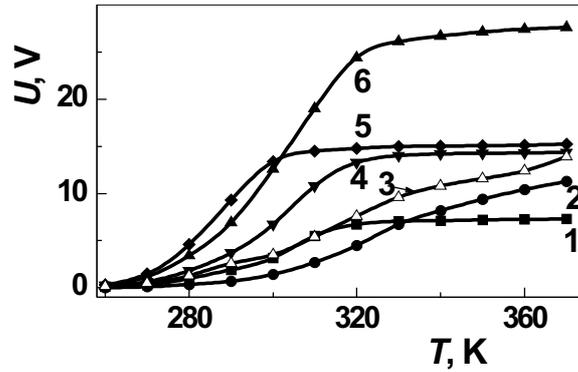

Fig. 1. Dependences of electret potential of $Zn_{0.7}Cd_{0.3}S$ layers on the poling temperature at different poling electrical field: $E = 17$ (1), $E = 68$ (6) and $E = 34\,V/\mu m$ (2–5); poling duration: $t_p = 15$ (1, 4, 6), $t_p = 2$ (2) and $t_p = 60\,min$ (5). Layer thickness $L = 3.0\,\mu m$.

to lower temperatures when poling time is increased. Electret voltage U_e shows linear dependency on the poling electric field. It is necessary to note, that the ratio of electret voltage to polarisation one in the case of positive surface electrical charge is larger by 20–30% neither in the case of negative one is, when the other polarisation conditions (the temperature, duration of polarisation as well as poling electrical field voltage) to maintain the same. The dependencies of ratio just noted on the sample thickness are more pronounced in the positive surface charge case, also: the ratio decreases by 3 times (~ 1.4 times in the case of negative charge), when layer thickness has been increased from 1.5 to 7.8 mm.

These dependencies indicate that the polarisation effects are the case in the near-electrode regions of polycrystalline layer. The occurrence and the significance of these near-electrodes regions has been also substantiated by analysis of peculiarities of longitudinal kinetics of photoconductivity as well as by results of investigations of the same samples by means of TSD.

The dependency of the rates of thermodepolarisation on the temperature in the $Zn_{0.7}Cd_{0.3}S$ layers has been presented in Fig. 2 and shows linear run.

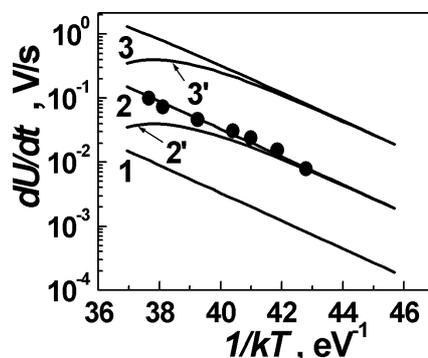Fig. 2. Dependencies of the rates of thermodepolarisation on the temperature in the $Zn_{0.7}Cd_{0.3}S$ layers ($\bullet$) as well as the results of computer simulation. It has been supposed in the model, that the effective density of states in the conductivity zone N_c is equal to: $2 \cdot 10^{23}$ (1), $2 \cdot 10^{24}$ (2), $2 \cdot 10^{25}$ m^{-3} (3); recombination times: $t_r = 10^{-3}$ (1–3), 10^{-4} (3') and 10^{-6} s (2'); poling electrical field $E = 5$ V/μm; activation energy $W_t = 0.5$ eV.

The peculiarities of TSD on the electrode materials and on the polarity of initial charge as well as known information on the similar to $Zn_{0.7}Cd_{0.3}S$ struc-

tures suppose to the possibility of monomolecular recombination type in the layers under investigation.

In such a case – (i) blocking electrodes (ion cantact mode), (ii) near-electrode polarisation process and (iii) monomolecular recombination type – the general equation for depolarisation current, equation (2) can be simplified and expressed explicitly by expressions for the displacement current density [1], where:

$$j(T) = e\mu\tau_r\omega_t E_0 n_{t0} \exp\left(-\frac{W_t}{kT} - \int\limits_{T_0}^{T} \frac{\omega_t}{\beta} \exp\left(-\frac{W_t}{kT}\right) dT'\right) \tag{3}$$

in the case of weak secondary capture ($\tau_r \ll \tau_t$, $\tau \approx \tau_r$), and

$$j(T) = e\mu\tau_t\omega_t E_0 n_{t0} \exp\left(-\frac{W_t}{kT} - \int\limits_{T_0}^{T} \frac{\omega_t\tau_t}{\beta\tau_r} \exp\left(-\frac{W_t}{kT}\right) dT'\right) \tag{4}$$

in the case of strong ($\tau_t \ll \tau_r$, $\tau \approx \tau_t$) one (the case can be realised when the trap levels are thinly occupied, i.e., $n_t \ll N_t$. Here E_0 is the poling electrical field voltage, n_{t0} – initial concentration of trapped electrons, $\omega_t = N_0 S_t \nu_T$ – frequency factor, N_c and N_t – effective density of states in the conductivity zone and in the trap levels, S_t – cross-section of capture centers, ν_T – dark velocity of the free electron, T_0 – initial temperature (so, temperature $T = T_0 + \beta t$), W_t – activation energy, k – Boltzman constant. The τ_t, i.e., the time constant of the capture to the centers, possessing energy W_t and τ_r – time constant of recombination can be expressed as follows:

$$\tau_t = \frac{1}{(N_t - n_t)S_t\nu_T}, \quad \tau_r = \frac{1}{p_r S_r \nu_T}, \tag{5}$$

where S_r is the recombination cross-section.

Both cases of weak and strong secondary capture have been examined, fitting to the experimental results.

The activation energy has been chosen from present and earlier experimental investigations (e.g., $0.4\,\text{eV}$, if $E_0 = 23\,\text{V}/\mu\text{m}$ and $0.5\,\text{eV}$ at $E_0 = 5\,\text{V}/\mu\text{m}$ [2]). The other parameters have been chosen to be adequate to those of the related compounds and have been calculated by means of approximation of experimental results by expressions (3), (4), using the least-square technics. The calculated

results, when the model of weak secondary capture has been used, were not succeeded to match with the experimental ones. The best coincidence of experimental and calculated results has been obtained in the case of strong secondary capture (Fig. 2, curve 2), when $\tau_r = 1 \cdot 10^{-3}$ s and $N_c = 2 \cdot 10$ m^{-3} have been taken. It must be stressed, that N_c act only as the scaling factor, but the diminishing of recombination time τ_r leads to the sublinear deflection from linear temperature dependence of thermodepolarisation rate. The effect become more pronounced, when elevating the temperature.

5 Conclusions

The polarisation phenomena take place in the near-electrod region of $Zn_{0.7}Cd_{0.3}S$ layers.

The thermodepolarisation processes in $Zn_{0.7}Cd_{0.3}S$ layers can be described by the model, based on the strong secondary capture and monomolecular recombination. The parameters, effective density of states in the conductivity zone $N_c = 2 \cdot 10^{23} \div 2 \cdot 10^{24}$ m^{-3} and the recombination time $\tau_r = 10^{-3} \div 10^{-2}$ s, has been obtained.

References

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