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ATHERMAL MOTION OF DONORS UNDER ULTRASOUND IN CdS CRYSTALS

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Abstract. For the first time it has been found that under ultrasound pulse (10^{-5}s) the considerable decrease of shallow mobile donor density is observed in CdS single crystals both at 300 and 77K. This effect results in the change of crystal photosensitivity, thermally stimulated current spectra, etc. The effect is explained as a gettering of donors by some sinks in the crystal bulk. Since the phenomenon occurs at low temperature and in 10^{-5}s, it is assumed that gettering process is athermal one.

Introduction

The problem of electronically stimulated defect diffusion and transformations including various types of photochemical reactions in semiconductors became very important now especially after creation of blue and green II-VI compounds LED's and lasers, having very short life time operation [1]. It is well known that just these processes lay in a background of degradation phenomena in III-V and II-VI optoelectronic devices [2]. At the same time the similar processes of defect transformations and/or diffusion can take place also under ultrasound (US) treatment, even if the US intensity is so low (subthreshold) that the new defects are not generated and the dislocations are not multiplied [3-7].

We had shown earlier that the influence of sinusoidal US of subthreshold power at 300K could result in noticeable changes of electrical, photoelectrical and optical characteristics of semiconductors [3,6,7]. These effects were accounted for stimulated by US gettering of mobile defects by sinks [3,6,7]. This process as well as the initial state restoration in the absence of US in all cases had activation energy close to diffusion activation energy of mobile ions (usually, Cd_i) [3,7].

In the present paper we demonstrated for the first time that pulsed US can result in quick (10^{-5}s) shallow donor density decrease even at 77K, which can been interpreted as athermal process.

Experimental

Highly resistive and photosensitive bulk CdS crystals grown by zone sublimation [8] have been used. Samples have been treated both at 300 and 77K with US pulses excited in crystal by ruby laser nanosecond pulse irradiation [9]. To avoid the possible effect of laser light on the sample characteristics the irradiated surface has been covered with opaque coat, namely, copper foil which was sticked to the crystal surface. The duration and intensity of US pulse have been controlled by measuring of piezoelectric voltage which arise in the sample under laser pulse irradiation. US pulse excited by laser pulse has been found to be a tandem of damped pulses with damping time $\tau_{us} \approx 10^{-5}$s. The intensity of the first pulse at irradiation power density $P \approx 10^{9}$W/cm^2 corresponds in average to relative deformation $D \approx (1 \div 3) \cdot 10^{-4}$. The etching of the sample with selective etchant before and after irradiation has shown that dislocation multiplication does not occur in this case.

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Before and after US treatment photocurrent, I_{ph}, and thermally stimulated current (TSC) I_{TS} spectra as well as I_{ph} relaxation kinetics have been investigated.

Results and discussion

Under pulsed US two effects have been observed which always accompanied each other: (i) considerable I_{ph} drop over the whole spectral range (Fig.1); (ii) I_{TS} decrease in 100-250K temperature range. These effects occur even after one laser pulse, i.e. in 10^{-5}s both at 300 and 77K.

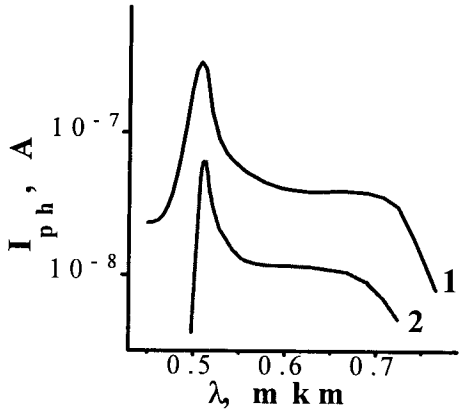

Fig.1. Photocurrent spectra at 300K before (1) and after (2) US treatment.

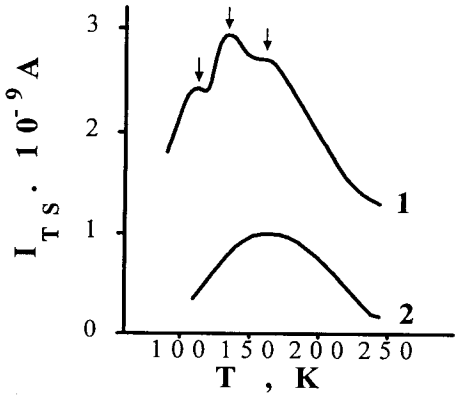

Fig.2. TSC spectra before (1) and after (2) US treatment.

In TSC spectra of investigated crystals three peaks connected with three types of electron traps, named Tr_1, Tr_2 and Tr_3, have been observed at 100, 130 and 170K correspondingly (Fig.2). Tr_1 and Tr_2 centers were investigated by us earlier [10,11] and it was shown that they drifted in the external electric field from anode to cathode, and thus they were the mobile donors [11]. Tr_1 and Tr_2 diffusion activation energies E_1 and E_2 were found to be 0,4 and 0,3 eV correspondingly [11]. Tr_1 centers are probably Cd_i atoms [11].

The decrease of area under TSC i-peak (Q_i) can be caused either by the decrease of the corresponding trap density N_i ($Q_i \sim N_i$) or can be the result of decrease of photoelectron life time τ_n ($Q_i \sim \tau_n$) [12,13], and, in this latter case will be accompanied by the decrease of photocurrent ($I_{ph} \sim \tau_n$) [12,13]. Both this reasons, of course, can act simultaniously. In our case the only Q_3 value decrease can be accounted for τ_n reduction, i.e. Tr_3 density does not change under US. In the same time Q_1 and Q_2 value decrease is much greater than τ_n reduction. Therefore, US treatment results in Tr_1 and Tr_2 density decrease.

The detailed analysis of recombination scheme of CdS and its analogues which contains at least two types of recombination centers (photosensitizing centers and centers of fast recombination) shows that the shallow donor density decrease, i.e. the lowering of equilibrium Fermi level, always results in photosensitivity drop [12,13]. The investigation of stationary and kinetic I_{ph} characteristics in our case has shown that reduction of Tr_1 and Tr_2 densities is in a good agreement with I_{ph} drop.

It has been found that sample characteristic changes caused by pulsed US are reversible. The initial state restores after quick (1-2 min.) sample heating to 400K or its standing at 300K during one-two days. Photocurrent restoration curve $I_{ph}(t)$ consists of two sections which have different activation energies 0.3 and 0.4 eV(Fig.3). These values coincide with Tr_1 and Tr_2 diffusion activation energies E_2 and E_1 obtained from temperature dependence of Tr_1 and Tr_2 drift

kinetics [14]. Such coincidence confirms that I_{ph} drop under US treatment is caused by the decrease of shallow donor density indeed.

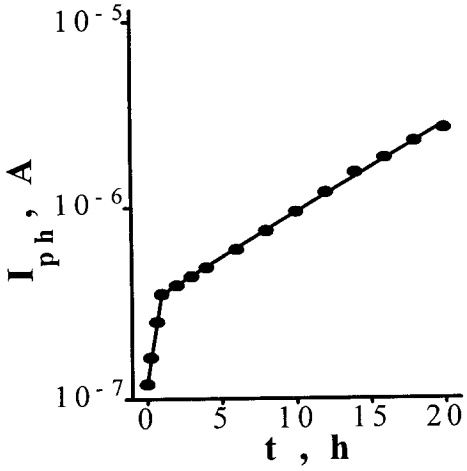

Fig.3.Kinetics of I_{ph} restoration process after US treatment at 300K.

Conclusion

It has been shown that in CdS single crystals the introduction of US short pulse of subthreshold power can result in noticeble decrease of various shallow donor densities. This process occurs at such low temperature as 77K in 10^{-5}s. In the same time the initial state restoration in the absence of US occurs with thermal diffusion activation energy of donors. These facts allow to assume that the donor density decrease under US is athermal process. It may be supposed that the mechanism of this process is resonance jump of mobile ion in the direction of the sink which is stimulated by US. The mechanism of this process is under investigation.

It should be noted that pulsed US can be generized in pulse lasers and cause defect redistribution, which may be the reason of their degradation.

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