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INFLUENCE OF ULTRASOUND VIBRATIONS ON THE STABLE METASTABLE TRANSITIONS OF EL2 CENTERS IN GaAs

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ABSTRACT

The new effect of ultrasound (US) stimulated regeneration of the ground state of EL2 centers is observed and investigated. A regeneration transition from metastable into ground state is caused by ultrasound vibrations induced in a GaAs wafer at the temperature of 105-120K after bleaching of EL2 centers with 1.2 eV light. The EL2 related absorption band and 0.64 eV luminescence band are examined. Kinetics of regeneration and dependence of the regenerated ratio on US intensity are measured at different temperatures. The arguments in favor of a dislocation model for the US regeneration are presented.

INTRODUCTION

The properties of EL2 centers in SI GaAs are still the subject of physical interest. The EL2 centers are recognized by low temperature metastability , attributed to their transition from the ground state, $EL2^{o}$, to the metastable state, $EL2^{*}$, under 1.0 - 1.4 eV illumination (T≤140K). This transition is accompanied by large lattice relaxation and leads to photoquenching of EL2 related bands in ESR, DLTS, absorption and photoluminescence (PL) spectra [1]. The regeneration of the ground state can occur: i) thermally in the dark with activation energy of 0.34eV [1]; ii) by free electron injection with reduced activation energy of 0.107eV [1]; iii) by illumination within the spectral range of 1.30 - 1.50 eV [2] or 0.80 - 1.0 eV [3] with the activation energy varying in the range of 0.035- 0.100 eV [4].

In this paper the effect of the ultrasound (US) stimulated regeneration of EL2 photoluminescence is observed for the first time. A new mechanism for the reduction of the thermal regeneration barrier caused by interaction of EL2 centers with dislocations is proposed. This interaction is invoked by oscillations of the dislocations as the result of US vibrations.

SAMPLES AND METHODS.

Czochralski - grown undoped SI GaAs single crystals with a dislocation density of $\approx 10^{5}cm^{-2}$ and EL2 center concentration of $10^{16}cm^{-3}$ are studied. Samples are glued by the (100) plane to the surface of circular piezoceramic transducer. US vibrations of a crystal are induced by the US transducer at its resonance frequencies in a range of f= 80 - 250kHz, and specified by the amplitude of the electric field applied to the transducer, U_{us}, by the temperature, T_{us}, and the duration time, t_{us}, of an US treatment. The ordinary set up is utilized for PL and absorption measurements [3].

EXPERIMENTAL RESULTS.

A well documented PL band with the maximum at 0.64 eV caused by free-to-bound recombination between conduction band and $EL2^{o}$ state [1] is observed. The intensity I of this band is quenched from the initial value, I_o, to a stationary level, I_{st}, under crystal illumination in the 1.0-1.4 eV spectral range. The bleached PL intensity, $I_o - I_{st}$, is proportional to the number of EL2 centers in the ground state [3]. Usually, 0.64 eV PL band is strongly overlapped with O-related luminescence [5], and hence its identification with EL2 related centers is ambiguous. In fact, the intensity of even non related to EL2 PL transition can be quenched due to the shift of Fermi level governed by EL2 bleaching. However, even in this case the intensity of such PL band can be used as the quantitative test for the ground-metastable state of EL2 centers. We checked this by measuring the intensity of the EL2 related absorption band with the threshold at 0.8 eV [1].

The warming of a sample up to 140K leads to the total regeneration of the initial PL intensity and absorption coefficient. Thermal regeneration is specified by the activation energy of ≃ 0.3eV that is consistent with a published data [1]. As a consequence, a thermal regeneration is negligible at T≤ 120K.

We have found out by controlling the EL2 optical absorption and PL that regeneration transition is stimulated at the temperatures within the range 105 -120K, if a crystal is treated by ultrasound vibrations (insert in Fig.1).

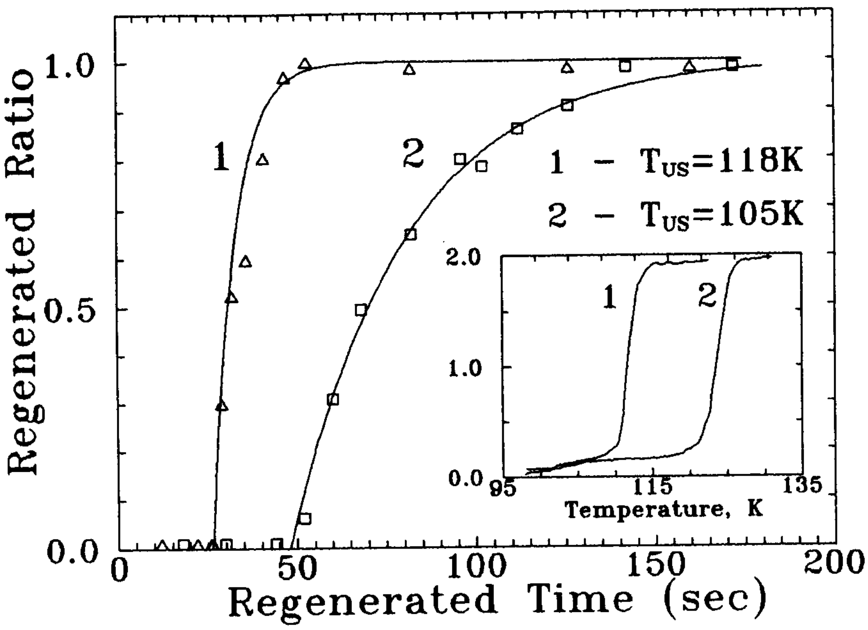

Fig.1. Kinetics of isothermal US regeneration. Points - experiment, solid lines - fit using Eq.(2) with t_o=26sec, τ_{us}= 6.5sec for (1) and t_o= 48sec, τ_{us}= 32sec for (2). Insert - regeneration of EL2 absorption (hν=1.2 eV) with (1) and without (2) of ultrasound.

The value of the regenerated ratio for the ground state can be defined using intensity of 0.64 eV PL band as following

$$\delta I = (I(t_{us}) - I_{st}) / (I_o - I_{st}), \qquad (1)$$

where $I(t_{us})$ is the initial PL intensity after US regeneration during a time of t_{us}. The value of δI is a function of the US parameters: t_{us}, T_{us} and U_{us}.

Kinetics of the isothermal US regeneration, $\delta I(t_{us})$, is shown in Fig. 1. The curve can be fitted well by the relation:

$$\delta I = 1 - \exp\,[(t_{us} - t_o) / \tau_{us}] \qquad (2)$$

A peculiarity of the kinetic curve is the delay time, t_o, which is attributed to the initial period of the US regeneration. This delay time is increased when either T_{us} or U_{us} are decreased. The total US regeneration is independent of T_{us} and U_{us} and is equal to the total thermal regeneration of PL intensity.

The characteristic time of the kinetics curve, τ_{us}, defined by Eq.(2), depends on the temperature of T_{us} (Fig. 1). The activation energy of US regeneration, $\varepsilon_{\mu s}$, has been evaluated from the Arrenius plot of τ_{us} vs T_{us}^{-1}. The value of ε_{us} varies as a function of U_{us}, and can be suppressed from $\simeq$ 0.3 eV up to 0.09 eV under the maximum value of U_{us} available.

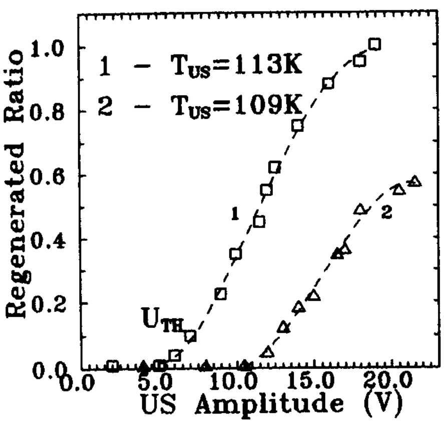

Fig. 2. Dependency of regenerated ration on the US voltage.

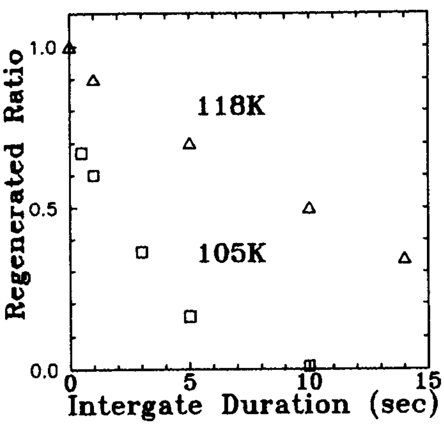

Fig. 3. Dependency of the regenerated ratio on intergate time Δt_i for the gate modulated US regeneration and two temperatures: 1- T_{us}=105K, 2- T_{us}=118K.

In Fig. 2 the amplitude dependencies of δI versus U_{us} are shown. This dependence is specified by a threshold amplitude, U_{th}, which is decreased with increasing temperature for the US treatment.

DISCUSSION AND CONCLUSIONS.

The ordinary thermal regeneration of $EL2^{o}$ state enhanced by US vibrations can account for observed US recovery. Actually, it could be caused by local heat release due to absorption of US vibrations in the vicinity of EL2 centers providing their thermal regeneration. A temperature of such "overheated" volumes is determined by a thermal balance of a heat supply via US vibrations and cooling process due to thermoconductivity of a crystal. We can check this idea by experimental study of a kinetics of the cooling process. The value of characteristic time, τ_c, estimated from the thermormoconductivity reasons is ~ 10^{-4}s. We will show that this time is inconsistent with the result of the following experiment.

The US regeneration can be studied using low frequency gate modulation of ultrasound (insert in Fig. 3), which is specified by the duration of a single gate, Δt_g, and by the intergate time interval between two subsequent modulation pulses, Δt_i (insert in Fig. 3). If the value of Δt_g is shorter than t_o, then EL2 regeneration occurs after a definite number of modulation pulses (n), as soon as the following inequalities hold true: $n \cdot \Delta t_g \geq t_o$ and $\Delta t_i \leq \tau_c$. Hence, varying Δt_i value one can measure the characteristic time of the cooling process. The results of such experiment are shown in Fig. 3 using two temperatures. The evaluated values of τ_c of 20s (118 K) and 5s (105 K) are in evident contradiction with expected value of 10^{-4} s. This contradiction demonstrates inconsistence of a local heating model with the experiments on the gate US regeneration.

The model for US regeneration

To interpret the new effect for EL2 regeneration stimulated by US vibrations we propose the model that utilizes the dislocation concept. It was observed that the distribution of $EL2^{o}$ centers is similar to the profile of the dislocation density in the same GaAs wafer [1]. On the other hand, the interaction of US waves with the dislocation can be considered within the string model [6]. The US vibrations of a crystal force the oscillations of dislocation lines which are fixed in pinning points (locks) by defects in a crystal. With an increase of US intensity the amplitude of dislocation oscillation is increased, and under some threshold value of a vibration amplitude the break of a dislocation from the lock occurs. A number of such breaks is increased with the time leading to the increase of crystal volume, which is affected by oscillating dislocations.

One can realize within dislocation model the physical reason of the reduction of the energy barrier for $EL2^{*} \Rightarrow EL2^{o}$ transition caused by US vibrations. The oscillations of a dislocation induce in the crystal an alternative strain field. It gives rise to the local tension and compression in lattice, in particular nearby the EL2 center. This suggestion is consistent with the hydrostatic pressure experiments [7], where the suppression of the regenerated barrier up to 75 meV was observed. This value reasonably match the minimum value of the barrier for US regeneration ε_{us}= 90 meV.

Within the dislocation model one can qualitatively account for specific features of the US regeneration kinetics (Fig.1), as well as its temperature and amplitude dependencies (Fig.2). The probability of a dislocation break is given by the relation:

$$W = W_o \exp[-(E-\sigma V)/kT_{us}] \qquad (4)$$

where E is the binding energy of a dislocation to the lock, σ is the amplitude of the elastic strain caused by ultrasonic vibrations, $V=\mathbf{b}^2/L$, **b** is the Burgers vector, and L is the average distance between the locks on a dislocation [5]. Hence the threshold behavior of the amplitude dependence for US regeneration is caused by that of a dislocation break from the lock, which is an exponential function on T_{us} (Eq.4). Consequently, U_{th} has to be decreased with the raising of T_{us} matching our experiment (Fig. 2). Concerning kinetics for US regeneration, the observed delay time, t_o, is related to the probability of a dislocation to be released from the definite number of locks, and consequently, $t_o \sim W^{-1}$ defined by Eq.4. This is also consistent with the temperature dependence of the t value (Fig. 1).

In accordance with the dislocation model it is reasonable to interpret the time τ_c (Fig. 3) as being attributed to the process of a dislocation recapture by locks. The probability of such recapture is decreased, and consequently, τ_c is increased, with the increase of T_{us} that is matched to experimental data (Fig. 3).

In the conclusion the new effect of the ultrasound enhanced regeneration of $EL2^o$ state is observed for the first time. It is specified by the reduced regeneration barrier until 90 meV, and peculiar kinetic and amplitude dependencies (Fig.1 and 2). The dislocation model is utilized to interpret the US regeneration. The experiments on the internal friction, which are able to check directly the dislocation concept are in progress.

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