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THE ULTRASONICS-INDUCED-QUENCHING OF PPC RELATED TO DX CENTERS IN $Al_xGa_{1-x}As$

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INTRODUCTION

At present the high level of understanding of the DX-centers nature has been achieved. The DX center in GaAs and related III-V compounds and alloys is now believed to consist of a substitutional donor which has relaxed into a strongly distorted configuration in the host lattice [1,2]. One of the main arguments in favour of the large lattice relaxation (LLR) model is the difference between the optical ionization energy (0.6-1.2 eV for different dopant) and the thermal ionization energy (0.1-0.2 eV). An analysis of LLR model and those experimental results which confirm the vacancy-interstitial model of DX centers was made in [3,4].

On the other side Yamaguchi [5] had early proposed a small lattice relaxation (SLR) model for the DX center. More recent work from Henning et al.[6], in which the photoluminescence data and existing data on thermal emission and capture were analysed also supports the SLR model. The same authors observed in $Al_{0.33}Ga_{0.67}As$:Si photosensitivity at photons energy lower than 0.25 eV, while maxima photoresponse was achieved at 1.7 eV[7]. This controversial result was examined by Northrop et al.[3]. They have measured the photoionization cross section over 7 to 8 orders of magnitude for number samples of differing alloy compositions and doping levels but in no case was there any detectable photoionization below 0.8 eV. The reason of these apparently different results is not clear up to now.

Thus the question concerning with both threshold of photoionization and the shape of its spectral dependence has important meaning for choose of conventional model. Moreover, the questions are arised in connection with the results on the kinetics of photoconductivity, in particularly, with the nature of "fast" and "slow" transients observed in [8,9]. The solution of questions above noted straightforward follows, on our opinion, from configurational environment of defect. On the second side, it is not clear how the excited or intermediate states of the deep

donor which play the important role in processes of capturing and emission are dependent on nearest and second-nearest neighbours. To answer on these questions we used original method of dynamic deformation of sample which was produced by ultrasonic vibrations. So called ultrasonic treatment (UST) of semiconductors gives a possibility to modify the spectrum of point, complex and extended defects that permits both to obtain additional information about the structure and symmetry of defects and to produce the intentional action on ones.

EXPERIMENTAL PROCEDURE

The measurements have been carried out on epitaxial films of $Al_{0.3}Ga_{0.7}As$ doped by Si up to $10^{18}cm^{-3}$. The thickness of the films which were grown by MOVPE method was centered near 1 μm. The undoped AlGaAs film was used as buffer layer between semiinsulating GaAs substrate and manufactured epitaxial film. Ohmic contacts were prepared from Au-Ge alloy. The photoexcitation was produced by monochromatic light. As a source of one, a tungsten lamp with grating monochromator was used. To avoid the illumination by visible light the wide band filters (1.5-0.9μm or 2-1.5μm) were sampled on output aperture of monochromator. During temperature measurements the rate of the temperature change was 5K/min at cooling and 1K/min at heating. These rates of cooling and heating were chosen to provide the similar starting conditions during measurement both the kinetics of photoconductivity growth and the relaxation of the persistent photoconductivity (PPC). The dynamic deformation was created by means of piezo-electric vibrator with resonance frequencies 120-250 kHz. So called assemble vibrator system allowed to generate in sample longitudinal vibrations with given polarization. The magnitude of deformation which is dependent on applied voltage was varied in the range of 10^{-5}-10^{-8}. Because of the thickness of piezo-electric vibrator was much greater than the sample thickness and taking into account the ultrasound wave length in respect to sample dimensions the deformation may be considered as uniform. Acousto e.m.f. was measured as voltage arising on current contacts of the sample in broken curcuit during propagation of elastic wave.

EXPERIMENTAL RESULTS AND DISCUSSION

The spectral dependence of PPC has threshold behaviour with $\hbar\omega \cong 0.8$ eV that one is in agreement with most of data obtained up to date (see for example [3]). The kinetics of photoconductivity growth after switch-on light observed in experiments are not described by monoexponential function. This is especially seen with lowering of photons energy. A detailed shape analysis shows that similar situation is possible if the photoionization process of ground state of DX-centers (DX^-) occurs as two steps process via intermediate state (DX^0) [10]. When capturing of electrons may be neglected one can use the initial slopes technique (IST) [11] in this case in order to determine the photoionization cross-section of the ground DX^--state. Such dependences are presented in Fig.1. The curve 1 corresponds to case without ultrasonics whereas

the curve 2 has been obtained under ultrasonic vibrations. It is seen that dynamic deformation leads to appearance of deep falldown on the spectral dependence of σ in $(1.0^{+}_{-}0.3)$eV band. This effect can be explained as formation of new effective channel for capture of electrons from neutral state or from conduction band, i.e. by negative photoconductivity effect (NPE). Thus the using of IST is not valid in this case because of the obtained value is

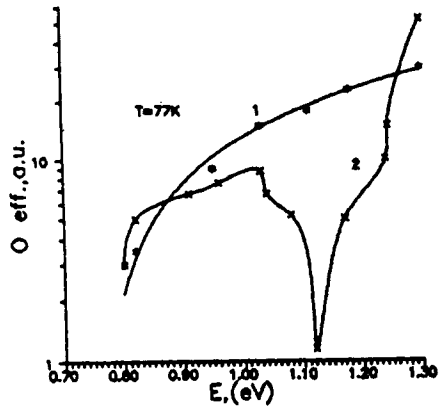

Fig.1.

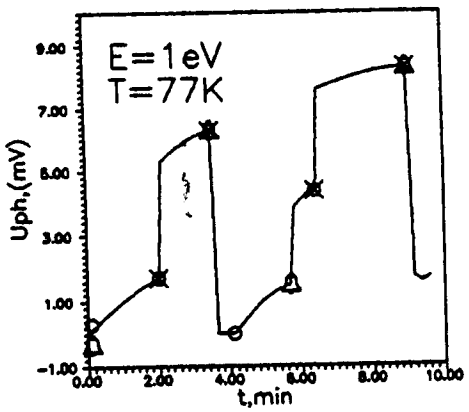

Fig.2.

Fig.1. Spectral dependences of photoionization cross-section (sample n°146). 1-without UST, 2-during UST.
Fig.2. The kinetics of photoconductivity growth under illumination (open circles) and ultrasonic vibrations (open bells) and without ones (crossed symbols).

complex combination of the photoionization and capture cross-sections for processes involving the ground and intermediate states of defect and conduction band.
It should be noticed that "fast" component of transient induced by ultrasonics is appeared when photoconductivity is excited by light with energy corresponding to NPE (Fig.2). The mentioned effect is not observed at excitation of photoconductivity by light with energy outside of given band so as without ultrasonics. Besides, the appearance of acousto e.m.f. under ultasonic influence attracts one's attention as consequence of exhibition of acousto-electric effect due to carrying away of free electrons by ultrasound wave [12]. The monotonous decreasing of ΔU at illumination of sample by light in spectral range from 0.8 to 1.5 μm reflects apparently the increase of electron concentration in the conduction band excluding band in the range from 1.1 to 1.15 eV (Fig.3).

The influence of ultrasonics on temperature relaxation of PPC has also specific feature connected with dynamic deformation. The basic peculiarity is concluded in lowering the temperature threshold of PPC relaxation under ultrasonics action (Fig.4).

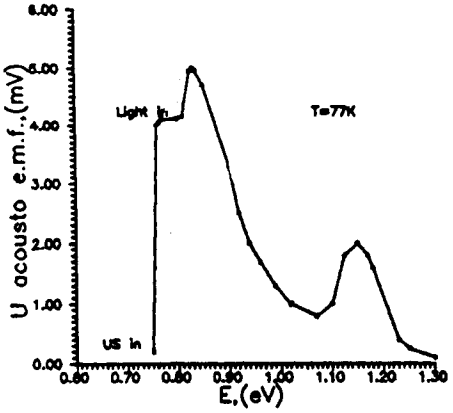

Fig.3.

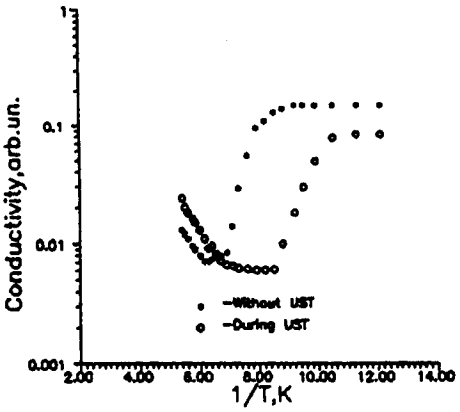

Fig.4.

Fig.3. Spectral dependence of acousto e.m.f under illumination.
Fig.4. Temperature relaxation of PPC.

So, we observe under simultaneous action of ultrasonics and incident light the manifestation of new defect or complex with following characteristics:
i)the transformation process, i.e. creation and disintegration of defect, is dynamic process;
ii)the photoconductivity connected with this defect has no persistent character;
iii)excitation by light of energy near 1.0 eV transfers given defect in metastable state and the NPE is observed due to this transition.
From our point of view the most simple explanation of all these features may be done if suggest the appearance of deep stable one-electron state similar to DX^0 under deformation.
The photoionization of ground DX state transfers one electron in conduction band and leaves the donor in neutral state. The nature of latter still is matter of discussion. There are two points of view. According to first one [1], the DX^0 is the one-electron state in strongly distorted lattice (with the same value of configuration coordinate Q as for DX) with total energy upper than for DX on correlation energy U. This state must be thermodynamically unstable, but obviously should play a role in all electron capture and emission processes as transition state.

This suggestion was examined experimentally [10]. Second point reviewed in [13] look at neutral state of the DX as one-electron deep state, formed by antibonding orbitals of the short-range part of Coulomb potential. The parabola corresponding to this state has minimum in Q_o as for state in undistorted lattice. Substitution of Ga by Al atoms in alloys may lead to small lattice relaxation for this state. The energy of this state (named in [14] as A_1(ab)) depends on both chemical kind of donor and alloy composition. In our case (Si as dopant and x=0.3) A_1(ab)-state is little upper the bottom Γ band [14]. Returning the donor to the DX^- state may occur by two-steps: firstly, the capture of electron in A_1(ab) and then the capture of second electron in DX^- state.

We suggest that both neutral states, namely d^0 (atom is in substitutional site) and DX^0 (atom is in displaced position) may coexist. The ultrasonics creates in the sample sinusoidal deformation field or field of displacements. Under this field distance between Q and Q_0 will be periodically changed. It is clear that the decrease of $(Q-Q_0)$ leads to lowering of barrier for electron capture in DX^-. Moreover, at definite magnitude of deformation intracenter transition ($d^0 \rightarrow DX^0$) with sequent capture of electron ($DX^0 + e \rightarrow DX^-$) has to occur. Thus, the rate of photoconductivity growth will be decreased.

In conclusion, the results presented above on the one hand confirm the LLR model and on the second hand they give us the possibility to observe the intermediate state (DX^0) as one-electron in strongly distorted lattice.

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