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OPTICALLY INDUCED ANNNEAL OF GaAs AND AlGaAs LAYERS.

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ABSTRACT

GaAs and AlGaAs epitaxial layers, grown under ultra fast cooling rates, have been investigated by DLTS and photoluminescence (PL) measurements. It was observed, that unequilibrium growth conditions lead to formation of defects, which are typical for irradiated GaAs and AlGaAs and are connected with V_{As} and As_{Ga}. Irradiation of these layers by laser with wavelength λ=0.5μ results in changes of DLTS spectra in GaAs and AlGaAs and in changes of PL spectra in AlGaAs. These changes in DLTS and PL spectra are connected with particle optically induced annealing of defects and with recombination-generation diffusion of impurity, leading to formation of complex arsenide vacancy- donor impurity.

INTRODUCTION

Usually, epitaxial layers of $A^{III}B^{V}$ are grown with cooling rates of solutions 0.6-1.0 ^{o}C/s. Crystallization processes, taking place in molten solution, are close to equilibrium conditions, which ensures the formation of high quality layers. It was shown in paper [1], that application of ultra fast cooling rates (10^{2}- 10^{3} ^{o}C/s) essentially extends possibilities of LPE technique. The application of ultra fast rates must lead to formation of another ensemble of defects, differing from that, which is formed under equilibrium growth conditions. So the purpose of present paper is to investigate the ensemble of defects and impurities with deep levels, formed under ultra fast cooling. Moreover, we report about investigations of optically induced annealing of defects, discovered in this materials.

EXPERIMENT

N-type GaAs and AlGaAs epitaxial layers were grown under crystallization from molten Ga+As and Ga+As+Al solutions on N-type substrates with carrier concentration $n=10^{18}$ sm^{-3} in wide temperature range. Growth temperature was about 750-950 ^{o}C. Cooling rate was equal to 10^{3} ^{o}C/s. GaAs layer thickness was 0.5m. Free carrier concentration measured by voltage-capacitance (C-V) method was equal to 10^{16} sm^{-3} in GaAs layers. Composition of epitaxial solid solutions $Al_{x}Ga_{1-x}As$, grown by ultra fast rates varied from 50% of Al at the surface to 34% at 1μ depth. Composition along layer thickness was determined by second ion mass-spectroscopy (SIMS) at the ion microprobe CAMECA IMS-42. Carrier concentration in AlGaAs was about 10^{16} cm^{-3}. PL spectra were measured under Ar laser excitation with generation wavelength 0.51μ (2.43eV). Laser beam, focused by optical system to the sample surface, was 200μ. Excitation power was 50mW. Laser annealing was performed at irradiation power 600mW during 5-10 minutes at temperature 77K. Power density under annealing was 1.9 kW/cm^{2}. DLTS spectra and C-V measurements were carried out on Shottki diodes by BIO-RAD DL4600 spectrometer. The capacitance was measured on a Boonton-72B bridge operating at a frequency of 1 MHz. The sensitivity of this apparatus is $\Delta C/C_{0} \approx 10^{-4}$. Au-Ge ohmic contacts were applied to the substrates by vacuum deposition followed by annealing. Au Shottki barrier was then deposited on the epitaxial layers.

RESULTS

Photoluminescence (PL) spectra of undoped AlGaAs and GaAs measured at temperature 77K are represented on Fig. 1a,b. It is shown, that PL spectra of GaAs before and after annealing are identical (Fig. 1b). There are essential changes in PL spectra of AlGaAs. PL peak with energy E=2.060eV is quenched, but new line with E=1.680eV appears. DLTS measurements of

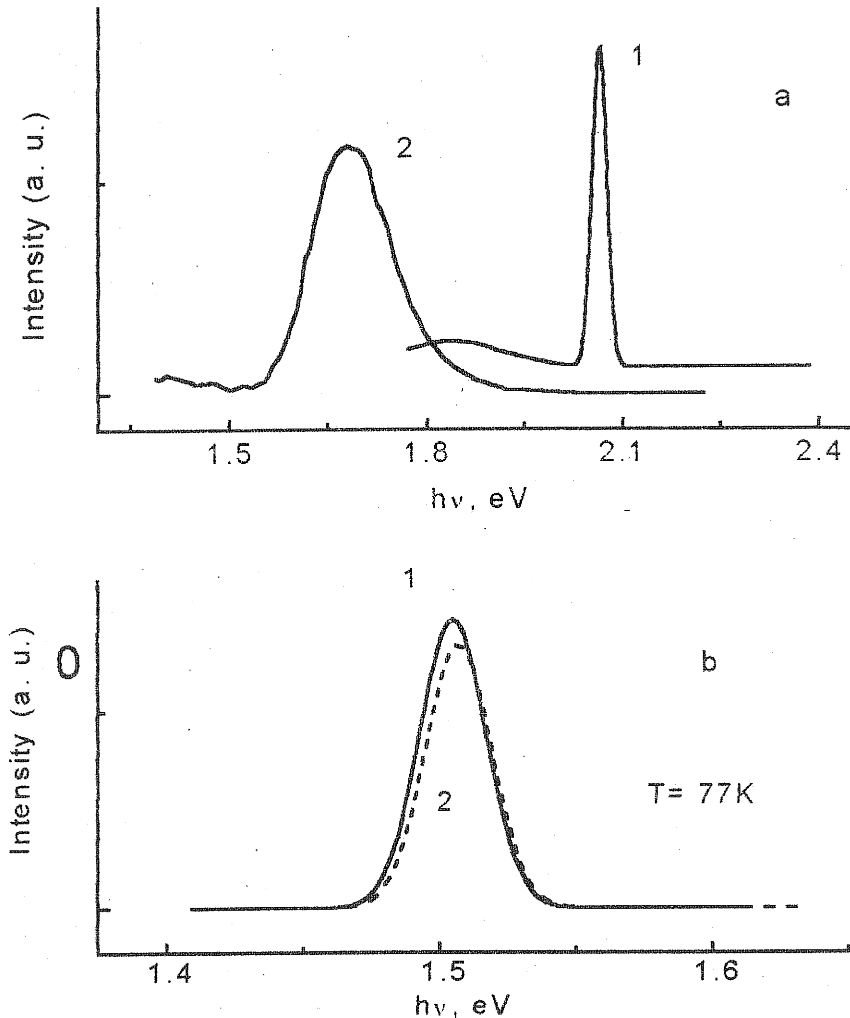

Figure1. PL spectra of n- AlGaAs(a) and n-GaAs(b) layers: 1 -before and 2- after laser annealing.

AlGaAs layers (Fig. 2a) demonstrate the formation of four electron traps (E1-E4) and one hole trap H1 during process of epitaxial growth. Table shows the parameters of these levels observed in DLTS spectra and determined from an Arrhenius plot (Fig. 3a). E2 is similar to E2

level, first observed by Lang [2] after irradiation of AlGaAs layers. The nature of this level is connected with V_{As}. E3 level is identified as DX-center of VI group donor [3]. The epitaxial layers have manifested the effect of persistent photo conductivity (PPC), typical for DX-center [4]. The parameters of E4 level are close to those of EL2 defect [5]. After laser anneal concentration of El and E4 defects reduced by 1.7 times, and that of E2 and E3 defects became

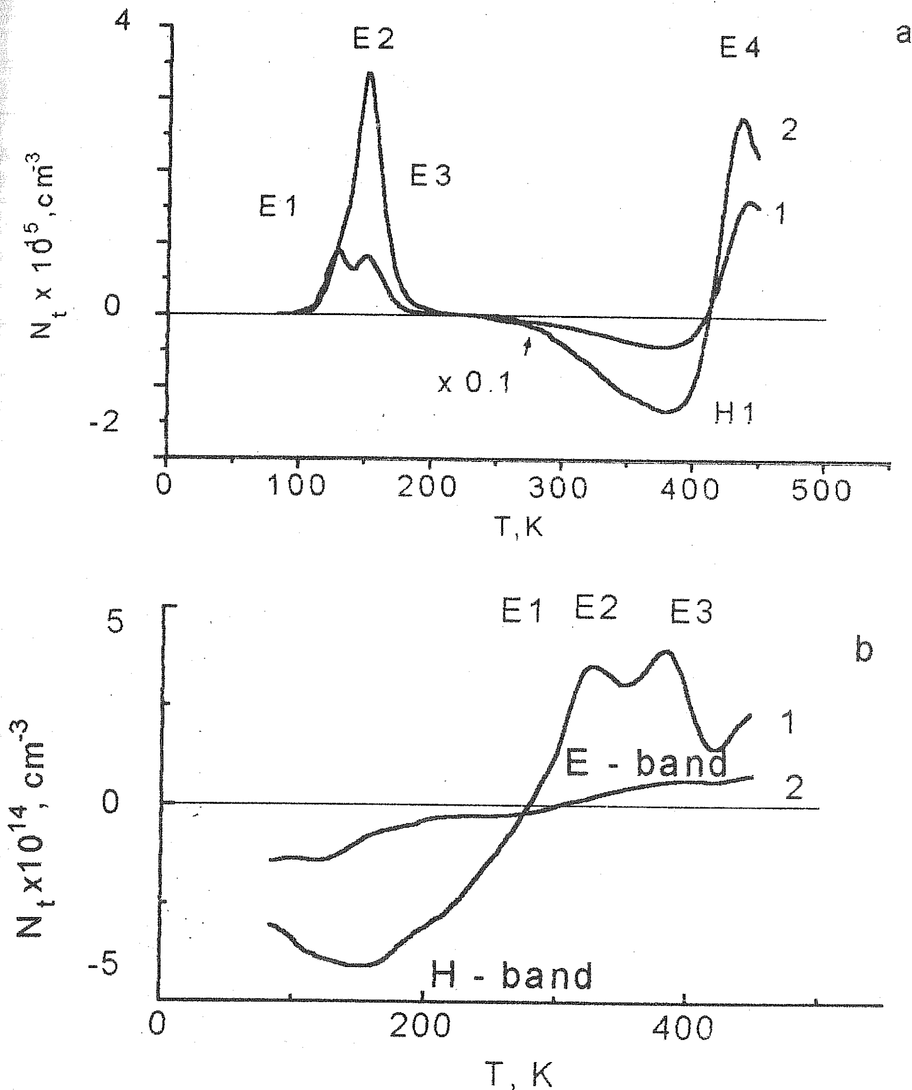

Figure 2. DLTS spectra of a) n-AlGaAs and b) n-GaAs: 1- before and 2- after annealing.

3.6-3.9 times lower. H1 level is identical to HL2 level, which is attributed to defect, including V_{As} [6]. Its concentration also reduced by 3.4 times. The free carrier concentration became about two times lower. In DLTS spectra of *n*-GaAs (Fig. 2b) epitaxial layers broad minority

carrier peak was observed, and it was difficult to determine the parameters of corresponding levels. The presence of three electron traps in these spectra was also unusual. One of them E3 level is identical to EL2 defect. Two others are typical for irradiated GaAs and are connected with cluster of As_{Ga} and V_{As} defects [7]. Fig . 3b shows Arrhenius plot of these levels in n-GaAs layers. After laser anneal the reduction in concentration of all traps and formation of cluster of electron and hole traps were observed (Fig. 2b).

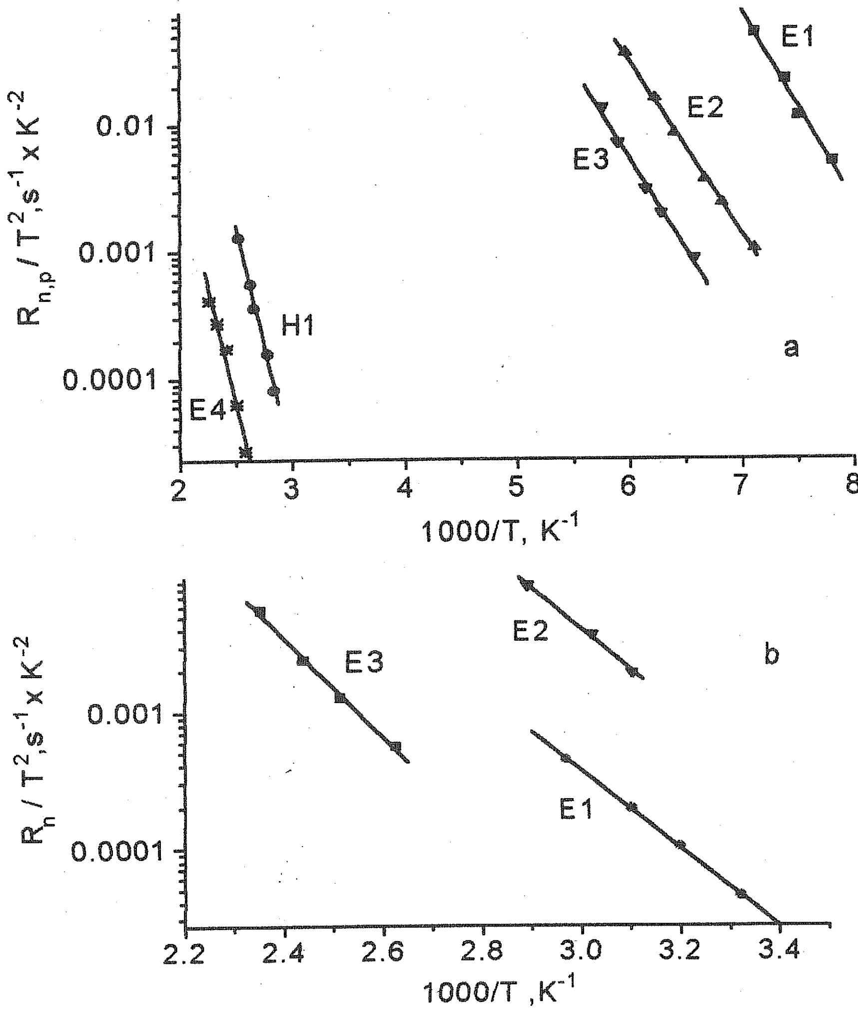

Figure3. Arrhenius plot of thermoionic emission of deep levels in n-type AlGaAs(a) and GaAs(b) layers.

DISCUSSION

PL spectrum of AlGaAs before annealing had a narrow spectral line with E=2.06 eV. The peak energy was independent of excitation density. Its intensity increased linearly from excitation density. On the basis of these facts it was supposed, that peak is defined by exciton bound to a

neutral donor (BE) [8]. Measurements, carried out at low temperature (2K), also showed the presence of phonon replica with maximum location at E=2.003eV. It is typical for high quality AlGaAs with composition near crossover point direct-indirect transition [8]. Lines E_a=1.680eV, appeared after anneal, have already observed earlier [9] and it is attributed to complex arsenide vacancy -impurity. The strengthens after annealing under vacuum is typical for this line. There were no changes in spectra after annealing with ultrahigh arsenide pressure. Changes in PL and DLTS spectra can be understood as recombination-generation process, consisting of recombination-enhanced anneal (REA) of defects and recombination-enhanced diffusion (RED) of impurity [10,11]. Interstitial As_i, such as impurity, has sufficient mobility under annealing, led to its annihilation with V_{As} [12]. In particular, it was shown in [12], that annealing of E3 defect, representing V_{As}-As_i complex, is significantly strengthened under minority carrier injection. Under annihilation of defects its energy is converted to phonon energy, which strengthens annihilation. Moreover, it is possible to create another defects, stimulating donor impurity diffusion. These donors during diffusion are probably united with part of V_{As}, which have not annihilated with As_i. Likely, quenching of line with E=2.06eV in AlGaAs in such case was connected with RED process of donor and formation of complex impurity-arsenide vacancy. In case of GaAs layers RED leads to annihilation of part of defects, connected with V_{As} and As_{Ga}.

Level	Activation energy, m eV	Cross section, cm^2	Identification
AlGaAs			
E1	297	$8.3x10^{-12}$	
E2	268	$1.3x10^{-14}$	E2[2]
E3	285	$7.5x10^{-15}$	DX[3]
E4	732	$3.6x10^{-16}$	EL2[5]
H1	740	$3.9x10^{-15}$	HL2[6]
GaAs			
E1	563	$5.2x10^{-16}$	
E2	592	$1.6x10^{-14}$	
E3	726	$9.4x10^{-15}$	EL2[5]

CONCLUSIONS

The formation of electron traps, connected with V_{As} and As_{Ga}, was observed in GaAs and AlGaAs epitaxial layers, grown by LPE method by ultra fast cooling rates. Irradiation of these layers by laser with E=1.5eV led to particle optically induced anneal of defects and to recombination-generation process of impurity diffusion with formation of complex V_{As}-D.

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