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On the Physical Origins and New Interpretation of the EL-2 Electron Trap in GaAs*

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SUMMARY

The deep-donor trap, commonly known as the EL-2 center, with activation energy ranging from E_c - 0.76 eV to E_c - 0.83 eV, has been observed in GaAs grown by LEC, VPE, and MOCVD techniques. The physical origins of this electron trap is a subject of great interests in recent years. Although a large number of papers has been devoted to finding the physical origins of the EL-2 electron trap, unfortunately, none of these published results offering a consistent and unambiguous explanation for the observed EL-2 center in GaAs. Possible physical origins including gallium vacancy (V_{Ga}), arsenic-antisite (As_{Ga}), arsenic antisite- arsenic vacancy complex ($As_{Ga}V_{As}$) as well as arsenic-antisite-oxygen complex have been proposed by many researchers as the likely candidates for the EL-2 center in GaAs grown under As-rich or high arsenic pressure condition. However, the subject is still highly controversial, and a quantitative modelling of the EL-2 electron trap is needed in order to identify the physical origins of this native defect in GaAs.

The objectives of this paper are: (1) To present a new defect model derived from the thermal kinetic reaction equations which would provide a coherent explanation of the activation energy of EL-2 level reported in the literature, (2) to propose the physical origins of EL-2 electron trap based on our new defect model and the experimental evidence, and (3) to determine the potential well for the EL-2 electron trap from analyzing the nonexponential DLTS response data by taking into account the electric field dependent electron emission rates, the Poole-Frenkel and phonon-assisted tunneling effects.

A detailed theoretical and experimental study of the EL-2 electron trap in GaAs grown by VPE, LEC, and MOCVD techniques has been carried out in this work, and the results are summarizied as follows:

(1) A new defect model for the EL-2 electron trap in GaAs has been developed in this work. It is shown that EL-2 electron trap may be attributed to two different types of native defects: One is identified as the EL2-a (i.e., E_c-0.83 eV level) electron trap, and the other is designated as the EL2-b (i.e., E_c - 0.76 eV) electron trap. The physical origin for the EL2-a level is attributed to the double-charged arsenic

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antisite defect (i.e., As_{Ga}^{++}), whereas, the physical origin for the EL2-b electron trap is due to the arsenic-antitsite-arsenic vacancy complex (i.e., $As_{Ga}V_{As}$). Based on this model, relationship between the density of EL2 electron traps and the [As]/[Ga] mole fraction ratio for the MOCVD and VPE grown GaAs is established. The results show that the density of EL2-a level is proportional to the mole fraction ratio of $(r-1)^{1/2}$, while the density of EL2-b level is proportional to the mole fraction ratio of $(r-1)^{1/4}$, where r = [As]/[Ga]. This prediction is supported by experimental data for the MOCVD and VPE grown GaAs epitaxial materials. (see Fig.1)

(2) Theoretical analysis of the nonexponential capacitance transient (DLTS) due to electric field dependent emission rates of the EL-2 electron trap has been carried out. By taking into account the field dependent emission rates, theoretical calculations of the DLTS response for the EL2-a level were performed for the cases in which the trap center was assumed to have Coulombic potential well, square well, Dirac well, dipole- well or polarization potential well. A comparison of the calculated DLTS response with the DLTS data for the EL2-a electron trap in GaAs reveals that DLTS signal for the EL2-a electron trap can be best fitted by assuming that this charge center has a Coulombic potential well with a double-charge state. (see Fig.2) This result leads us to conclude that the most likely candidate for the EL2-a electron trap is due to the double-charged arsenic-antisite defect (i.e., As_{Ga}^{++}). This conclusion is further supported by our DLTS data in which Poole-Frenkel and phonon-assisted tunneling effects were observed in the field enhanced electron emission rate data for the EL2-a trap in the MOCVD grown GaAs.

(3) Thermal annealing experiment performed at 200 to 500 $^{\circ}C$ in H_2 ambient on the LEC grown n-type GaAs yields the following results: (a) EL2-b electron trap was observed in the unannealed samples; its density decreases with increasing annealing temperature, (b) As the annealing temperature increases to 500 $^{\circ}C$, the DLTS signal for the EL2-b level diminishes, while EL2-a trap becomes the dominant level in the DLTS scan. Thus, the EL2-a electron trap may be created in the LEC grown GaAs via high temperature thermal annealing. A similar result was also observed in the MBE grown GaAs epitaxial layers in which EL2-a center was observed in samples annealed at elevated temperatures. The reason for the annihilation of the EL2-b center and the creation of the El2-a center via thermal annealing process in LEC grown n-GaAs will be discussed in this paper.

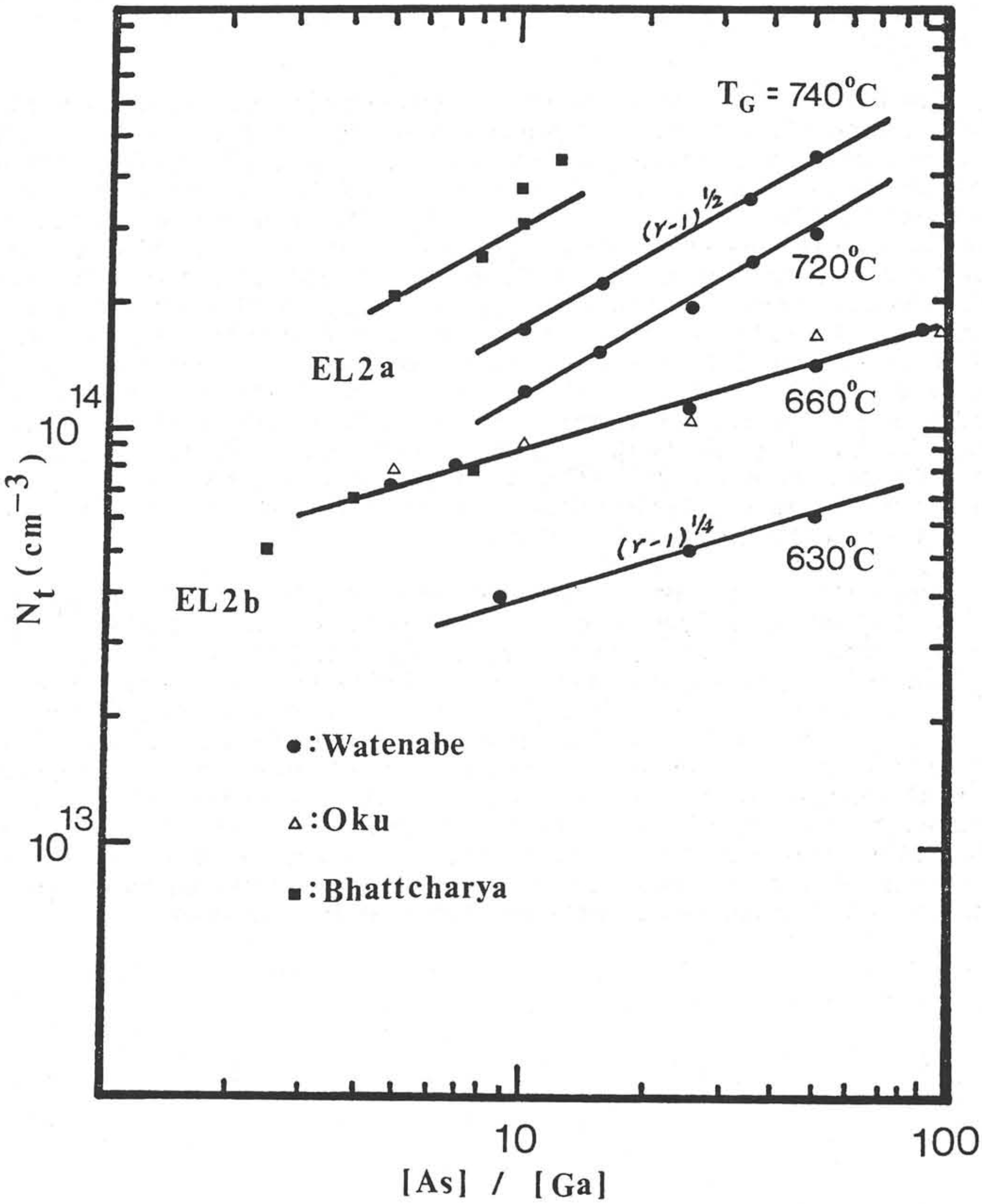

Fig.1 Density of EL2-a and EL2-b electron traps vs [As]/[Ga] mole fraction ratio.

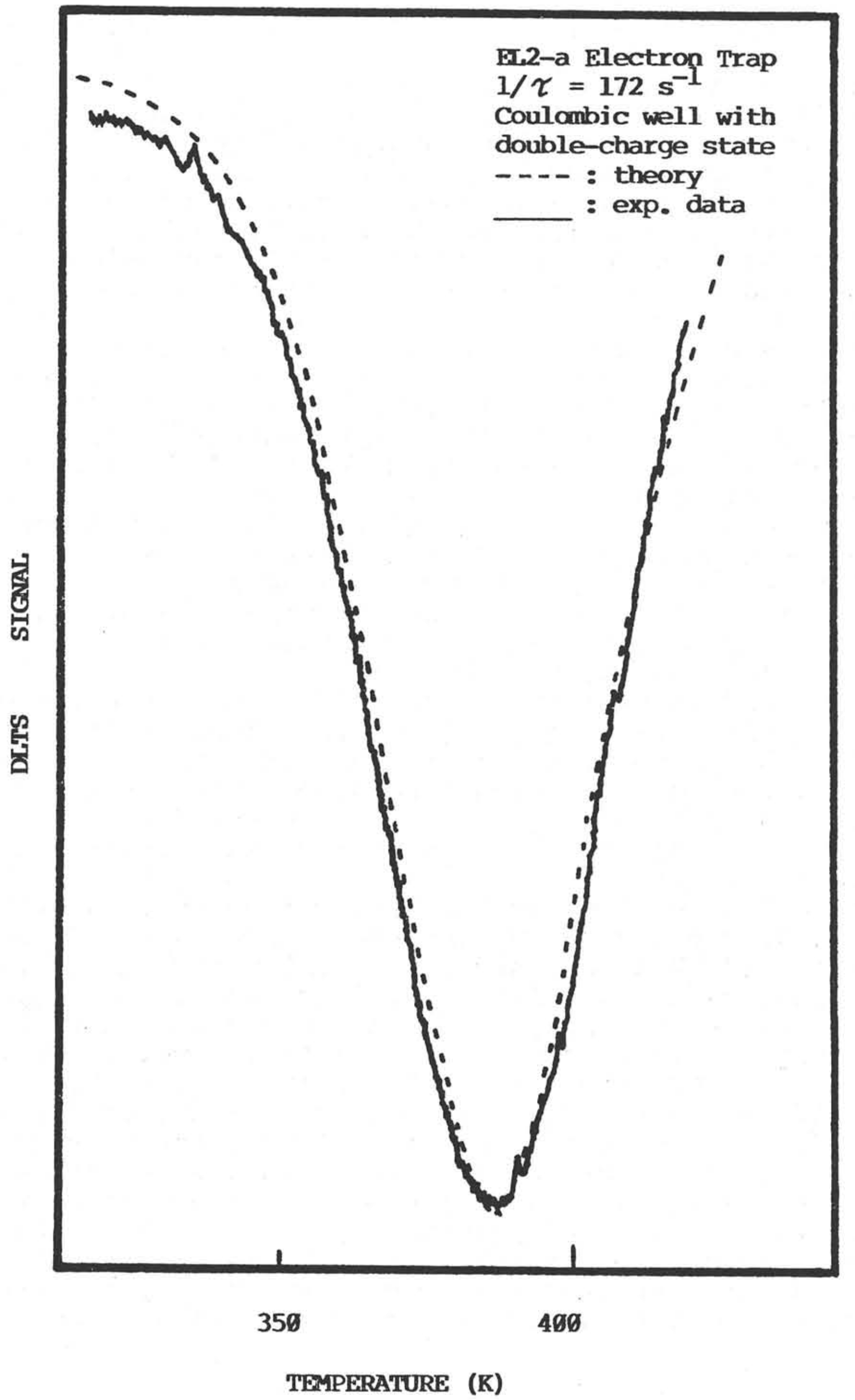

Fig.2 DLTS response of EL2-a electron trap in n-GaAs. Solid line :experimental data; dashed line theoretical calculations assuming Coulombic well with double-charge state.