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## FORMATION OF THE DX STATE BY DONORS IN $\text{Al}_x\text{Ga}_{1-x}\text{As}$ — EXPERIMENT\*

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A high-resolution Laplace-transform deep level transient spectroscopy was used to study electron emission from the DX centres related to group IV and VI donor elements in AlGaAs. This provides the experimental evidence that substitutional-interstitial atom motion is responsible for DX behaviour and for the associated metastability effects.

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The fundamental problem related to the properties of DX centres is understanding the mechanism for the metastability of these defects. Since the early work of Lang [1] this has been thought to be due to the large lattice relaxation (LLR) following electron capture by the DX state. However, the problem of the microscopic structure of these centres, namely the type or symmetry of the lattice relaxation, is less certain. The computations of Chadi and Chang [2], and Morgan [3], suggest that a substitutional-interstitial defect reaction may be responsible for LLR phenomena.

In the present study experimental evidence is presented which can only be interpreted in terms of substitutional-interstitial defect motion being responsible for the DX state formation. It is based on the detailed observation of the influence of the defect local environment on the electron thermal emission process from DX centres in  $\text{Al}_x\text{Ga}_{1-x}\text{As}$ . The direct comparison of this process for the DX centre related to silicon, which can replace gallium or aluminium, with that observed for tellurium, which resides in the arsenic sublattice, allowed us to deduce the configuration of atoms when the centre is in the ground state. Our experiments were possible because of a newly developed Laplace-transform isothermal deep level transient spectroscopy (DLTS) technique [4] which gives orders of magnitude better resolution than the conventional DLTS method and enables the influence of the defect local environment on the electron thermal emission process to be observed in detail. The conventional DLTS spectra taken for both types of samples

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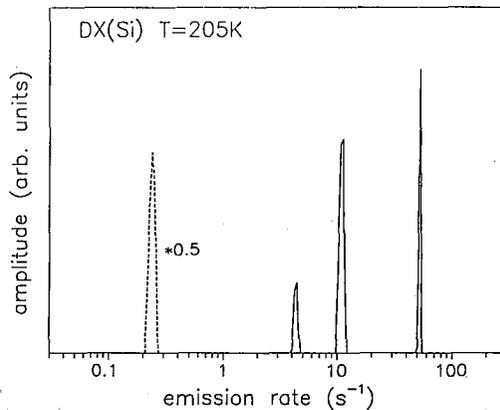


Fig. 1. The Laplace-DLTS spectrum of the DX(Si) defect in  $\text{Al}_{0.35}\text{Ga}_{0.65}\text{As}$ . In the spectrum there are four well-resolved peaks. Only three of them (at the higher emission rates) are associated with the DX(Si) centres. The fourth (dashed line) can be related to an unrecognized defect whose concentration increases with the aluminium content in the crystal; even for  $x = 0.74$  its concentration is orders of magnitude lower than that of the DX centres.

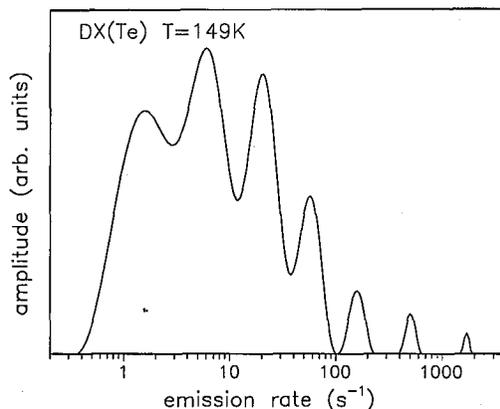


Fig. 2. The Laplace-DLTS spectrum of the DX(Te) defect in  $\text{Al}_{0.35}\text{Ga}_{0.65}\text{As}$ .

revealed only one dominant broad peak. This was associated with the DX centre and did not have the additional structured features reported for heavily doped  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  with silicon [5].

For the DX(Si) defect in a wide range of alloy compositions ( $0.20 < x < 0.76$ ) three peaks forming one group are always observed (Fig. 1). Each of them is characterized by almost the same activation energy of electron emission (approximately equal to 420 meV). The same pattern of peaks (with minor modifications) is observed for *all* alloy compositions investigated. These peaks are attributed to the

DX(Si) defect ionization process associated with substitutional-interstitial motion of the silicon itself.

For the DX(Te) centres, the atom which is subjected to the substitutional-interstitial motion could be either gallium or aluminium, and thus, two groups of peaks can be expected. In the Laplace-DLTS spectra for DX(Te) up to eight peaks are observed. These peaks form indeed two groups of peaks, each of them is characterized by a different activation energy of the thermal emission process. The activation energies for three peaks on the right-hand side of the spectrum (Fig. 2) are similar and approximately equal to 180 meV. For three peaks on the left-hand side of the spectrum these energies are approximately 270 meV. The activation energy of the peak which is in the middle of the spectrum (230 meV) is intermediate between the two groups. Its position in the spectrum can be strongly affected by both groups of neighbouring peaks.

This observations provide the first detailed experimental evidence of the DX-type state microscopic structure. The number of observed peaks and splitting between them rule out the possibility that this energy state is attributable to a stable configuration of a donor in a substitutional position with fully symmetric LLR. The number of emission rates and the differences between them in the group can be explained by a spatial degeneracy of the substitutional-interstitial atom motion [6].

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