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# High resolution diffraction and DLTS investigation results of the epitaxial $Ga_{1-x}Al_xAs/GaAs$ layers produced with the MOCVD method

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*Results of the crystallographic investigations of the epitaxial $Ga_{1-x}Al_xAs/GaAs$ layers with different compositions are presented. The epitaxial layers were produced using the MOCVD technology. Based on the obtained results, the structural analysis of the layers and appreciation of the perfection degree of the structure of investigated layers have been performed. A misfit $\Delta a/a$ of the elementary lattice of the $Ga_{1-x}Al_xAs/GaAs$ layer deposited on the GaAs substrate at room temperature was determined. For the sample with aluminium content of $x = 0.440$, a map of the reciprocal lattice points is presented. A sample with composition $Ga_{0.755}Al_{0.245}As/GaAs$ was investigated using the DLTS method. One energy level with activation energy depending on the time of filling pulse has been found.* 

## Introduction

In recent years, intensive investigations have been carried out on the application of the low dimensional structures in semiconductor device construction. A large class of semiconducting heterostructures that are used in optoelectronics and microwave technics are based on the semiconductor compounds $Ga_{1-x}Al_xAs$ and GaAs. The progress in epitaxial technology now enables crystallisation of $Ga_{1-x}Al_xAs/GaAs$ heterostructures with good structural, electrical and optical properties.

Two experimental techniques were applied in order to determine the properties and quality of $Ga_{1-x}Al_xAs$ and GaAs structures: X-ray spectroscopy with high resolution and deep level transient spectroscopy (DLTS).

In this paper the results of crystallographic investigations of the epitaxial layers $Ga_{1-x}Al_xAs/GaAs$ with various compositions ($x = 0$; 0.245; 0.315; 0.440; 0.465) obtained in the MOCVD technology are presented. For the sample with composition of $x = 0.440$, a map of the reciprocal lattice points is shown. Moreover, the sample with composition of $x = 0.245$ was investigated using the DLTS method.

## Experimental results

The structural investigations have been carried out using a high resolution difractometer (Philips, MRD-HRD) at the Institute of Electron Technology, Technical University of Wrocław. The measurements were performed using monochromatized $CuK_{\alpha 1} = 1.54062$ Å X-rays. Our experimental set-up allows a monochromatization of the light beam $\Delta\lambda/\lambda = 2.3 \times 10^{-5}$ and is at a maximum with a $\Delta\Theta = 5''$.[1]

Based on the analysis of the X-ray measurements, it has been found that in the investigated samples a tetragonalization of the elementary cells of the epitaxial layer[2] arises. From the shapes of the reflection curves the misfit $\Delta a/a$ of the elementary cells of the $Ga_{1-x}Al_xAs$ layer deposited on the GaAs substrate has been calculated. The results of calculations are presented in Table 1.

In Figure 1 a typical reflection curve for the $Ga_{0.560}Al_{0.440}As/GaAs$ sample is presented. The reflection curve obtained for the real heterostructure is compared with the simulated curve,

**Table 1.** The network misfit ($\Delta a/a$) for $Ga_{1-x}Al_xAs$ samples with various contents of aluminium

| Sample | Network misfit ($\Delta a/a$) [ppm] |
|---|---|
| $Ga_{0.833}Al_{0.165}As$ | 401 |
| $Ga_{0.755}Al_{0.245}As$ | 602 |
| $Ga_{0.685}Al_{0.315}As$ | 789 |
| $Ga_{0.560}Al_{0.440}As$ | 1133 |
| $Ga_{0.535}Al_{0.465}As$ | 1205 |

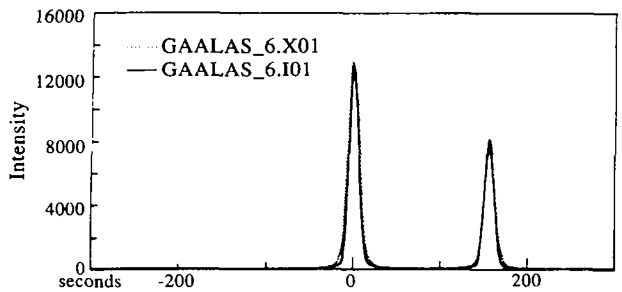


**Figure 1.** Reflectivity vs scan angle for the $Ga_{0.560}Al_{0.440}As/GaAs$ sample. ······· measured reflectivity curve for the sample under study, ——— simulated reflectivity curve with a lattice misfit data of 1133 ppm.

calculated based on the assumed misfit of the structural parameters of the layer and substrate. The simulation agrees well with the experiment. The misfit depends linearly on the layer composition. The bigger the aluminium content in the solid solution, the bigger is the mechanical stress. When the lattice constants differ strongly (GaAs epitaxy on Si) the epitaxial layer can relax that results in defects and microfractures.[3]

For the same sample ($Ga_{0.560}Al_{0.440}As/GaAs$) for which the reflection curve is presented in Figure 1, the map of the reciprocal lattice points is shown.[1] In Figure 2(a) the intensity and mutual localisation of the symmetrical reflex (006) from substrate (S) and the epitaxial layer (L) is shown. Figure 2(b) presents the

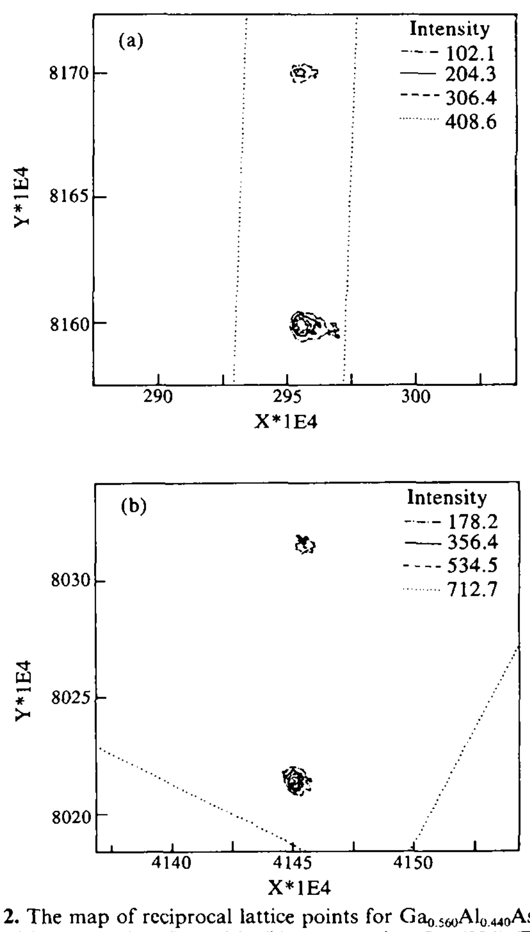


**Figure 2.** The map of reciprocal lattice points for $Ga_{0.560}Al_{0.440}As/GaAs$ sample. (a) Symmetric reflex (006), (b) asymmetric reflex (226). The plot is in units $\lambda/2d_{hkl}$.

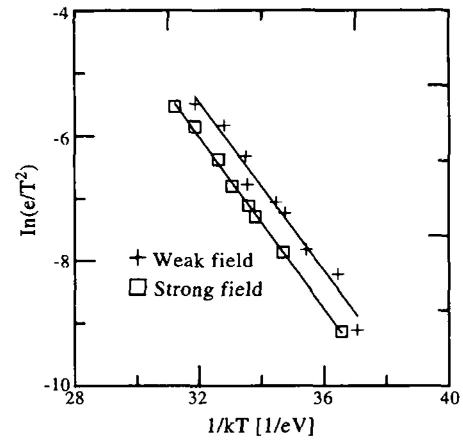


**Figure 3.** The energy activation plot for the weak and strong electric fields.

same relationships for the asymmetric (226) reflex. An essential difference between the diffraction images of the reciprocal lattice map of the stressed and relaxed layers manifests itself in the asymmetric reflexes. In the case of stressed layer the reciprocal lattice points are displaced perpendicular to the surface of the sample. In the case of the relaxed layer the reciprocal lattice points are displaced along the radius-vector.

The sample $Ga_{0.835}Al_{0.165}As/GaAs$ was investigated using the DLTS method.[4] The potential barrier was a gold contact on the $Ga_{0.835}Al_{0.165}As/GaAs$. The DLTS measurements were carried out using the DLS-82E lock-in spectrometer (Semitrap, Hungary). The measuring method with two filling pulses of different heights and the same filling time was applied. The observed signal was emitted from the narrow layers of the depletion region of the junction. Within the temperature range of 250–400 K one maximum with a half width of 50 K connected with majority carriers has been found. The dependence of hole emission from the trap responsible for observed maximum on electric field was investigated. In Figure 3 Arrhenius plots for two different electric fields are shown. The filling time for both curves was equal to 84 $\mu s$. The activation energy determined from the Arrhenius plots was found to be equal to $(0.69 \pm 0.01)$ eV for the strong field and $(0.68 \pm 0.01)$ eV for the weak field. Capture cross sections obtained from both plots were the same within the experimental error ($\sigma = (2.5-3.1) \times 10^{-15}\,cm^2$).

The dependence of the DLTS signal on filling pulse time was also studied. In Figure 4 the DLTS signal spectra for different

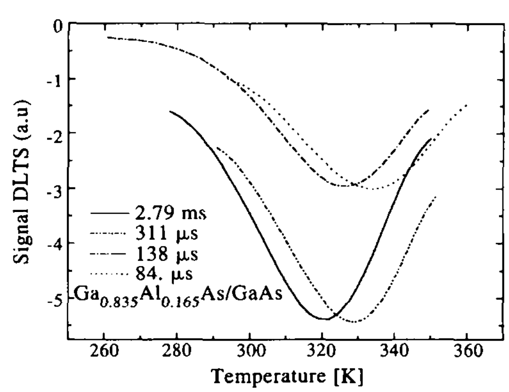


**Figure 4.** DLTS signal for different widths of filling pulse. Measuring parameters: $f = 12.7$ Hz, $U_1 = -6$ V, $U_2 = -8$ V, $U_R = -10$ V.

filling times $t$ are presented. Both the amplitude and the temperature position of the peak depend on the filling pulse time. The maximum of the DLTS signal moves toward the lower temperature with increasing filling time.

## Discussion

The results of crystallographic investigations on $Ga_{0.560}Al_{0.440}$ As/GaAs samples are the following: the reciprocal lattice map of asymmetrical reflexes indicate existence of stress within a whole epitaxial layer. The tetragonalisation of elementary layer cell seems to be responsible for the stress.

With the help of DLTS measurements one hole trap was found with an activation energy that is independent on the electric field. The activation energy however, was strongly affected by the duration of filling pulse time.

Usually in the case of point defects the temperature position of the DLTS maximum remains constant whereas its amplitude increases with increasing time of the filling pulse. In Ref. 5 it has been shown that for the so-called extended defects, both the amplitude of DLTS signal and its temperature position change with filling pulse time. As a result, decreasing activation energy with increasing filling pulse time was observed. This effect was also found in our sample. The value of activation energy was equal to 0.90 eV for filling pulse time $t_1 = 8\,\mu s$ and 0.69 eV for $t_2 = 84\,\mu s$. The variation of the maximum of the DLTS signal with a change of the filling time indicates that the defects that are responsible for the observed maximum have a character of extended defects. This observation confirms the supposition of existence of mechanical stresses of the elementary cells in the epitaxial layer, as indicated by the X-ray analysis. The tetragonalisation of the elementary cell of the epitaxial layer is the possible origin of observed trap level.

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