ESRF	**Experiment title: Investigation of the lateral ordering and chemical composition in lattice matched A_3B_5 quaternary and ternary superlattices**	**Experiment number:** 20-02-037
Beamline:	**Date of experiment:** from: 03 06 2000 to: 05 06 2000	**Date of report:** 16 10 2000
Shifts:	**Local contact(s):** Dr Norbert Schell Phone: 0033476882367 e-mail: schell@esrf.fr	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Krystyna Mazur , Jaroslaw Gaca, Marek Wojcik Institute of Electronic Materials Technology, 01- 919 Warsaw, ul Wolczynska 133, Poland (+48 22) 835 30 41 (144)

Report:

The aim of the experiment was to investigate the structural properties of the InGaAsP/InP multilayered crystals grown on laterally inhomogeneous (001) InP substrate crystals. A lateral inhomogeneity may appear as a result of the off-cut, local fluctuations of the interplanar spacing or small misorientation of adjacent regions in substrate crystal. In consequence, there may appear a perturbation of the shape of the interface between epilayer and substrate crystals that affects the lateral structure.

The lateral inhomogeneity of the epilayer structure modifies the density distribution of reciprocal space nodes. In order to investigate the structure of reciprocal lattice nodes, a mapping of the region of reciprocal space around a chosen reflection of the substrate crystal is required. Such a map contains information concerning the crystal structure both in the growth direction and in the direction parallel to the interface.

The reciprocal space map of the 20 period of quaternary $In_{0.595}Ga_{0.405}As_{0.35}P_{0.65}$ /InP superlattice crystal grown on (001) InP substratate in vicinity of 004 InP has been performed. The X- ray synchrotron radiation with λ=1.196 A was used. The radiated area of the sample was 0.2mm x 0.2mm. The data for the map has been collected as a series of succeeding $\theta/2\theta$ asymmetrical scans for different initial values of θ angles.

To establish the appropriate angular range for map measurement $\theta/2\theta$ and ω scans were performed. They are presented in fig. 1 and 2.

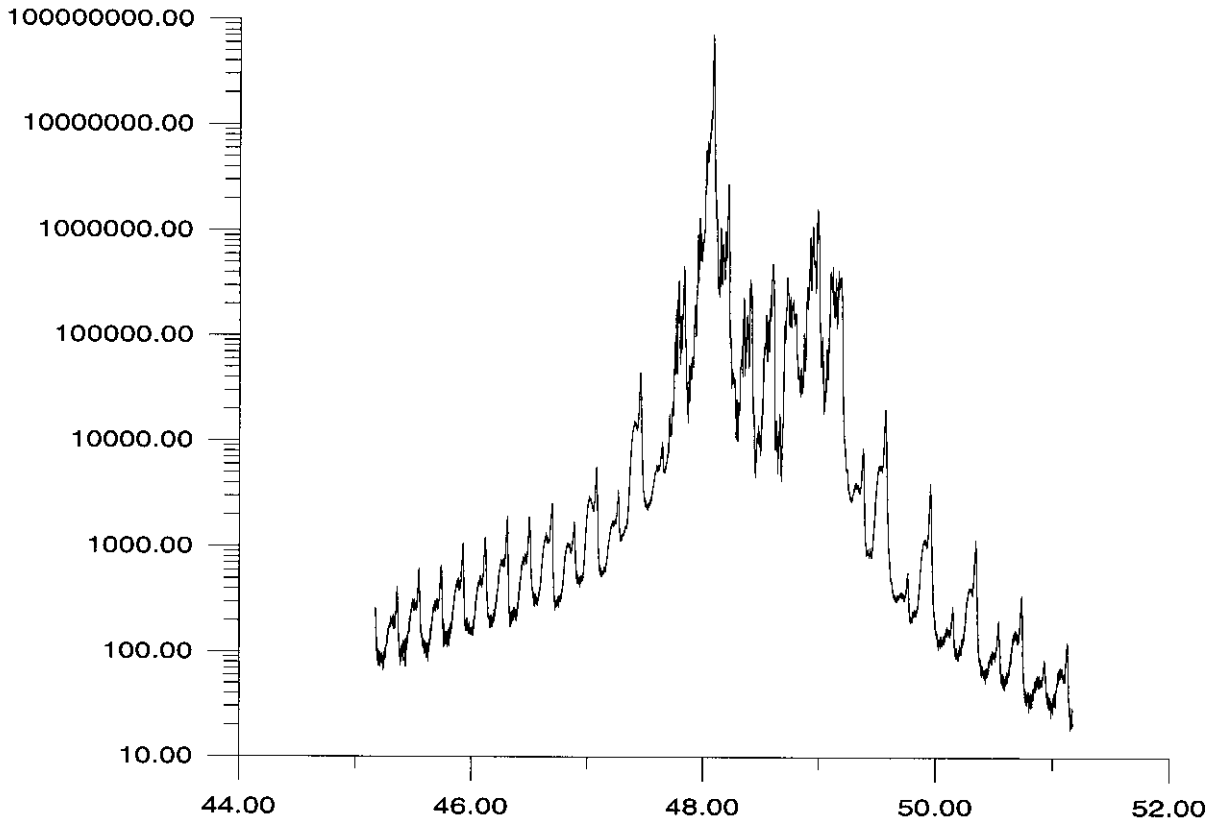

Fig. 1) The θ/2θ scan measured for the angular range: -2deg <2θ < +2deg, step = 0.001deg, time per point 1 sec.

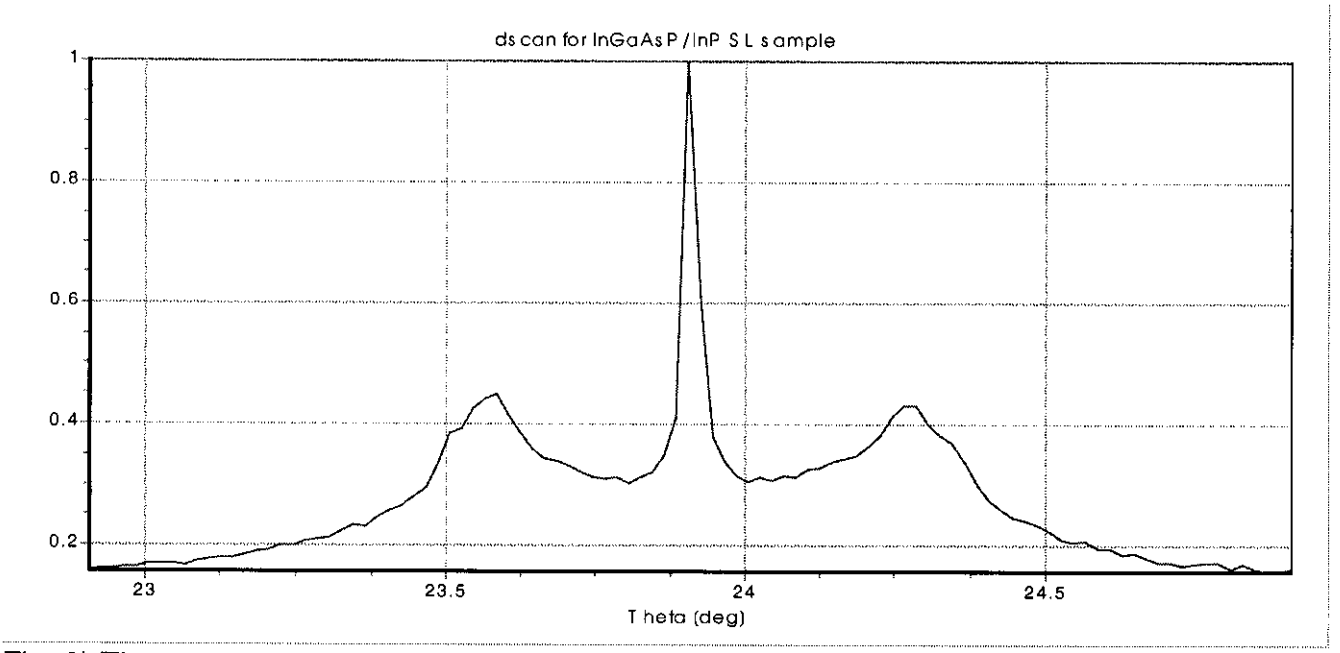

Fig. 2) The ω scan measured for the angular range -0.1 deg < ω < +0.1 deg and 2θ = constans = 47. 845 deg

On the basis of obtained X- ray diffraction profiles the angular ranges were chosen to be -2deg <2θ <+2deg, -0.1 deg < ω < +0.1 deg.
The profile in fig. 2 proves that there exists interesting disturbance of the lateral structure in the investigated quaternary superlattice. This result justifies the measurement of the reciprocal space

map in order to perform the sample structure analysis. The measured reciprocal space map enabled to establish the exact values of satellite intensities what resulted in determination of the chemical composition and interplanar spacing profiles of investigated SL by means of computer simulations. Hence we have been able to calculate such parameters as: the modulation wavelenght = 389.22 A, number of 004 atomic planes in one modulation period = 272, and the mean interplanar spacing parallel to the growth direction = 1.4523A. The work concerning the determination the lateral structure of the investigated SL crystal is still under way.

Similar measurement procedure was adopted to ternary $In_{0.524}Ga_{0.476}As$/ InP superlattice.

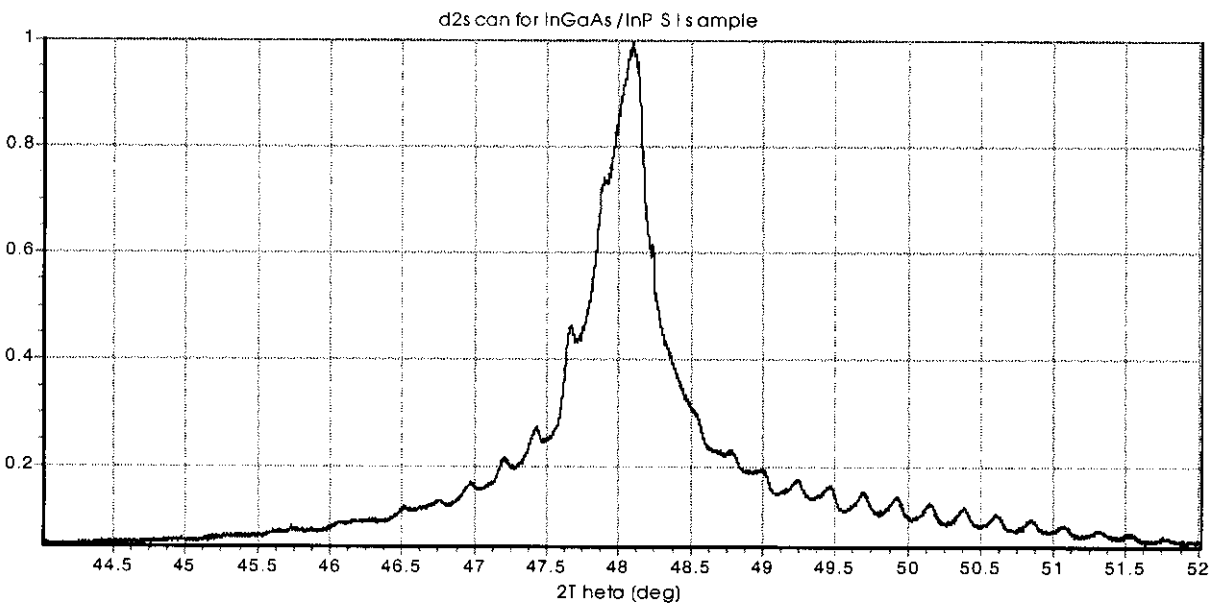

Fig. 3) The $\theta/2\theta$ scan measured for the angular range: -4deg <2θ < +4deg, step = 0.001deg, time per point 1 sec.

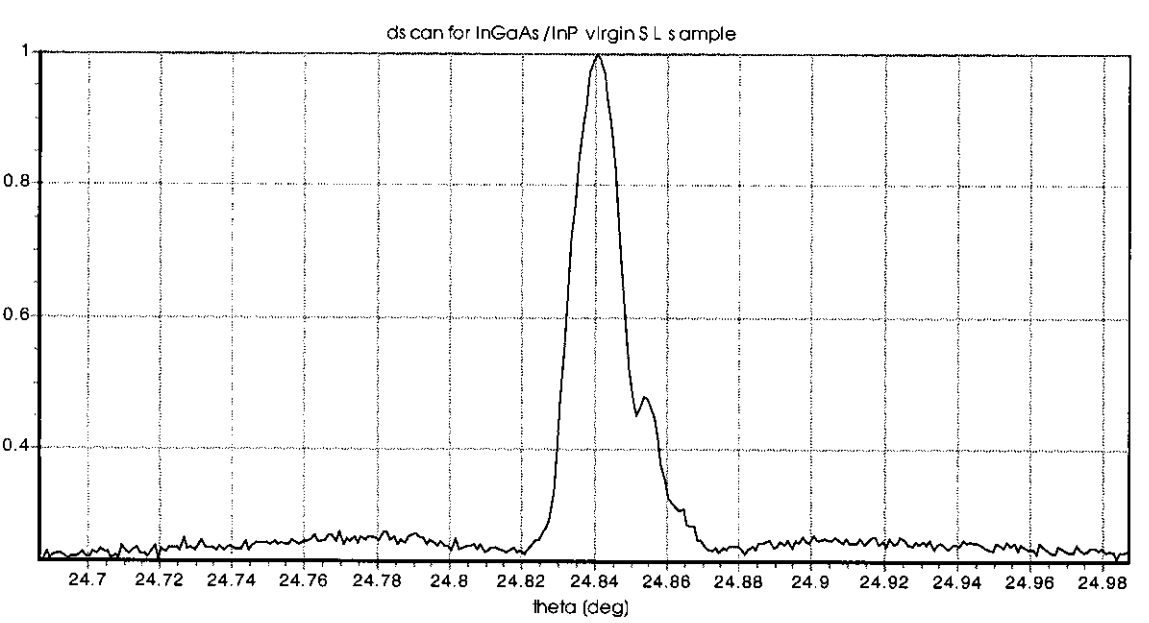

Fig. 4) The ω scan measured for the angular range -0.15 deg < ω < +0.15 deg and 2θ = constans = 48.152 deg

On the basis of obtained X- ray diffraction profiles the angular ranges were chosen to be -4deg <2θ <+4deg, -0.15 deg < ω < +0.15 deg.

As in previous case the measured reciprocal space map enabled to establish the exact values of satellite intensities what resulted in determination of the chemical composition and interplanar spacing profiles of investigated SL by means of computer simulations. Hence we have been able to calculate such parameters as: the modulation wavelength = 322.67 A, number of 004 atomic

planes in one modulation period = 220, and the mean interplanar spacing parallel to the growth direction = 1.4667A. The work concerning the determination the lateral structure of the investigated SL crystal is still under way. It was found that there have been four layers with different chemical composition in one modulation period instead of assumed two. These two additional layers are composed of 10 atomic planes, and their chemical composition is InGaP and InAs, respectively. We were not able to perform similar measurement for implanted ternary superlattice because of the device break-down.

The last experiment concerned the investigations of a series of epitaxy layers $In_{0.86}Ga_{0.14}As$ grown on the InP(001) were performed. In relation to the layer thickness either the isomorphic or relaxed growth is expected. The lattice misfit for investigated heterostructures is equal to $\Delta a/a = 2.3 .10^{-2}$ and the critical thickness
$h_c \cong 40$Å. The investigations of structural properties was performed (above the critical thickness) for three layers with following thickness $h_1 = 85$ Å , $h_2 = 240$ Å,
$h_3 = 360$ Å in 004 reflection. Analysing diffraction rocking curves, the following angular distances between the layer and substrate peaks have been found :
$\Delta\theta_{h1} = -95^{\circ}$ $\Delta\theta_{h2} = -0.77^{\circ}$ $\Delta\theta_{h3} = -0.71^{\circ}$.
Comparing the above mentioned data and the one obtained for heterostructure with the layer thickness h = 28 Å, where $\Delta\theta = -1.16^{\circ}$ it may be concluded that the whole investigation samples were significantly relaxed. The thicker is the layer the greater is the percentage of relaxation, what can be inferred from the observation that the increase of layer thickness results in the decrease of the angular distance $\Delta\theta$. The thickness fringes are noticeable for the layer thickness $h_1 = 85$ Å (Fig. 5) and their vanishing for greater thickness is observed, what can be explain by the formation of mosaic structure in the layer.
Analysing the intensity distributions of the "ω-scan" for all layers it has been observed that the intensity of the diffuse tails was increased comparing to that with the thickness h =28 Å. Formation of the local maximum has been observed for the heterostructure with layer thickness $h_1 = 85$ Å. According to the literature this effect can be explained by the appearance of the diffuse scattering due to the misfit dislocations in this heterostructure (the case $\rho h < 1$, where ρ - linear density of dislocation, h – layer thickness).

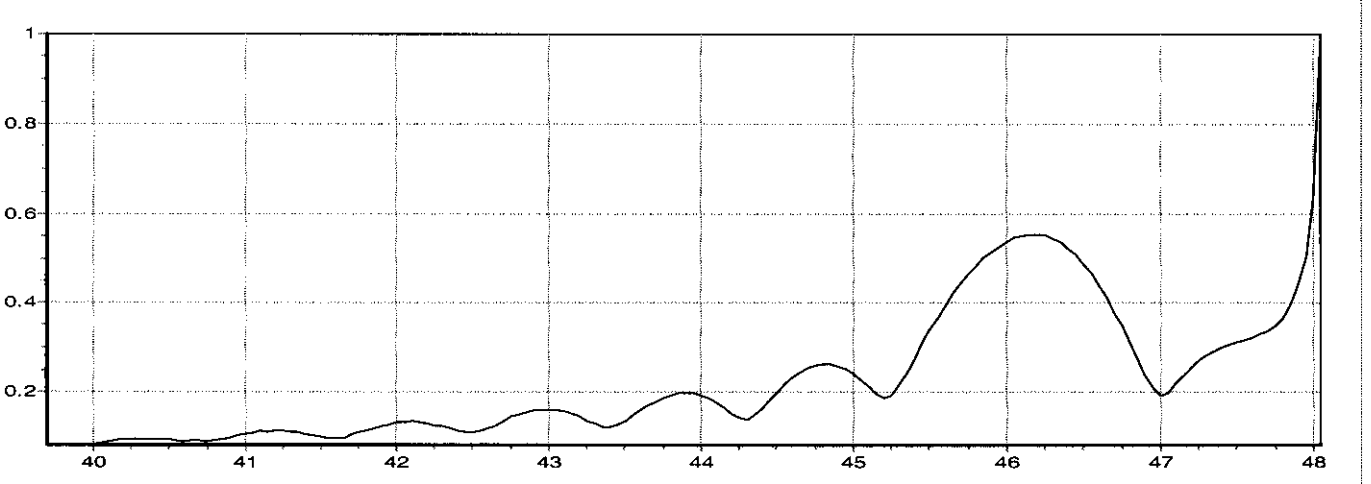

Fig. 5) The example of rocking curve in the vicinity of maximum for the epitaxial layer with thickness h = 85Å