Ga$_{1-x}$Mn$_x$As layers with nominal Mn contents $x = 0.025, 0.03, 0.04, 0.05$ and $0.063$ were grown by MBE method on the (001)-oriented GaAs substrates at 230°C. The Ga$_{1-x}$Mn$_x$As layers were subjected to annealing at 500°C for 30 min in argon atmosphere under ambient pressure ($10^5$ Pa) or under HP = 1.1 GPa. The HP-HT treatment was performed in specially designed high temperature-pressure furnace. The granular GaAs:(Mn,Ga)As layers were produced by this way.

Determination of the lattice parameters of hexagonal NiAs-type MnAs nanoclusters was performed using synchrotron radiation ($\lambda = 1.54056$ Å) at the W1 beamline at DESY-HASYLAB. Hexagonal nanoclusters were detected only for the samples with Mn concentration $x > 0.03$. The orientation of the MnAs nanoclusters embedded in GaAs matrix is well-defined – (00.1) planes of MnAs are parallel to {111} GaAs planes. Therefore, the lattice parameters of MnAs were calculated from the 20.2 and 30.0 reflections detected by the $\omega$ scan in the vicinity of symmetrical 004 GaAs reflection, and from the $2\theta/\omega$ scan around the asymmetrical 224 GaAs reflection, respectively. Detailed description of this procedure is given in [1,2].

The $\omega$ scan recorded around the 004 GaAs reflection allowed the detection of the two 20.2 reflections originating from the hexagonal NiAs-type MnAs nanoclusters [1,2].

Figure 1: The X-ray patterns of Ga$_{0.97}$Mn$_{0.03}$As after annealing at 500°C under 1.1 GPa: $2\theta/\omega$ scan of 20.2 MnAs reflection (a); $2\theta/\omega$ scan of 30.0 MnAs reflection (b).
From the $2\theta/\omega$ scans of the 20.2 MnAs reflection and around the 224 GaAs asymmetrical one (Fig.1a,b) the lattice spacing $d_{20.2}$ and $d_{30.0}$ were calculated. On the basis of these values the $a$ and $c$ lattice parameters of the hexagonal unit cell of MnAs clusters, as well as the strain values were determined. The obtained results are given in the Table 1.

Table 1: Lattice parameters ($a, c$) and strains ($\varepsilon$) of the hexagonal MnAs inclusions produced in Ga$_{1-x}$Mn$_x$As layers after HT and HP-HT annealing.

<table>
<thead>
<tr>
<th>Layer</th>
<th>After HT annealing</th>
<th>After HP-HT annealing</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>$a$ ± 0.002 [Å]</td>
<td>$\varepsilon_a$ ± 5×10$^{-4}$</td>
</tr>
<tr>
<td>0.04</td>
<td>3.711 ± 2×10$^{-3}$</td>
<td>5.812 ± 19×10$^{-3}$</td>
</tr>
</tbody>
</table>

Enhanced hydrostatic pressure applied during annealing at 500°C of the MBE grown GaMnAs layers results in creation of increasingly strained MnAs inclusions. The strain induced by this procedure is definitely dependent on the crystallographic structure of MnAs clusters (cubic or hexagonal) and it is much higher for the hexagonal ones. In consequence, the annealing under pressure leads to the increase of the strain of the GaAs matrix, especially for the layers containing the hexagonal MnAs inclusions [2].

References