Temperature dependent magnetoresistance characterization of ordered strained InGaP grown by MOVPE

S. Hasenöhrl [1)] , J. Betko [1)] , M. Morvic [1)] , J. Novák [1)] , J. Fedor [1)]

1) Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska cesta 9, 841 04 Bratislava, Slovak Republic

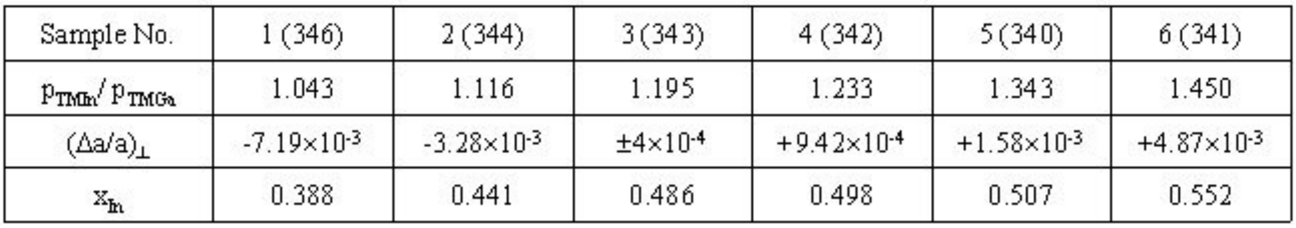
1. Introduction

The MOVPE grown InGaP exhibits tendency to a CuPt−B type of ordering. Physical properties of epitaxial layers with various degree of order are different. The unequal distribution of the atoms with regard to the crystallographic directions in ordered layers leads to anisotropic behaviour of material features [1]. In our first report on transport anisotropy in $In_xGa_{1-x}P$ [2] we revealed, that the resistivity anisotropy is a feature observable in samples with the highest degree of order grown at 640 ^oC. The evaluation of electrical properties using the van der Pauw (vdP) method [3] showed that the layers even slightly mismatched from substrate are electrically anisotropic. The layer exactly lattice−matched to the substrate at the growth temperature showed Hall concentration and Hall mobility corresponding with theoretical calculations from [4]. Samples tensile or compressive strained at the growth temperature exhibited higer Hall mobilities; at 77 K up to 16 000 $cm^2\ V^{-1}s^{-1}$. Because these layers exibited also structural defects described in [5] we concluded, that the layer inhomogeneity has significant impact on parameters determined from measurement in vdP configuration.

2. Experimental procedure

A set of $In_xGa_{1-x}P$ layers was prepared on the GaAs(100) semiinsulating substrates with a 300 nm thick undoped GaAs buffer layer. The low−pressure organometallic chemical vapour phase epitaxy (OMVPE) was operated at a total pressure of 20 mbar and a growth temperature of 640 ^oC. Ordering in the layers was confirmed by TEM. The degree of the order calculated from 6 K photoluminescence (PL) spectrum peak position for lattice−matched layer was 0.39. Changing the layer composition x_{In} from 0.39 to 0.55 induced the epitaxial strain which influence on electrical parameters in ordered layers was studied. A set of layers under study is summarized in Table 1.

Table 1. Review of samples under study.



Sample No.	1 (346)	2 (344)	3 (343)	4 (342)	5 (340)	6 (341)
p_{TMIn}/p_{TMGa}	1.043	1.116	1.195	1.233	1.343	1.450
$(\Delta a/a)_\perp$	-7.19×10^{-3}	-3.28×10^{-3}	$\pm4\times10^{-4}$	$+9.42\times10^{-4}$	$+1.58\times10^{-3}$	$+4.87\times10^{-3}$
x_{In}	0.388	0.441	0.486	0.498	0.507	0.552

Magnetoresistance measurements were performed on stripe samples using the four−point probe method. 1×8 mm^2 stripes were prepared by cleaving in two mutually perpendicular crystallographic directions ([011] and [0−11]) and contacted with In alloyed 4 min. at 400 ^oC in forming gas. The temperature dependent magnetoresistance measurements were done in LHe continuous flow cryostat with samples in the dark ranging from 5K to 300 K. A current of 10 µA was applied to the samples. The magnetic field was varied from −540 to +540 mT. On the stripes also two short−distance contacts were prepared to measure the geometrical magnetoresistance effect (GMR). GMR measurements were used to calculate so called GMR mobility which is close to the Hall mobility. Both magnetoresistances, measured with four−point probe (magnetoresistivity) and with two short distance contacts (geometrical magnetoresistance), are illustrated in Fig. 1.

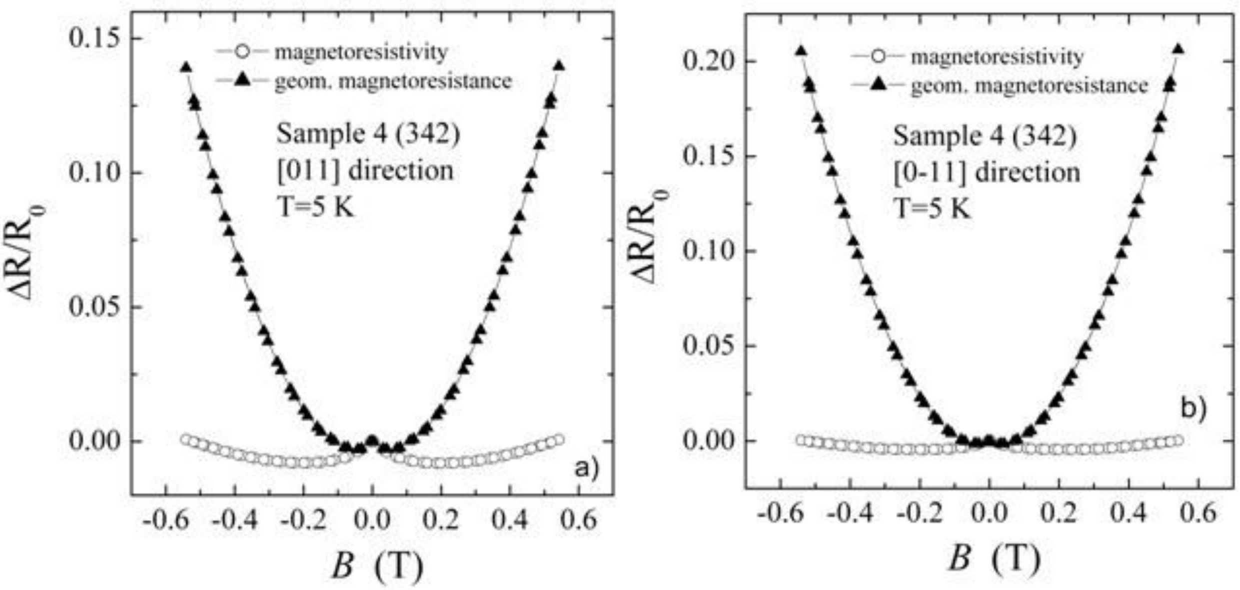


Fig. 1. Magnetoresistivity and geometrical magnetoresistance of sample 4 (342) measured at 5K.

3. Results and discussion

Samples with the lattice mismatch lower than $\pm 1\times 10^{-3}$ exhibit a negative magnetoresistance at low magnetic fields and at low temperatures. After the simulations we ascribe this feature to the phenomenon of carrier weak localization. This is an indication of existence of region with the two−dimensional electron gas (2DEG) probably at the GaAs−InGaP interface. However, values of Hall mobility estimated from magnetoresistance curves simulations are much lower than those usually measured in GaAs 2DEG structures with AlGaAs as a barrier. The low Hall mobility in the 2DEG and the dependence of resistivity on the crystallographic orientation can be

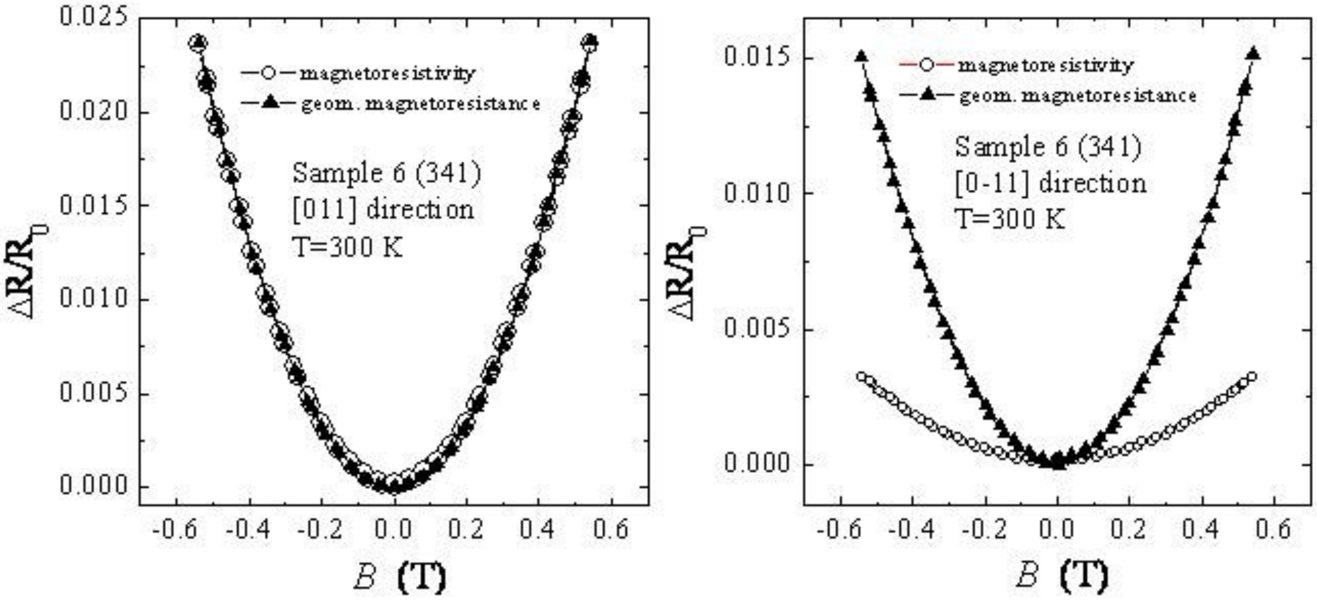
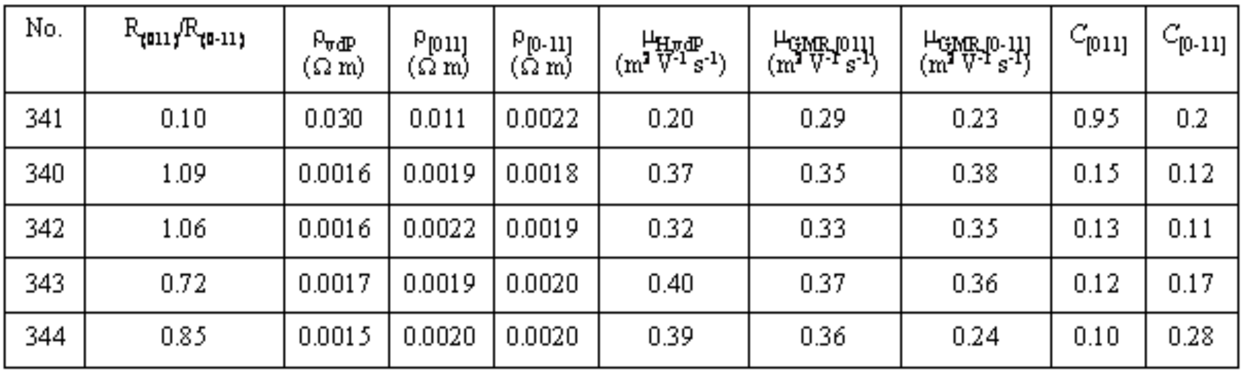


Fig. 2. Magnetoresistivity and geometrical magnetoresistance of compressively strained sample 6 (341) measured at 300K.

explained by the strong influence of InGaP barrier/GaAs well interface on carrier transport in the well. There is significant role of the crystallographic anisotropy of ordered InGaP layer and the interface strain in mismatched structures. The resistivity dependence on the crystallographic orientation is higher in samples with higher lattice mismatch. Layers with the lattice mismatch higher than $\pm 1\times10^{-3}$ are electrically anisotropic with strong resistivity dependence on the crystallographic orientation. Samples having [0−11] misfit lines oriented across the stripe probe exhibit considerably higher resistance and magnetoresistance effect than that in samples without misfit. This indicates that the [0−11] misfit lines induce high resistance regions across the sample, so the sample becomes inhomogeneous. Therefore, a shortening of the Hall electric field and consequently a large magnetoresistance effect occure due to alternating low and high resistive regions across the current flow. As a consequence, the magnetoresistances measured on four contacts stripe probe and between two short−distance contacts are the same, Fig.2. In Tab. 2 the ratio of the van der Pauw resistances R(011)/R(0−11), the resistivity (ro), the Hall mobility (μH), the GMR mobility (μGMR), and the ratio (C) of the "physical" (measured on four contacts probe) and GMR (measured on two short−distance contacts probe) magnetoresistances measured with van der Pauw (vdP) and stripe samples are presented.

Table 2. Experimental results obtained with samples of van der Pauw and stripe geometry at 300 K.



No.	$R_{(011)}/R_{(0\text{-}11)}$	ρ_{vdP} (Ω m)	$\rho_{[011]}$ (Ω m)	$\rho_{[0\text{-}11]}$ (Ω m)	μ_{HvdP} ($m^2 V^{-1} s^{-1}$)	$\mu_{GMR[011]}$ ($m^2 V^{-1} s^{-1}$)	$\mu_{GMR[0\text{-}11]}$ ($m^2 V^{-1} s^{-1}$)	$C_{[011]}$	$C_{[0\text{-}11]}$
341	0.10	0.030	0.011	0.0022	0.20	0.29	0.23	0.95	0.2
340	1.09	0.0016	0.0019	0.0018	0.37	0.35	0.38	0.15	0.12
342	1.06	0.0016	0.0022	0.0019	0.32	0.33	0.35	0.13	0.11
343	0.72	0.0017	0.0019	0.0020	0.40	0.37	0.36	0.12	0.17
344	0.85	0.0015	0.0020	0.0020	0.39	0.36	0.24	0.10	0.28

4. Conclusion

In conclusion, the magnetoresistance measurements on the stripe samples confirmed the anisotropic behaviour of transport parameters in strained ordered InGaP.

References

[1] T. Suzuki, MRS Bulletin 22 (1997) 36.
[2] Novák, J., Hasenöhrl, S., Kúdela, R., Kucera, M., Wüllner, D., Wehmann, H.−H.: Appl. Phys. Lett. 73 (1998) 369.
[3] Hasenöhrl S., Novák J., Kúdela R., Betko J., Morvic M., Fedor J.: J. Cryst. Growth 248 (2003) 369.
[4] C. Besikci and M. Razeghi, IEEE Trans. on Electron Devices 41 (1994) 1066.
[5] S. Hasenöhrl, R. Kúdela, J. Novák, T.O. Tuomi and L. Knuuttila, Mat. Sci. Eng. B 88 (2002) 134.