Structural & Magnetic Properties of (Ga,Mn)(Bi,As) Thin Epitaxial Layers

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MOTIVATION

Our present work is concentrated on structural and magnetic properties of (Ga,Mn)(Bi,As) thin epitaxial films, grown under either compressive or tensile strain. Basic material, (Ga,Mn)As, has already become one of the most intensively studied dilute magnetic semiconductors (DMS), and stays in the first line among the probable compatible alternatives of the existing technologies. On the other hand, highly mismatched ternary SC Ga(Bi,As) is among promising materials, that contribute positively to the development of photonic and spintronic devices due to a large band gap decrease and a strong enhancement of the spin-orbit coupling [1].

HR-XRD

- high structural perfection of the layers, grown by LT-MBE (T_g = 230°C);
- pseudomorphical layers growth under compressive strain on GaAs substrate and under tensile misfit strain on the InGaAs buffer.
- Bi addition to the (Ga,Mn)As thin films resulted in a distinct increase in their lattice parameters.
- Post-growth annealing treatment resulted in decrease in their lattice parameters.

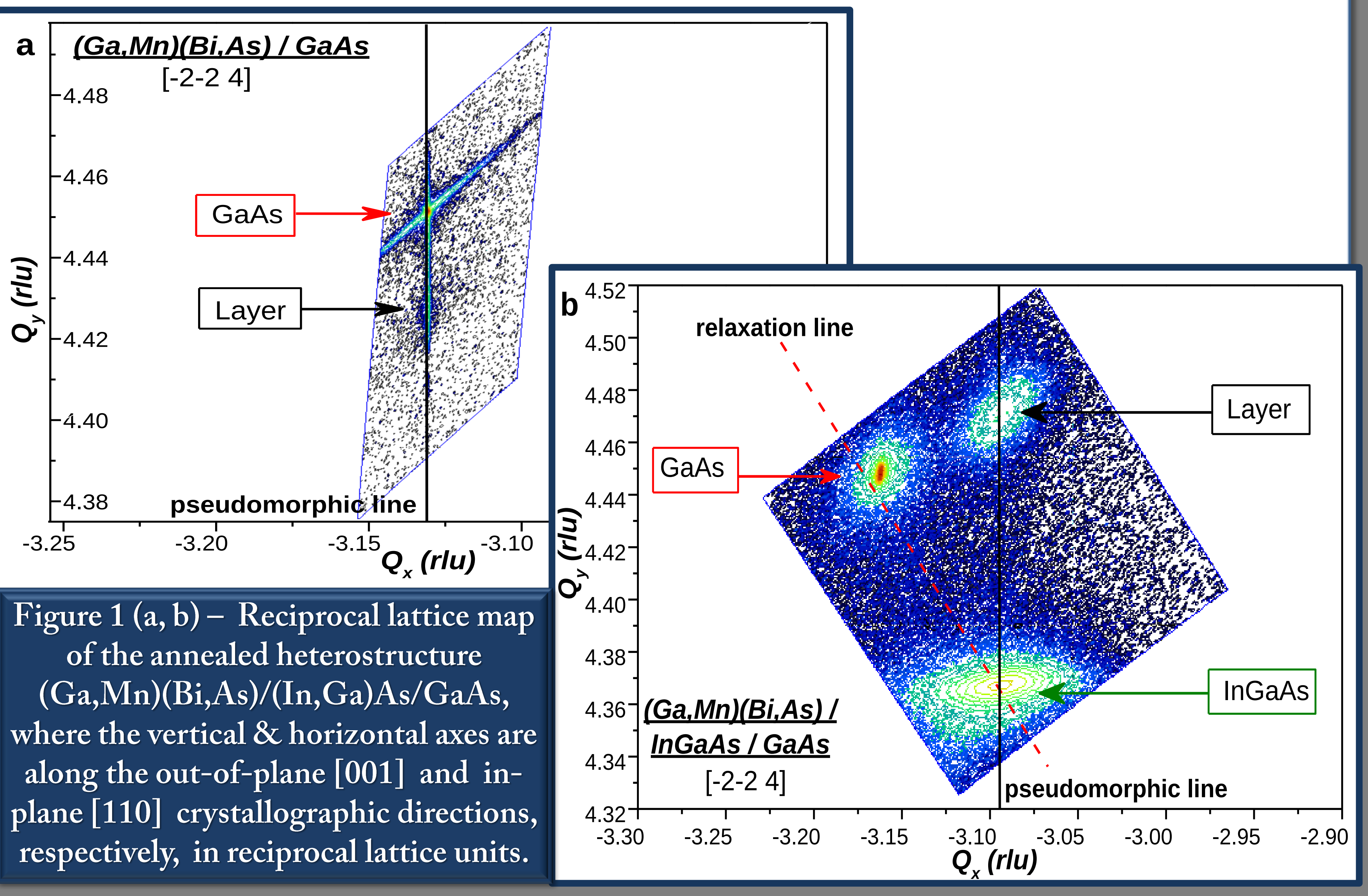


Figure 1 (a, b) – Reciprocal lattice map of the annealed heterostructure (Ga,Mn)(Bi,As)/(In,Ga)As/GaAs, where the vertical & horizontal axes are along the out-of-plane [001] and in-plane [110] crystallographic directions, respectively, in reciprocal lattice units.

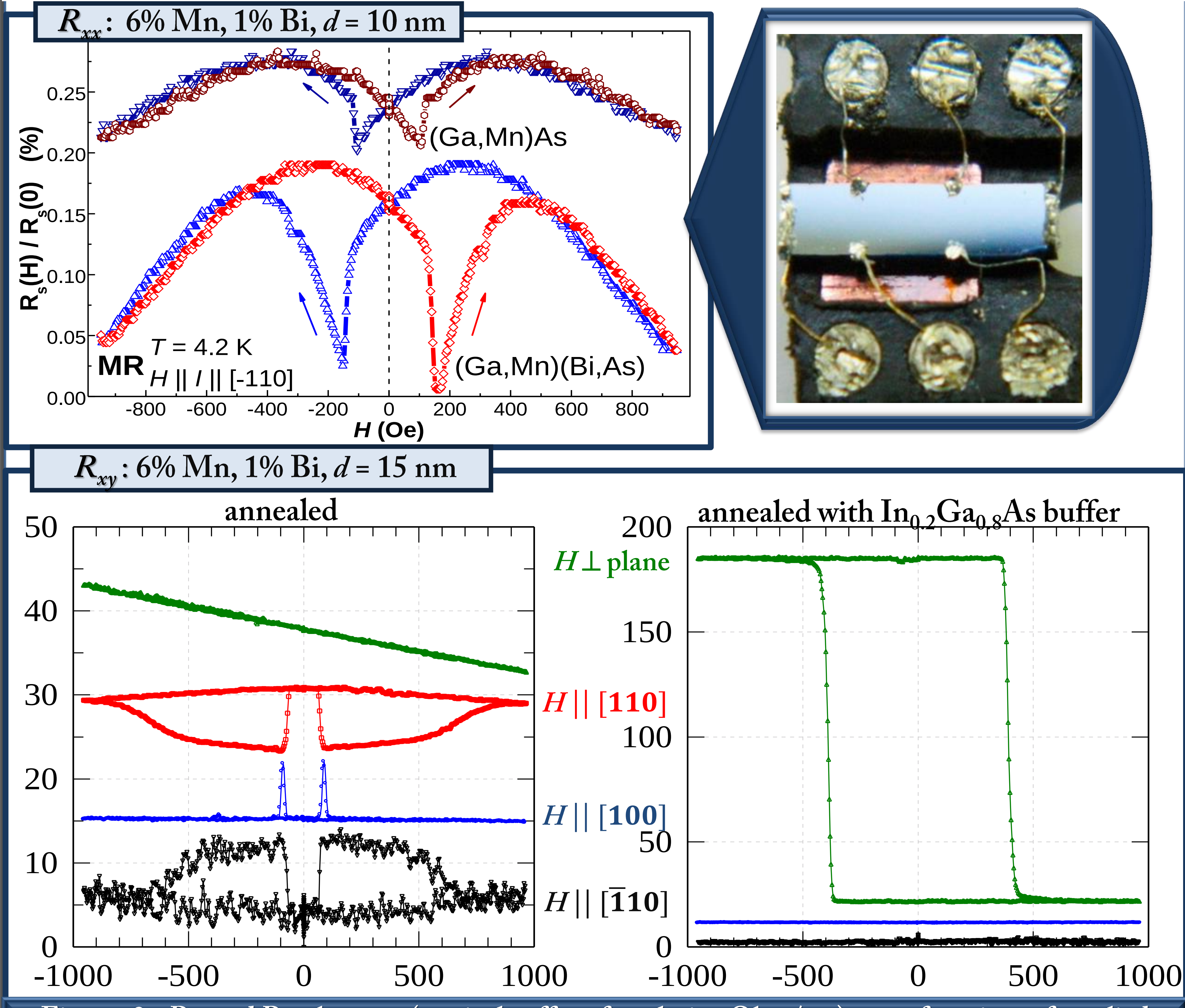
MOKE MAGNETOMETRY

Magneto-optic properties were measured as a function of temperature, starting from 6K up to the approximate Curie temperature (T_c) with a 5K step, for every crystallographic direction orientations: [100], [-110] and [110] for (Ga,Mn)(Bi,As) & (Ga,Mn)As on GaAs, showing maximum T_c at the level of 105K (*Figure 3b*); [001] for (Ga,Mn)(Bi,As) on InGaAs with the highest T_c = 125K (*Figure 3a*).

MAGNETO-TRANSPORT MEASUREMENTS

Magneto-transport properties of the layers were measured in samples of Hall-bar shape supplied with Ohmic contacts to the thin layers. Using a low-frequency lock-in technique we measured four-probe longitudinal magneto-resistance (MR) and Planar Hall effect (PHE) as a function of magnetic field (T = 4 K).

Sample	Buffer – easy axis	Mn (%)	Bi (%)	d (nm)	Annealing (T_A = 180°C)	ρ (H = 0) (10^{-2} cm)
(Ga,Mn)As	in-plane ⟨100⟩	6	0	10	-	6
(Ga,Mn)As	in-plane ⟨100⟩	6	0	10	50h	0,6
(Ga,Mn)(Bi,As)	in-plane ⟨100⟩	6	1	10	-	~1000
(Ga,Mn)(Bi,As)	in-plane ⟨100⟩	6	1	10	50h	1
(Ga,Mn)(Bi,As)	in-plane ⟨100⟩	6	1	15	-	0,4
(Ga,Mn)(Bi,As)	in-plane ⟨100⟩	6	1	15	50h	0,3
(Ga,Mn)(Bi,As)	$In_{0.2}Ga_{0.8}As$ – [001]	6	1	15	-	0,8
(Ga,Mn)(Bi,As)	$In_{0.2}Ga_{0.8}As$ – [001]	6	1	15	50h	0,3


R_{xx} : 6% Mn, 1% Bi, d = 10 nm

R_{xy} : 6% Mn, 1% Bi, d = 15 nm

Figure 2 - R_{xx} and R_{xy} changes (vertical offset for clarity, Ohm/sqr) as a function of applied magnetic field (*H*, Oe), measured at different orientations for (Ga,Mn)(Bi,As) : at *T* = 4K

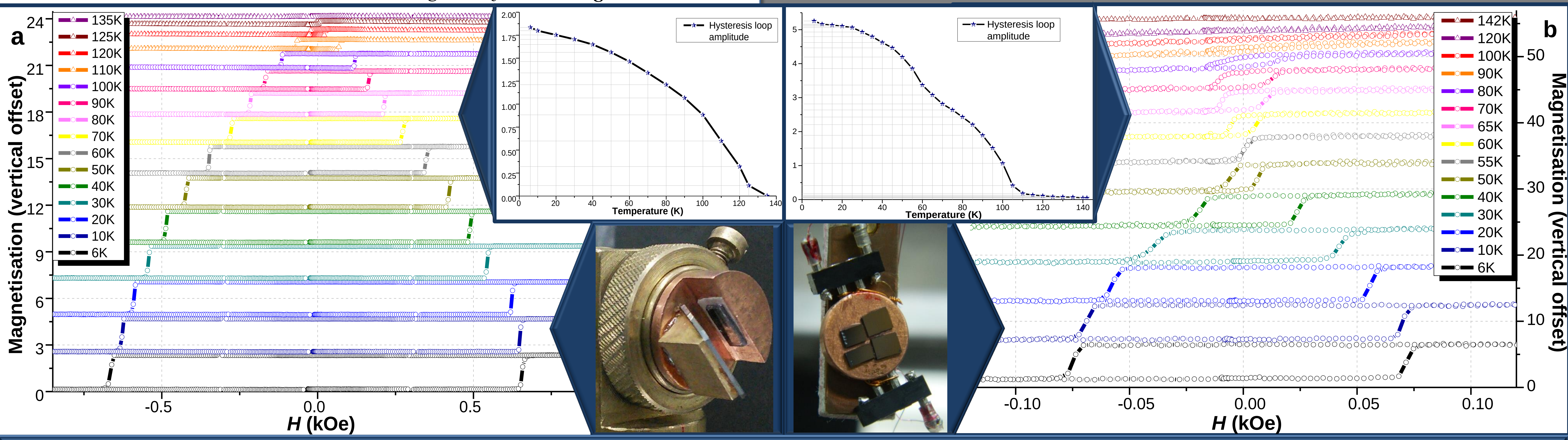


Figure 3 - Polar MOKE (a) for annealed (Ga,Mn)(Bi,As)/InGaAs & Longitudinal MOKE (b) for (Ga,Mn)(Bi,As)/GaAs 15 nm thin layers (6% Mn, 1% Bi) along [001] / [100] directions respectively.

CONCLUSIONS

- Bi incorporation into (Ga,Mn)As layers results in hole concentration decrease, which leads to the increase of the layers coercivity and T_c decrease that, however, may be enhanced by the annealing [2].
- MOKE & PHE revealed the in-plane/out-of-plane easy axis of magnetization in the films grown under compressive/tensile misfit strain respectively.
- Decrease in the lattice parameters of the (Ga,Mn)(Bi,As) layers and the increase in their T_c under the annealing treatment resulted mainly from the outdiffusion of the charge- & moment- compensating Mn interstitials, taking into account that Bi requires at least T_A = 600 °C to diffuse out of Ga(Bi,As) [3].

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