Mechanisms of strain relaxation and magnetic properties of (Ga,Mn)As layers grown on highly mismatched (In,Ga)As/GaAs(100) buffers

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(Ga,Mn)As - a prototype diluted ferromagnetic semiconductor investigated for almost two decades became a canonical material combining semiconducting and magnetic properties [1,2]. One of the basic magnetic characteristics of (Ga,Mn)As e.g. magnetic anisotropy is predominantly governed by strain inherently in-built in (Ga,Mn)As layers, which is a consequence of the method used to crystallize this material. (Ga,Mn)As can only be grown by low-temperature molecular beam epitaxy (MBE), and due to the relatively low variation (increase) of the (Ga,Mn)As ternary alloy lattice parameter with alternating Mn content usually the close-to-lattice matched GaAs substrates are used for deposition of (Ga,Mn)As. In consequence (Ga,Mn)As layers grown on GaAs are always in the compressive strain state, the reverse of the strain sign requires crystallization of the relaxed buffer layer, with lattice parameter higher than that of (Ga,Mn)As. Most often such a buffer is fabricated from (In,Ga)As ternary alloy thick enough to adopt its native lattice parameter value, i.e. with epitaxial strain released by misfit dislocations.

In order to exploit the upper strain limits in (Ga,Mn)As we have investigated the layers grown on highly mismatched (In,Ga)As buffers deposited on GaAs(100) substrates. The In composition was chosen to be in the range of 15% – 30%, in consequence the magnitude of tensile strain in subsequently deposited (Ga,Mn)As layers is varied from 0.4% up to about 2%. The epitaxial strain in (Ga,Mn)As grown on such highly mismatched buffers is relaxed for certain layer thickness via two mechanisms: (i) formation of micro-cracks for some critical value of the lattice mismatch, (ii) formation of misfit dislocations for higher mismatch. Here we focus on the first case where, in spite of the micro-cracks, (Ga,Mn)As preserves good structural and magnetic properties (see Fig.1). The (Ga,Mn)As layer with cracks shown in Fig.1 has Mn content of 6% and is 0.3 μm thick. It should be noted that (Ga,Mn)As in between the micro-cracks is fully strained to the (In,Ga)As buffer. Moreover, in the case of very thick layers (above about 1 μm) the (Ga,Mn)As stripes in between the micro-cracks separate spontaneously from the substrate. This last property enables easy fabrication of strain-free (Ga,Mn)As microstructures which can be interesting for basic studies of this compound.

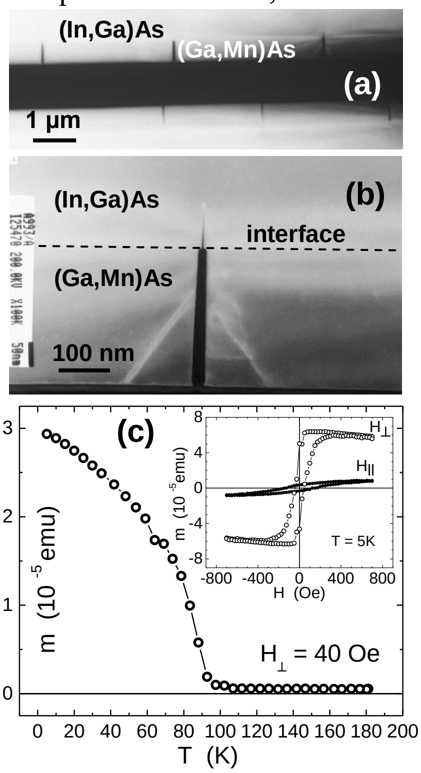

Fig. 1. *(a), (b) – cross-sectional TEM images of (Ga,Mn)As/(In,Ga)As interface with micro-cracks; (c) temperature (main panel) and field dependence (inset) of the magnetic moment of the same sample (0.3 μm thick $Ga_{0.94}Mn_{0.06}As/In_{0.20}Ga_{0.80}As$).*

[1] H. Ohno, *Science* **281**, 209 (1998).
[2] T. Dietl and H. Ohno, *Rev. Mod. Phys*. **86**, 187 (2014).