Reciprocal space and transmission electron microscopy study of heterogeneous GaP:MnP magnetic epilayers containing MnP nanoclusters

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Abstract

The integration of magnetic nanoclusters in thin III-V semiconductor films can enhance magneto-resistance and magneto-optic effects with the potential to be integrated in novel devices for room temperature applications [1-3]. The magnetic properties of heterogeneous films strongly depend on the structural properties of the clusters and film matrix, which are in turn determined by the growth conditions. We show how a three dimensional mapping of reciprocal space by X-ray diffraction combined with transmission electron microscopy measurements can determine the texture of GaP epilayers containing embedded Mn_xP nanoclusters grown on GaP substrates by metal organic vapor phase epitaxy [4-5]. This systematic approach allows identification of all phases present in the heterogeneous films, in particular showing traces of hexagonal Mn_2P precipitates, whose formation can be avoided by lowering the film growth temperature. Growth at 650 °C produces mostly orthorhombic MnP nanoclusters, responsible for the magnetic properties, which are oriented along specific GaP crystallographic directions, forming six well defined families. The population of these families can be quantified and is influenced by the growth temperature and the film thickness. The MnP clusters principally grow on GaP(001) and GaP{111} facets with a small fraction of clusters nucleating on higher-index GaP{hhl} facets. Most epitaxial alignments share a similar component: the MnP(001) plane (c-axis plane) is parallel to the GaP{110} plane family. Axiotaxial ordering between the MnP clusters and the GaP matrix has also been observed [5].

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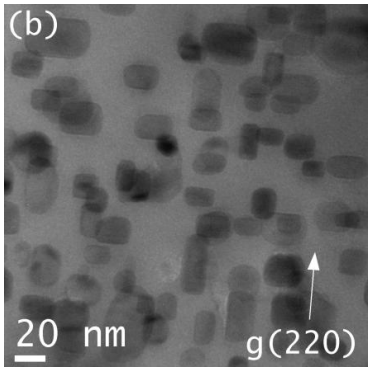
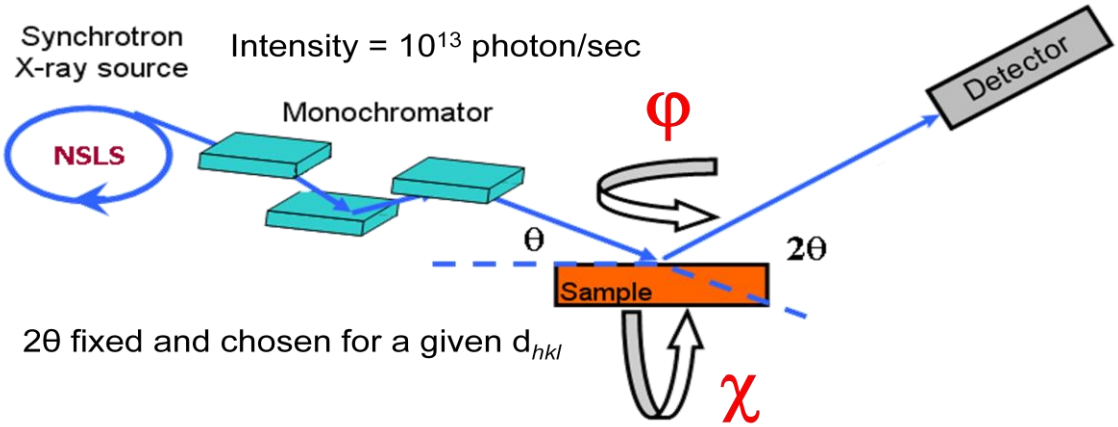


Fig. 1: The TEM image on the left shows a plan view of a heterogeneous GaP:MnP epilayer containing MnP nanoclusters grown at a substrate temperature of 650°C [ref. 4]. The heterogeneous films are grown on semi-insulating GaP(001) substrates in a low-pressure cold-wall MOVPE reactor, using trimethylgallium, tertiary-butylphosphine, and methyl cyclopentadienyl manganese tricarbonyl as precursors for Ga, P and Mn respectively, and Pd-purified hydrogen as the carrier gas. The reactor pressure was set at 40 Torr with a total flow rate maintained at 4000 sccm. Growth rate is 1.2 µm/ h for GaP(001) at a growth temperature of 650°C

Reciprocal space measurements: were carried out at the National Synchrotron Light Source (NSLS) (Brookhaven National Laboratory) X20A and X6B beam lines. The figure below illustrates the large photon flux provided by the synchrotron source, a key feature to obtain a full 3D reciprocal space map which will allow texture determination.



Texture and phase quantification: is obtained from X-ray diffraction (a set of more than 600 pole figures, as the example illustrated below) combined with transmission electron microscopy (TEM) analysis