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TEM Characterization of Thin, Epitactic Ni_2MnGa films on GaAs.

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Spintronics is a concept based on the intimate interaction between magnetics and semiconductors that is being applied to the fabrication of advanced devices. Advances in this field require an understanding of three principal components: a suitable spin injector material, the detection of electron spin once it has been injected into a semiconductor, and the fundamental limitations on spin transport across interfaces.

Several materials have been proposed for the spin injector layer, which is required to be a high quality single crystal ferromagnet with a Curie Temperature greater than ~300K for room-temperature operation of a device. Most choices of ferromagnetic metals have large lattice mismatches with any semiconductor substrate, resulting in a defect-rich interface. Recently we have reported the MBE growth of the ferromagnetic Heusler Alloy Ni_2MnGa on GaAs [1]. This alloy has a 3% lattice mismatch with the substrate, and can be grown pseudomorphically with respect to the substrate using suitable intermediate layers. It exhibits a number of different polymorphs depending on the temperature and stress of the alloy. At high temperature the structure is the cubic $L2_1$ ordered structure. At low temperature it undergoes a martensitic phase transformation to either a non-modulated $L1_0$ structure or one of several modulated variants [2]. In order to determine the suitability of the structure for spintronic device fabrication the magnetic and structural properties have been determined by a number of techniques.

Samples of the thin Ni_2MnGa films on GaAs substrates were prepared for TEM by traditional dimpling and ion-milling techniques in both cross-section and plan-view geometries. The plan-view samples were back-thinned to remove the substrate material, leaving the epilayer film able to relax without the constraint of the substrate.

Images obtained from the plan-view samples show that the microstructure is evidently not one of a continuous single crystal. In Fig 1 it can be seen that there are several domains present, (these are elongated in shape 100-200 nm wide and ~1μm in length) and within these domains twin-bands are observed . The twins are irregularly spaced down to the 5 nm scale. The diffraction pattern from the central twinned domain is shown in figure 4. Dark-field images from this region are shown in figures 2 and 3, corresponding to the reflections indicated in figure 4. It can be seen that the minor component of the twins in the central domain is strongly present in the bottom domain. The diffraction pattern from this domain is shown in figure 5, and is indexed in terms of the “double” $L1_0$ lattice according to Pons et. al. [2]. Using this indexing scheme, the close packed planes in the structure are {111} planes, and it is apparent that both the twin boundaries and the domain boundaries are edge-on in this orientation, and parallel to {111}. In none of the domains observed here were any additional diffraction spots observed that could not be accounted for by twinning, indicating that this is a non-modulated martensite. This observation is borne out by the fact that the structure remained in this state to well above 400C whereas the modulated martensite structures would have transformed to the parent cubic structure below that temperature.

The structures of the relaxed epilayer film are consistent with those described in bulk Ni_2MnGa [2], although our TEM and XRD measurements show that the film is strained in order to be lattice matched to the substrate. The strain relief may be the reason that the crack in the epilayer visible in figure 1 has occurred. The crack edges appear to follow the {220} planes in the differently oriented domains.

The presence of these defects in the released and unreleased epilayer, and the quality of the semiconductor-ferromagnetic interface will be discussed. [3]

References
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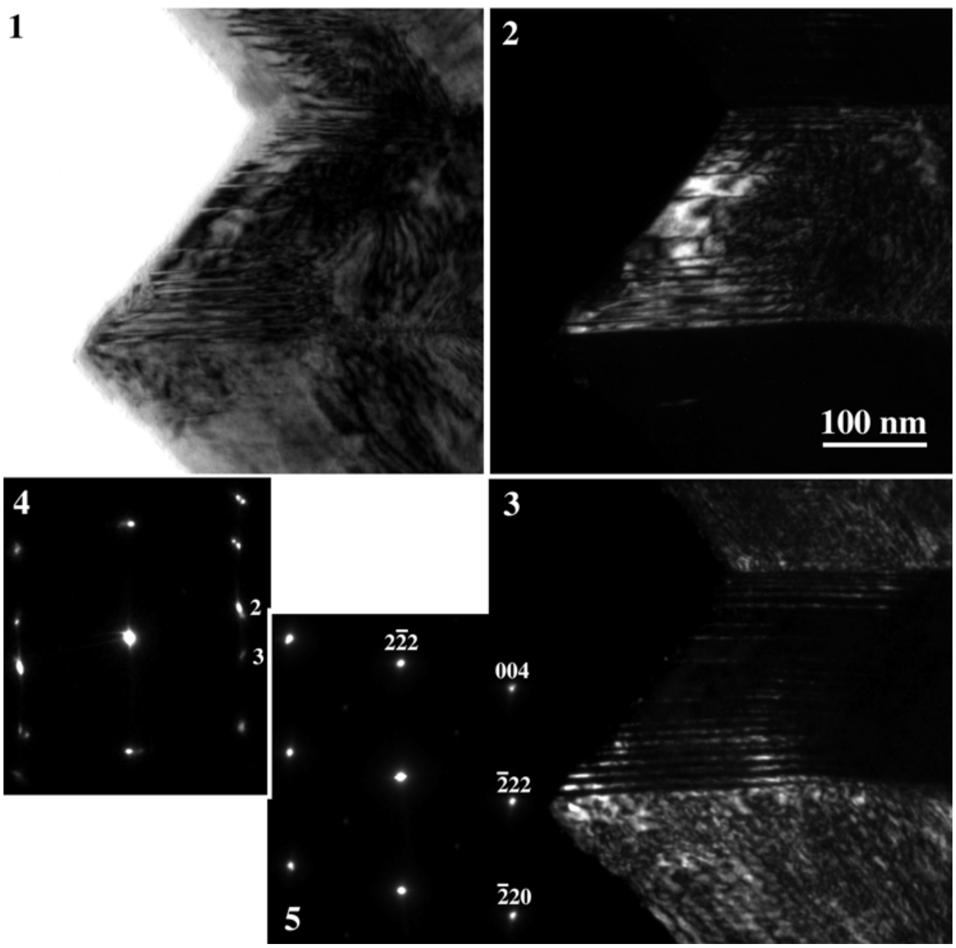

FIG 1. Bright-field image of Ni_2MnGa after back-thinning of the GaAs Substrate.
FIG 2 and 3. Dark field images of the region shown in fig 1 using the reflections indicated in fig 4.
FIG 4. Diffraction pattern of central domain in fig 1.
FIG 5. Diffraction pattern of lower domain in fig 1 indexed as a “double” $L1_0$ lattice

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