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Defect analysis of NiMnSb epitaxial layers

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Abstract

NiMnSb layers grown on InP substrates with InGaAs buffer were studied by the backscattering/channeling spectrometry (RBS/C) with He beams. The nature of predominant defects observed in the layers was studied by determination of incident-energy dependence of the relative channeling yield. The defects are described as a combination of large amount of interstitial atoms and of stacking faults or grain boundaries. The presence of grains was confirmed by transmission electron microscopy.

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Keywords: Spintronics; Half-metals; Molecular beam epitaxy; Ion channeling; Structural defects

1. Introduction

NiMnSb, a ferromagnetic half-metal, crystallizes in the cubic half-Heusler structure. It exhibits high Curie temperature of 760 K. According to theoretical calculations [1,2] at the Fermi level the bands for one spin direction overlap resulting in metallic behavior while for the opposite spin direction there is a finite energy band gap. In result, at the Fermi level electrons are spin polarized making NiMnSb an attractive candidate for spin injectors, spin aligners and spin filters in spintronic devices [3].

The spin polarization of conducting electrons can be, however, significantly lowered due to imperfections of the crystal lattice of NiMnSb.

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Thus a crucial issue for application is the understanding of the nature of the defects present in NiMnSb crystals. In this paper, basing on backscattering/channeling (RBS/C) and transmission electron microscopy (TEM) data we attempt to describe the lattice imperfections of the NiMnSb layers grown on a semiinsulating InP substrate with a $In_{0.53}Ga_{0.47}As$ buffer [4,5]. Magnetic properties of such layers were recently studied [6]. Growing NiMnSb on top of semiconductor structures is considered to be a technique for preparation new epitaxial tunnel magnetoresistive elements.

2. Experimental

Heusler-alloy samples prepared by molecular beam epitaxy technique at Würzburg University were studied with Rutherford backscattering in channeling geometry (RBS/C). Transmission electron microscopy (TEM) at FZR Rossendorf was applied as a complementary technique. The NiMnSb layers were grown on the InP substrate with $In_xGa_{1-x}As$ buffer ($x = 0.53$). Thickness of the NiMnSb layers was in the 30–60 nm range, while that of the buffer were close to 300 nm. Other details of the preparation are described in [4].

Ion backscattering studies of the NiMnSb/InGaAs/InP structures were performed with Van de Graaff accelerator *Lech* at SINS Warsaw, and tandem accelerator *Aramis* at CSNSM Orsay. Helium beams with energies $E_0 = 0.8$, 1.4, 2.0, 2.6, and 3.2 MeV were applied. Energy resolutions of measurements were 13–17 keV. All channeling spectra were measured with the beam aligned to [0 0 1] axis perpendicular to the sample surfaces. Random spectra were measured by rotation of the samples with tilt angle of 4°.

3. Results

A random spectrum for $E_0 = 3.2$ MeV is shown in Fig. 1. Major portion of the spectrum originate from backscattering on In atoms. The signals of As, Ga, Ni, and Mn form a large bump seen in the 2100–2550 keV energy region, while the P edge is located at 1520 keV. Sb atoms contained in the surface layer forms a separated peak over the In edge.

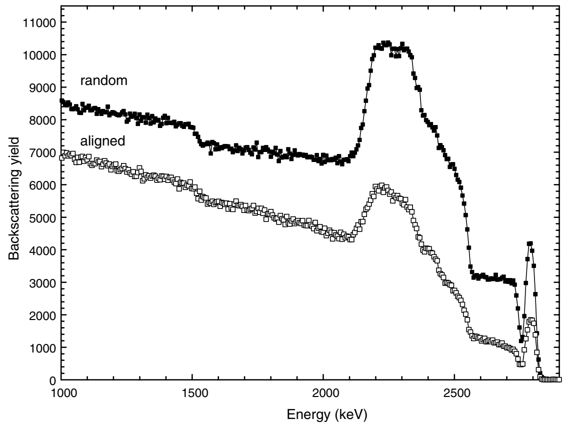

Fig. 1. Backscattering spectra of NiMnSb/InGaAs/InP sample for random and axial geometry obtained with 3.2 MeV He ions.

Axial-channeling spectra (Fig. 1) measured for several samples demonstrated bad channeling properties independently of the buffer thickness. The relative channeling yield χ_{Sb} of backscattering on Sb varied between 21% and 44% of the random yield (including the surface peak), and similar values were determined basing for a window corresponding to the In signal of the InGaAs layer (Fig. 2). The planar channeling was also strongly disturbed: 1 0 0-type planar dips were noticeable but shallow. Analysis of axial-channeling spectra

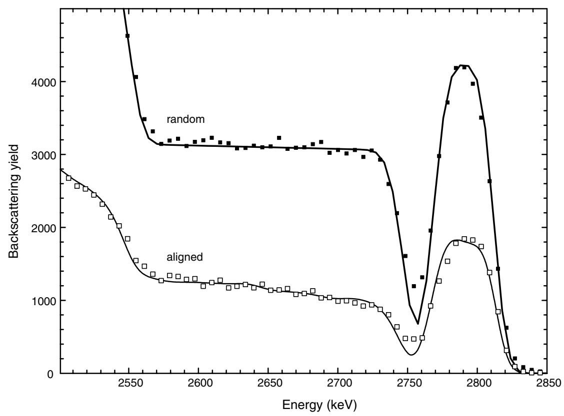

Fig. 2. High-energy portion of the backscattering spectra shown in Fig. 1 (symbols) compared with the results of Monte Carlo simulations (lines).