Magnetic properties and spin polarization of Co_2MnSi Heusler alloy thin films epitaxially grown on GaAs(001)

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Conceptually new devices taking advantage of the spin degree of freedom promise increased data processing speed, decreased power consumption and non-volatility. The emerging field of spintronics combines small scale magnetic elements with conventional semiconductor electronics. These new devices require magnetic elements as sources of highly spin-polarized current operating with small magnetic fields at environmental temperatures.

Half-metallic ferromagnets have been proposed as ideal candidates for efficient spin injection because they have been predicted to exhibit 100 % spin polarization at the Fermi level. They have crystal structures and lattice parameters similar to many semiconductors, and thus could be easily epitaxially grown on top of them. Recently, the full Heusler alloy Co_2MnSi has attracted interest because it is predicted to have a large minority spin band gap of 0.4 eV and reaches the highest Curie temperatures of 985 K among the known full and half Heusler alloys [1].

The aim of our work was to grow perfect single-crystalline Co_2MnSi thin films on GaAs(001) and to study their spin polarization. Our films were grown by pulsed laser deposition (PLD) from stoichiometric polycrystalline Co_2MnSi pellet targets. The best crystalline quality of the films was achieved at a substrate temperature of 450 K. The observation of in situ reflection high-energy electron diffraction (RHEED) intensity oscillations was characteristic of a layer-by-layer growth mode. Actually, the RHEED oscillation period corresponds to half of the unit cell of Co_2MnSi, i.e. to the thickness of two atomic layers (bilayer) which is necessary to satisfy the chemical composition and electrical neutrality of the growing film.

The magnetic properties were probed in situ by magneto-optical Kerr effect (MOKE) measurements. At 70 K, a significant Kerr signal in remanence is first detected for a Co_2MnSi thickness of 4 bilayers indicating the onset of ferromagnetic order. An in-plane uniaxial magnetic anisotropy with the easy axis parallel to the [1-10] direction appears at the same thickness.

Immediately after deposition, the Co_2MnSi/GaAs(001) samples grown in Halle were transported under UHV conditions to BESSY, where spin-resolved photoemission and x-ray magnetic circular dichroism (XMCD) measurements were carried out at the UE56/2-PGM2 beam line [2], [3].

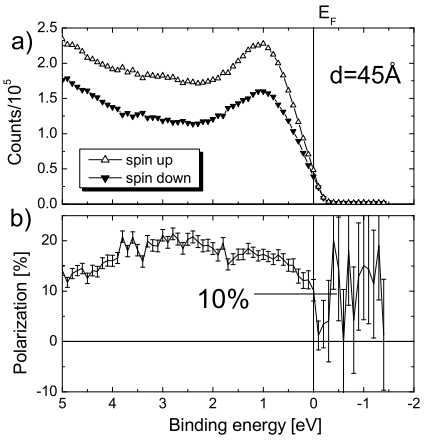

Fig. 1: Spin-resolved photoemission spectra (a) and spin polarization (b) of the 45 Åthick Co_2MnSi film detected at 70 eV photon energy. Filled (open) triangles denote majority- (minority-) spin spectra.

Spin resolved photoemission spectra were taken for excitation with 70 eV photon energy. Fig. 1 shows the representative spin-resolved valence band photoemission spectrum measured at room temperature and corresponding spin polarization for a 45 Å(16 bilayers) thick Co_2MnSi film. The spectrum shows the

majority-spin signal of higher overall intensity than the minority one. A broad peak at 0.9 eV is suggestive of a mixture of metallic-like Co and Mn components. We define the spin polarization as the difference between the intensity spectra for majority and minority spins, normalized to the total intensity. One can see that at room temperature the spin polarization at the Fermi energy for the 45 Åthick Co_2MnSi film is 10 % only.

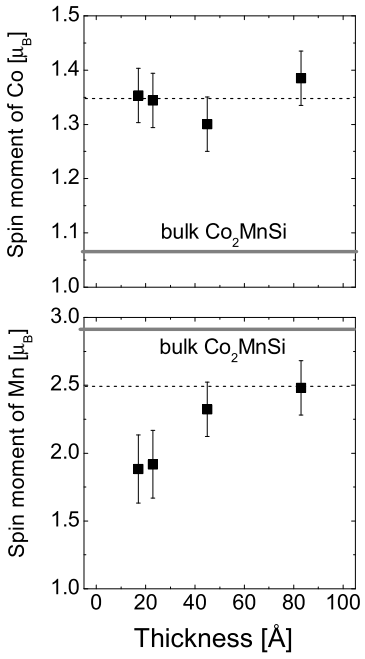

Fig. 2: The magnetic spin moments of Co and Mn, extrapolated to 0 K, plotted vs. film thickness together with theoretical values calculated for bulk Co_2MnSi (grey lines [4]). Dotted lines suggest the spin moment values measured without "thin film effects".

Spin polarization at the Fermi level is related to the magnetic moments of Co and Mn. Since atomic disorder is suggested as a mechanism to reduce spin polarization, this should also have an influence on Co and Mn magnetic moments. Thus, we have studied the magnetic properties of Co_2MnSi films by XMCD. Absorption spectra were recorded at room temperature by directly detecting the sample current while scanning the photon energy of the 80 % circularly polarized light. Clear dichroic signals (defined as the normalized difference in absorption between right and left polarized light) were obtained at the edge of Co and Mn, corresponding to a significant magnetic moment on the Co and Mn atoms, respectively. The values of the spin moment of Co and Mn atoms obtained after extrapolation to 0 K for the Co_2MnSi films of varying thickness are plotted in Fig. 2 together with theoretical predictions for bulk Co_2MnSi alloy [4] ($1.06\mu_B$ for Co and $2.92\mu_B$ for Mn, and a total magnetic moment of $5.0\mu_B$ per formula unit). The spin moment of Co we found in our films ($1.35\mu_B$) is almost 30 % larger than that predicted for Co_2MnSi in the bulk form. By contrast, the spin moment of Mn we found experimentally ($2.5\mu_B$) is 15 % smaller than what is predicted by theory.

There is a plausible explanation of diminishing spin polarization and changed magnetic moments which relates to the local atomic disorder in the films. The band theory applied for several Heusler alloys predicts that the conduction gap at E_F in the minority spin states can be closed if some disorder is introduced into the crystal lattice. It is also found [4] that in any case disorder results in an increased spin moment of Co atoms occupying Mn sites. On the other hand, Mn atoms which occupy Co sites are coupled antiferromagnetically to the Mn atoms sitting in their normal positions, which results in a strongly reduced average moment of Mn.

References

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