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Spin polarization and interlayer coupling in Fe/FeAl/Fe sandwiches

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Abstract

Epitaxial FeAl superlattices were used as nonmagnetic spacers in MgO(0 0 1)Fe/FeAl/Fe trilayers. The magnetic hyperfine field at the nuclei of a ^{57}Fe probe layer, situated in the center of the FeAl spacers, being a measure of the spin polarization from the ferromagnetic Fe layers, was investigated as a function of the total spacer thickness d. A decaying oscillatory dependence of the polarization effect vs. d was found. Magnetization measurements revealed the existence of a temperature dependent 90° coupling. Finally, the correlation of the spin polarization and coupling behavior was clearly identified.

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Keywords: Interlayer coupling; Cems; Spin polarization; Feal ordered alloy; Epitaxy

The interlayer exchange coupling (IEC) is one of the most important phenomena observed in metallic multilayers composed of ferromagnetic (FM) films separated by nonmagnetic (NM) spacers. The magnetic interaction between FM layers in the stack is mediated via spin polarization of the conduction electrons in the NM spacers [1]. Usually, the IEC studies relay on the analysis of macroscopic magnetic properties of the whole system such as magnetization curve measurements. The experiments probing the spacer magnetism are rare [2]. Moreover, a direct experimental confirmation of the correlation between the coupling character and the spacer spin polarization is still missing.

FeAl monoatomic superlattices, composed of alternating pure Fe and Al atomic layers, forming the B2-FeAl ordered alloy were used as NM spacers in the epitaxial MgO(1 0 0)/FeI/$(\mathrm{Fe_1Al_1})_n$/FeII/Al samples. The details of the sample preparation and characterization can be found in Ref [3]. The thickness of the FeI and FeII layers (made up of ^{56}Fe) was 20 and 5 nm, respectively. The number n of double layers in the spacer varied from 3 to 13, corresponding to the spacer thickness variation between 0.9 and 3.8 nm. In the center of each spacer (containing otherwise ^{56}Fe), two or three ^{57}Fe monolayers, for even and odd n, respectively, were situated during the deposition, forming the Mössbauer probe. In such a way the Conversion Electron Mössbauer Spectroscopy (CEMS) analysis, using the ^{57}Fe probe layer concept could be applied to a chemically homogenous spacer, avoiding structure modifications caused by foreign probe atoms in the spacer structure. The room temperature Mössbauer spectra showed a clear dependence on the spacer thickness [3]. The fitted average hyperfine magnetic field $\langle B_{\mathrm{hf}} \rangle$, which can be taken as a measure of the spin polarization in the center of the spacer [3], is shown as a function of n in Fig. 1. Several oscillations can be clearly identified in agreement with the RKKY theory.

Magnetization curves were measured by MOKE and VSM in a broad temperature range. The rectangular RT MOKE loops indicated the presence of a strong FM coupling between FeI and FeII films for all spacers.

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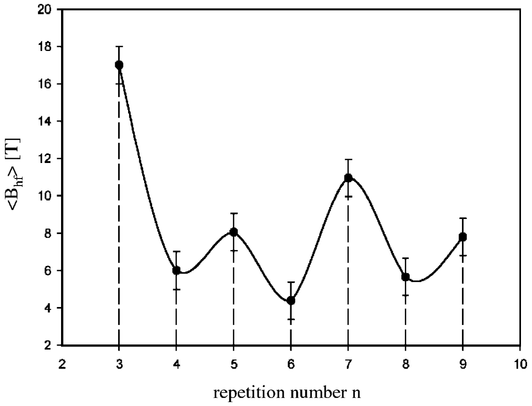

Fig. 1. Average hyperfine magnetic field $\langle B_{\mathrm{hf}} \rangle$ derived from CEMS spectra as a function of n.

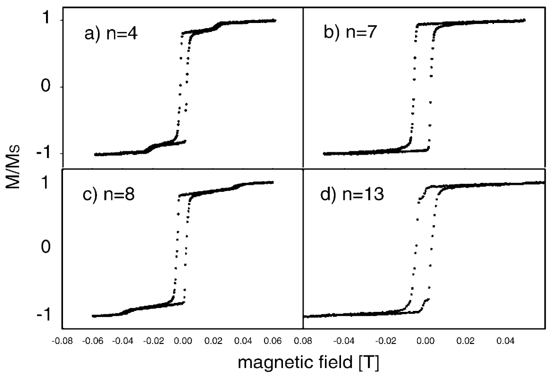

Fig. 2. Comparison of VSM magnetization curves measured at 4.5 K for $\mathrm{FeI/(Fe_1Al_1)_n/FeII}$ trilayers for: (a,c) $n=4,8$, biquadratic coupling; (b) $n=7$, FM coupling; (d) $n=13$ uncoupled system.

We attribute this behavior to iron magnetic moments existing in the spacer due to point defects typical for the B2 FeAl structure. The defect concentration as low as 5% (a typical value for our FeAl alloys [3]) gives about 30% of Fe atoms carrying the magnetic moment [4].

At 4.5 K the in-plane easy axis VSM hysteresis loops showed a different behavior indicating 90° coupling for $n=4,6,8,9$ and FM coupling for $n=3,5,7$. For thicker spacers ($n=11,13$), the measured loops prove the FeI and FeII films to be uncoupled. The comparison of VSM loops for FM, 90° and uncoupled FeI and FeII layers is shown in Fig. 2. Additionally, a strong temperature dependence of the 90° coupling was found (Fig. 3). This result cannot be explained by any of the known mechanisms responsible for the biquadratic interlayer interaction such as the loose spin or interface roughness models [5]. Consequently, we interpret the observed behavior as a superposition of strong direct ferro-magnetic coupling, mediated by the spacer magnetic moments caused by the defects and the indirect IEC. The latter oscillates with the spacer thickness n between the FM and antiferromagnetic type explaining the low temperature magnetization loops. At higher temperatures the antiferromagnetic interaction is not strong enough to compete with the direct FM one, resulting in square hysteresis loops.

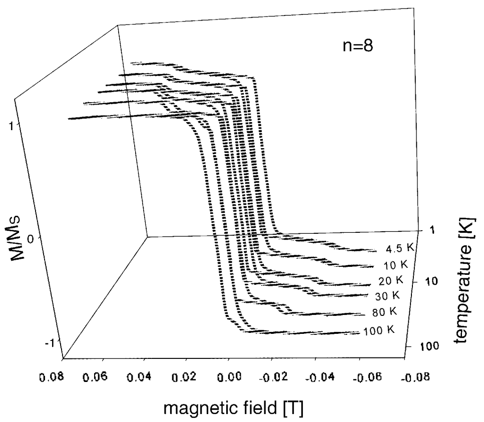

Fig. 3. VSM magnetization curves measured as a function of temperature, for $\mathrm{FeI/(Fe_1Al_1)\times 7/FeII}$ trilayers with $n=8$.

The 90° coupling at low temperatures was found for the n values, for which the minima of the $\langle B_{\mathrm{hf}} \rangle$ values were deduced from the room temperature CEMS spectra, giving evidence of the correlation between the oscillatory character of the coupling and the spacer spin polarization. It is worth to note that the coupling oscillations detected in the spacer are observed when the interactions are too weak to affect the orientation of the sublayers magnetization.

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