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Observation of the domain structure in Fe–Au superlattices with perpendicular anisotropy

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Abstract

Polar Kerr Microscopy was used to visualize characteristic transitions and external magnetic field driven domain structure evolution in a perpendicularly magnetized Fe–Au AF/FM double multilayer structure. Real time imaging performed in the external magnetic field allowed for identification of all sublayers magnetization reversal in accordance with measured PMOKE magnetization curve, showing strong dependence of transition character on the interlayer coupling type and adjacent sublayers magnetization orientation.

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Exchange bias is an effect caused by interfacial exchange interaction between an antiferromagnet (AF) and a ferromagnet (F). While it has been observed in a variety of AF/F thin films systems, in most cases the ferromagnetic layers are spontaneously in-plane magnetized. There are only a few experiments known [1] in which the ferromagnet with perpendicular magnetic anisotropy is biased by the underlying antiferromagnetic structure. As building blocks of our magnetic system we used epitaxial $(Fe_1Au_1) \times 3$ monoatomic superlattices blocks with perpendicular anisotropy, which were separated by Au spacers [2]. The thickness of the Au spacers was tuned to obtain the antiferromagnetic interaction of A–D layers and a weak ferromagnetic one between D and E layers as shown in Fig. 1. The polar MOKE hysteresis loop (Fig. 2) shows several transitions related to the magnetization reversal that are depicted by the arrows in Fig. 1. The sequence of the magnetization reversals was established taking into account that the outermost sub-layers are coupled to only one other sublayer, and that the reversal of deeper layers results in a smaller change of the Kerr intensity signal, as described in details elsewhere [2]. Following the magnetization curve from the negative to positive saturation, first magnetic moment of the C sublayer reverses due to the AF interaction with adjacent D and B sublayers (transition from the state labeled "0" to "1"). The A sublayer that is AF coupled only to the B sublayer, reverses at a lower field (transition from "1" to "2") and thus the remanent state is established in which A–D sublayers are aligned antiferromagnetically and the net magnetization is determined by E sublayer that has the memory of saturating field direction and is ferromagnetically ordered with the D sublayer. Only a small positive field is required to reverse the magnetization of E sublayer (transition $2 \rightarrow 3$) because its ferromagnetic coupling to D sublayer is relatively weak.

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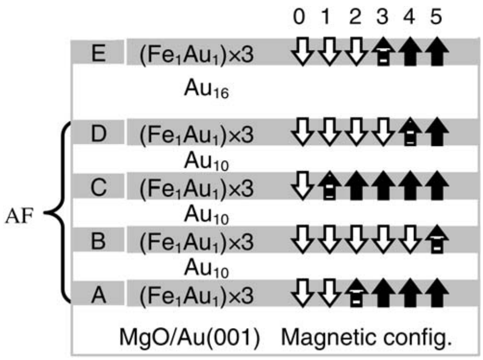

Fig. 1. Sample structure and magnetization reversals induced by field changes. Patterned arrows indicate the last reversed sublayer. Numbers correspond to plateaus in hysteresis loop (comp. Fig. 2).

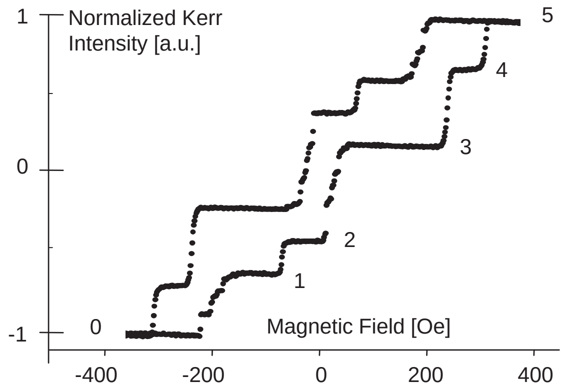

Fig. 2. Polar MOKE hysteresis loop with numbered plateaus.

The three reversal processes described above are characterized by the transition from a ferromagnetic alignment to an antiferromagnetic one between the adjacent sublayers. We also note that transition $2\rightarrow3$ could involve the spin flip in the antiferromagnetic A–D stack, but for the sake of simplicity we will not consider this possibility. The following transitions induced by a positive magnetic field ($3\rightarrow4$ and $4\rightarrow5$) are connected with magnetization reversals of D and B sublayers, respectively, which change the orientation with respect to the adjacent sublayers from antiferromagnetic to ferromagnetic. The stepwise character of the hysteresis loop means that between the transitions the multilayer is in a single domain state. With the Kerr microscopy [3] we were able to follow the evolution of the domain structure responsible for the transitions. The magnetic field along the normal was changed from -320 to 320 Oe in 150 steps and a series of images was collected for each field value. Characteristic domain patterns in the

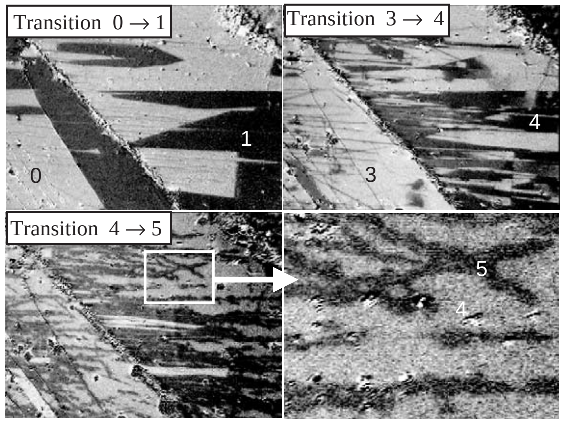

Fig. 3. Magnetic domain images for chosen magnetization reversals. Numbers indicate the areas with the magnetization state corresponding to the plateaus on the PMOKE loop (Fig. 2). Images size is 256 μm × 192 μm.

transitions are shown in Fig. 3. To better visualize the domain structure a relative gray scale is used. Two striking features of the domain structure are to be noted as a preliminary result: (i) The transitions are strongly diversified. When going from the ferromagnetic to antiferromagnetic configuration ($0\rightarrow1$, $1\rightarrow2$, $2\rightarrow3$), the reversal takes place predominantly via the domain wall motion over large areas limited by the macroscopic substrate defects (cleavage steps of the MgO substrate). During the reversal process from an antiferromagnetic to a ferromagnetic configuration ($3\rightarrow4$, $4\rightarrow5$) we observed an entirely different domain pattern, suggesting the domination of nucleation over wall propagation. (ii) The domain patterns confirms that the reversal processes in different sublayers are independent, despite interlayer coupling, which is, however, weak as compared to magnetostatic energies. This behavior opens a unique possibility to switch individual sublayers in a coupled multilayer system.

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