Abstract

Ferromagnetic (FM) thin films are considered as a founding stone of present day magnetism research due to their applicability in advanced magnetic data storage devices, sensors and newly emerged field of spintronics. FM ultrathin films adjacent to heavy metal (HM) buffer/capping layers can generate a number of interesting phenomenon such as : (i) antisymmetric exchange interaction i.e. interfacial Dzyaloshinskii-Moriya interaction (IDMI); (ii) existence of out of plane magnetization state - perpendicular magnetic anisotropy (PMA); (iii) a considerable amount of change in spin wave (SW) damping factor or morphology of magnetic domain structures.

The topic of the doctoral dissertation is the static and dynamic magnetic properties of ultra-thin layers and multilayers characterized by the presence of the IDMI effect. We have focused our attention on ultrathin FM films of Co and CoFeB surrounded by the HM layers of Ir, Pt, Au, Re and Ta, respectively. Samples were deposited by DC magnetron sputtering and molecular beam epitaxy (MBE) techniques. The magnetization processes and domain structures have been studied using magneto-optical Kerr effect (MOKE) magnetometry and microscopy, magnetic force microscopy (MFM), vibrating sample magnetometry (VSM). Characterization of the magnetization dynamics of the samples was performed using Brillouin Light scattering (BLS), X-band ferromagnetic resonance (FMR) and vector network analyzer FMR (VNA-FMR) spectroscopies.

Single Co layers properties are analyzed in the first part of the manuscript. The influence of HM layers on properties of wedge Co layers (with Pt, Ir and Au neighboring layers) deposited by sputtering technique is discussed. The Co thickness d_{Co} driven changes of IDMI strength, magnitude of magnetic anisotropy, coercive field and spin wave (SW) magnetic damping are determined. Large IDMI magnitude for Ir/Co/Pt system in comparison to the inverse stack ordering Pt/Co/Ir is observed, while IDMI strength of Au/Co/Pt and Pt/Co/Au is comparable. Damping parameter characterized by the linewidth of BLS spectra shows an asymmetry for ultrathin Co region.

FM layers of Co with Re (characterized by different Re thickness d_{Re} of buffer and overlayer) and Pt i.e. Pt/Re(d_{Re})/Co(d_{Co})/Pt and Pt/Co(d_{Co})/Re(d_{Re})/Pt were deposited by MBE technique. The dependence of the uniaxial magnetic anisotropy field as a function of d_{Co} for a constant Re thickness indicates that the presence of Re reduces Co thickness of the spin reorientation transition (SRT). Amplitude of these changes depends on the position of Re in buffer layer or in overlayer. For the d_{Co} constant, the dependence of the magnetic anisotropy on the thickness d_{Re} at the beginning sharply decreases and slight increases for a larger d_{Re}. An opposite sign of IDMI is found by interchange of Re as buffer or capping layer. Damping parameter (determined from BLS studies) decreases or increases while introducing Re in buffer or overlayer, respectively. Strong changes in the magnetic properties of cobalt took place when introducing Re layers with a thickness already below one nanometer.

Two sets of cobalt multilayers, deposited by DC magnetron sputtering, were analyzed. First set are the asymmetric multilayers (Ir/Co/Pt))$_N$ with the number of repetitions N=6. Domain images, obtained by MFM and MOKE, studies shows existence of : (i) 100 nanometer wide strip domains, domains differing in the perpendicular magnetization component and (ii)

large (few tens micrometer size) domains with in plane magnetization. Micro-magnetic simulation allowed to describe the spatial magnetization distribution sub-micrometer vortexes with cores oriented in sample plane. These simulations well describe: (i) experimentally determined stripe domain period and (ii) magnetization curves measured as a function of magnetic field applied in-plane or perpendicular to sample. The Stokes and anti-Stokes frequencies from BLS spectroscopy demonstrate hysteresis - switchable behavior while sweeping in-plane applied magnetic field. The switching field value coincides with in-plane coercivity field in which the domains switches with the magnetization component in the plane t (in the magnetization cores) directed opposite to the field direction. A hysteresis was also observed, as a function of the applied field in the plane, of the difference Δf of the Stokes and anti-Stokes frequencies.

In the second set of multilayers, symmetric multilayers (unlike asymmetric ones from previous set) of $[Co/Pt]_{N=24}$ and Co thickness of 2.2 nm are also deposited by the sputtering. Hysteresis of signal measured, as a function of in-plane applied field, by FMR and VNA-FMR is found. It is correlated with in-plane magnetization curve. This hysteresis can be explained by the switching of in plane 'core' magnetization. The large asymmetry in SWs propagation corresponding to Stokes and anti-Stokes frequencies is found. It could be explained by a possible IDMI contribution coming from the structural difference of bottom Pt/Co and top Co/Pt interface. A rich SW spectra was observed in the BLS studies. SW spectra at zero field depends on stripe domain orientation in relation to light incidence plane. So our multilayer could be treated as reconfigurable magnonic crystal with a hysteresis property.

In Ta/CoFeB/MgO stacks, magnetization reversal processes and magnetic domain structures are explored. Imaging of magnetic domain structures is performed for samples with out of plane easy magnetization axis. A major increase in domain nucleation density together with domain pattern evolution is noticed on approaching towards SRT thickness. Existence of narrow stripe domains (NSDs) is found. The potential of such NSDs as spin wave waveguides with sub-micrometer width could be promising. Measurements with the BLS spectrometer showed that the analyzed samples were characterized by a very low IDMI strength – in the range of experimental error.

Overall, the influence of HM layers on the magnitude and sign of the IDMI, magnetic anisotropy and other parameters in magnetic ultra-thin layers and multilayers was analyzed. Our findings can be applicable in creation of new nanostructures with properties controlled by the interfaces of the magnetic layer.