Magnetic properties of asymmetric layered heavy metal / ferromagnet systems

Abstract

Multilayerd thin-film structures are a relatively new group of artificial systems with significantly different properties than those of the component materials in the bulk form. Among them, magnetic materials focus an important attention in basic research and practical applications. Their key feature is dimensional confinement in the direction perpendicular to the layer plane. In such systems, the atoms forming the interface are in a large proportion to the entire layered structure. Their different surroundings cause that they show different properties compared to the atoms with homogeneous coordination inside the layer. Thus, in thin-film structures, interface effects play a clearly noticeable role. In the case of magnetic layers, for example, they significantly modify the perpendicular magnetic anisotropy (PMA) - one of the most important parameters. Another factor modifying the properties is the thickness of the component layers, e.g. the non-magnetic layer separating the magnetic layers. If their thickness is smaller than certain characteristic lengths, such as electron mean free path or spin diffusion length, additional effects of interlayer coupling appear. The selection of appropriate materials for the component layers and their thickness enable intentional modification of the properties of multilayer systems in a wide range.

This doctoral dissertation presents the results of research on asymmetric W/Co/Pt thin-film structures. In addition to the effects mentioned above, the asymmetric surrounding of the ferromagnetic (Co) layer with layers made of heavy metals (W and Pt), which are characterized by a strong spin-orbit coupling, additionally induces the Dzyaloshinskii-Moriya interaction (DMI). This interaction significantly modifies the spin structure of the magnetic layer systems, leading to the occurrence of, for example, spin spirals or skyrmions - topologically protected stable magnetization vortices. The investigated systems were produced using the molecular beam epitaxy technique. It provides a well-defined crystal structure of the component layers and high-quality interfaces that are crucial for the observed phenomena. A more perfect crystal structure enhances the observed effects compared to the similar layers commonly produced by sputtering.

The investigations were carried out in the systems with an increasing degree of complexity: from structures containing a single Co layer (Chapter 4), through structures with two or more (6 or 7) Co layers (Chapter 5), to multilayers with a 20-fold repetition of the basic W/Co/Pt trilayers (Chapter 6). With the increase in the aforementioned complexity, new interactions (magnetic coupling, magnetostatic interaction) appear, which additionally affect the magnetic properties. Such an approach allows for a deeper understanding of the impact of individual interactions on the resulting properties of the studied systems, which are manifested in their magnetic configurations, magnetization reversal processes, or domain structure. Experimental results were obtained using various experimental techniques, such as: SQUID magnetometry, magnetometry using the polar Kerr effect (PMOKE), magnetic force microscopy (MFM) or inelastic light scattering spectroscopy (BLS). Some of the samples were made in the matrix configuration – the component layers were made in the form of wedges or steps with mutually orthogonal thickness gradients. Such a structure of the multilayers, combined with local sampling of properties, enabled effective determination of their dependence as a function of the thickness of the component layers. Interpretation of experimental results was supported by numerical modelling involving micromagnetic simulations and calculations based on density functional theory (DFT). The described magnetic structures, taking the form of bubble domains (skyrmions) or strip systems, are not only the subject of fundamental research, but also arouse interest in the context of practical applications (e.g. as magnonic crystals or magnetic recording carriers).

In addition to the chapters describing the obtained experimental results, this doctoral dissertation includes a short introduction (Chapter 1), a theoretical approach to the investigated phenomena (Chapter 2) and a brief description of the applied sample production technologies and research techniques (Chapter 3). The dissertation ends with conclusions and a summary of the obtained results.

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