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ABSTRACT

The presented dissertation concerns the preparation of magnetic thin films of iron oxides in the form of nanocomposites and nanostructures. The fabricated materials were investigated by spectroscopic and magnetic techniques determining the influence of the shape of the nanostructures on the magnetic properties (mainly magnetic anisotropy). The most relevant measurement method, for which under the NCN grant titled "Sprzężenia i anizotropia magnetyczna wieloskładnikowych nanokompozytów i ferrofluidów badane technikami wysokorozdzielczej spektroskopii rentgenowskiej" the samples were prepared, was the RIXS-MCD (Resonant Inelastic X-ray Spectroscopy with Magnetic Circular Dichroism), which is an element- and site-selective spectroscopy method for studying the magnetic ordering of transition metal oxides.

At the beginning of the thesis, the theoretical magnetic properties of matter are presented. Magnetic loops (magnetization profiles) with their parameters, types of magnetic phases and properties and types of magnetic anisotropy are presented. The reasons for the occurrence of magnetic anisotropy and the effect of dimensional change, symmetry and interface effects on its magnitude are described. Next, the magnetic domains and properties of nanocomposites, including layered nanocomposites with vertically aligned nanocomposites (VAN) grains, are described.

The next chapter is devoted to a description of the properties of the studied iron oxides - magnetite, hematite and maghemite, whose nanostructures can be potentially used, in spintronics due to their high spin polarization at the Fermi level, in medicine for the sake of their biocompatibility with the human body, and photocatalysis due to their wide energy gap, respectively.

The next section describes the techniques and methods used for the fabrication of thin films by which two kinds of researched materials, made out of iron oxide, were obtained.

The first was made using the reactive magnetron sputtering method. Under suitable sputtering conditions, nanocomposites characterized by enhanced perpendicular magnetic anisotropy were obtained. Next, the Pulsed Laser Deposition (PLD) method used to obtain magnetite thin films was described, which were then subjected to electron beam lithography combined with etching using argon plasma. In this way, magnetite nanostructures with different shape anisotropy were produced. A nanostructurizing process was also carried out on some of the fabricated magnetite thin films using another method - Focused Ion Beam (FIB) in order to analyze the potential effect on the structure of the material and compare it to argon ion etching.

Inspection of the fabricated nanostructures was carried out using scanning electron microscopy (SEM) and transmission electron microscopy (TEM), with which the size and thickness of the resulting nanostructures were measured. A description of these methods and the other experimental techniques used to characterize the physical properties of the materials obtained is presented in the sixth section. In addition to electron microscopy methods, it presents the Vibrating Sample Magnetometer (VSM) method, which was used to develop the magnetic profiles of the nanocomposites.

The most important part of the chapter sixth is the description of synchrotron spectroscopic techniques used to study magnetic and structural properties. The basic interactions of X-rays with matter are also presented, as well as how to measure electronic excitations and relaxations that occur in irradiated materials, in particular the RIXS-MCD method and the resulting HERFD-XANES (High Energy Resolved Fluorescence Detected – X-ray Absorption Near Edge Structure) and HERFD-XMCD (High Energy Resolved Fluorescence Detected - X-ray Magnetic Circular Dichroism), which give information on the local and global structure of the material being measured and the magnetic properties. Finally, the RIXS-MCD magnetometry method used to obtain magnetic profiles of fabricated nanocomposites and nanostructures is presented.

After the description of the methods, the parameters of the used measuring stations at the ESRF (Grenoble, France) and Soleil (St Aubin p. Paris, France) synchrotrons are presented.

The next chapter presents the detailed methodology for the fabrication of the nanocomposite layers studied and the results of their inestigations. The origin of the formation of the enhanced perpendicular magnetic anisotropy and the influence of the morphology and thickness of the layers on their magnetic characteristics are analyzed. A method for correcting the hysteresis loop obtained from VSM measurements using the results of RIXS-MCD magnetometry is presented. The same chapter also presents the process of obtaining magnetite nanostructures by electron lithography using a photo-sensitive negative resist and a positive photoresist in the form of indentations reproducing nanostructures in a solid layer. The results of synchrotron measurements of magnetite thin films, magnetite nanostructures, and layers and nanostructures covered with copper and cobalt are described in detail. This chapter concludes with an analysis of the changes induced in the local magnetite structure as a result of argon and gallium ion bombardment processes. This analysis was carried out based on theoretical simulations of X-ray absorption spectra by means of the Finite Difference Method Near Edge Structure (FDMNES) package.

The final chapter of the paper summarizes the main results and presents possible directions for further research.