Poster

Growth of thin films of hexaferrites prepared by chemical solution deposition

Radomír Kužel[1], Milan Dopita[1], Lukáš Horák[1], Miroslav Soroka[2], Jan Prokleška[1], Josef Buršík[2]

[1]Charles University, Faculty of Mathematics and Physics, Ke Karlovu 5, Praha 2 121 16, Czech Republic,
[2]Institute of Inorganic Chemistry of the Czech Academy of Sciences, v.v.i., Husinec-Řež 1001, 250 68, Czech Republic

radomir.kuzel@matfyz.cuni.cz

Structural studies of thin films of several different hexaferrites have been a subject of our research in last years [1-3]. In this contribution, the growth of epitaxial thin films of $Sr_2Co_2Fe_{28}O_{46}$ (X-phase) on a $SrTiO_3$(111) (STO) by a chemical solution was studied. This phase was prepared in the form of a thin film for the first time. The orientation relation between film and substrate was established by detailed three-dimensional X-ray diffraction texture analysis. The magnetization and magnetic domain structure were investigated using magnetic measurements and Lorentz transmission electron microscopy. Electron diffraction, high-resolution transmission electron microscopy, and energy-dispersive X-ray spectroscopy have been applied. With changing temperature, the magnitude of magnetization in the (0001) plane changed drastically at ~355 K, while that along the [0001] direction remained almost unchanged, suggesting a spin reorientation transition. By ferromagnetic resonance methods, it was shown that the compound exhibits a change in the orientation of the magnetic anisotropy in the plane at ~ 155 K that supports the occurrence of the described multiaxial magnetocrystalline anisotropy state with three easy axes along the directions tilted from the c-axis direction towards $\langle 01\bar{1}0 \rangle$ directions [3].

X-ray diffraction (XRD) studies were performed on thin films as well as on the corresponding powders. Powder diffraction patterns were evaluated by the Rietveld method started from the structural model (#12815 of the ICSD database). Several restrictions were assumed in executing the refinement calculations: (i) only z-coordinates were allowed to vary, while x- and y-coordinates are kept constant. (ii) Me1-Me10 were assumed to be filled with iron and cobalt in the same way, as described in #12815 ICSD entry, and these values were not refined because the difference in X-ray scattering power between iron and cobalt is too small to be distinguished. The pseudo-Voight function was used for the refinement of optimized powders, and 57 parameters were fitted (15 instrumental parameters, 22 profile parameters, and 20 structural parameters). The lattice parameters of a = 5.891 Å, and c = 83.72 Å were obtained. The film contained an impurity (~10 %) of W hexaferrite.

From the Bragg diffraction profile along the normal direction of the substrate in reciprocal space, the information on the out-of-plane orientation of the film and substrate could be obtained. This was measured in symmetrical q-q scan and indicated a strong preferred orientation (000*l*). The w scans on these planes were narrow and comparable with those of the substrate diffractions. To obtain detailed information on the orientation of a thin film, one needs to get information on the in-plane orientation of the respective phases by observing additional Bragg reflections lying on non-specular directions. This can be achieved by means of the so called φ scans. This was performed for several asymmetric diffractions, for example 1 1 15 and all scans shown 6 clear narrow maxima (FWHM ~ 0.2°) indicating strong in-plane orientation (epitaxial growth). The lattice parameters of the film were obtained by the evaluating the maxima positions of 30 diffraction profiles measured at different sample inclinations and φ angles corresponding to the maxima (a = 5.881 Å, c = 83.85 Å). Comparison of these values with those of powders indicates a small compressive strain in the film. These experiments were performed in low-resolution parallel beam setup with polycapillary and parallel beam collimator. 00 *l* diffractions were also analyzed in high-resolution setup with hybrid K_{a1} monochromator and triple-axis analyzer. This was used for the XRD line profile analysis that showed non-negligible broadening and gave a small microstrain value of 0.027 % and crystallite size of about 400 nm.

Our findings demonstrate the feasibility of the CSD method in the synthesis of highly oriented films for compounds with extremely complex structure.

[1] Shin, KW; Soroka, M.; Shahee, A; Kim, KH; Buršík, J.; Kužel, R; Vronka, M; Aguirre, MH: (2022). *Advanced Electronic Materials.* v. **8** 2101294.

[2] M. Soroka, J. Buršík, R. Kužel, J. Prokleška, M.H. Aquirre, (2021) *Thin Solid Films,* **726**, 138670.

[3] M. Soroka, J. Buršík, R. Kužel, L. Horák, J. Prokleška, M. Vronka & V. Laguta (2023). *Journal of European Ceramic Society.* **43**, 6916-6924.

The authors appreciate the support by the grant of the Czech Grant Agency, no. 24-12710S.