Misorientations in [0 0 1] Magnetite Thin Films Studied by Electron Backscatter Diffraction

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Magnetite thin films grown on [0 0 1] oriented MgO substrates are analyzed by means of electron backscatter diffraction (EBSD) analysis and magnetic force microscopy in applied fields. The EBSD technique enables the crystallographic orientation of individual grains to be determined with a high spatial resolution up to 20 nm on such ceramic samples [1]. A high image quality of the recorded Kikuchi patterns was achieved enabling multi-phase scans and high spatial resolution measurements. Upon annealing in air, the magnetic properties of the magnetite thin films were found to change considerably [2,3], which is ascribed to anti-phase boundaries [4]. Using the EBSD analysis, we find that misoriented grains remaining after the annealing step form small islands with a size of about 100 nm and a spacing of 500nm. The size and distribution of these islands correspond well to the observations of antiferromagnetic pinning centers within the magnetic domain structures carried out by magnetic force microscpy (MFM) on the same samples.

Focused-ion beam (FIB) milling was employed to create a set of markers within the magnetite film, so that the exact area can be traced back in the subsequent MFM measurements. In total, five such $20 \times 20\ \mu m^2$ big sections were marked by cutting L-shaped markers (1 µm edge length) into the magnetite film. The dose for the FIB milling was kept low at 0.03 $nC\mu m^{-2}$ in order to ensure no significant damage caused by the ion milling [see fig. (3)]. The sample preparation and the changes of microstructure induced by the annealing step in air were discussed in detail in [2,3]. Here, we focus on the resulting microstructure after the 1 min. annealing step, i.e., after that the largest changes of the magnetic properties were observed [2,3]. The figures (1,2) illustrate an EBSD analysis of an area marked by FIB milling (L-shaped patterns as marked by arrows). Figure (1) is an IQ map, while map (2) presents the determined crystallographic orientations in an inverse pole figure (IPF) map normal to the sample surface. The applied EBSD step size is 40 nm for all maps shown here. Both maps are put together with an underlying SEM image. The colour code for the IPF map is given in the stereographic triangle at the bottom. Two L-shaped markers created by FIB milling are marked by arrows. The circle denotes an area with a 30° misorientation embedded in the magnetite matrix. Figure (3) gives an orientation analysis around such an L-shaped marker, revealing that the ion damage is focused on the marker itself. The edge length of the marker is 1 µm. The MFM images [image (4)] are taken in applied fields of -139 mT (top) and -175 mT (bottom). Details about the MFM measurements can be found in [5]. The areas marked by circles indicate spots which change polarity in this field range. These spots are discussed to be pinning sites for the magnetic domains. From the comparison with the EBSD measurements, it is obvious that the size and distribution of these sites coincides well with the misoriented regions seen by EBSD. The misorientation of more than 30° also creates a different form of magnetic coupling between the

islands and the remainder of the magnetite matrix.
The present comparison of EBSD and MFM data obtained on magnetite thin films reveals clearly the importance of a thorough crystallographic analysis of the films in order to understand the magnetic domain patterns measured by means of MFM or other magnetic imaging techniques [6].

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