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SEM Applied on Magnetic Materials: Magnetic Contrast and Morphology Imaging

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Fe-Nd-B and Co-Sm based permanent magnets are important components in high efficiency traction motors for e-mobility and generators for renewable energy (e.g. wind turbines). Their performance relies on exceptional intrinsic (visible in magnetic domain patterns) and extrinsic (microstructure) properties. In this respect, the implementation of in-column backscattered electron detectors opens avenues of new applications. Magnetic contrast imaging in the SEM is demonstrated for Fe-Nd-B, the strongest permanent magnet material today. The contrast can arise from two different interaction processes: (1) Magnetic contrast of the sample surface (type 1) is due to the interaction of secondary electrons with the stray field of the magnetic material at the sample surface. (2) Magnetic contrast of the sample volume (type II) results from backscattered electrons that are influenced by the internal magnetic field of the sample [1]. The conventional detection possibilities of backscattered electrons by semiconductor or scintillator detectors are limited to accelerating voltages above 3 kV. Further, the use of the ETD without suction power is restricted to small solid angles and, therefore, results in low signal to noise ratios. This restriction can be overcome with the inlens detection possibilities. Figure 1 shows a sample region that is correlatively imaged using a Kerr-Light microscope (Zeiss Axio Imager.Z2m) and SEM (Zeiss Crossbeam 540). The contrast/detector modes used are (a) polarized light, (b) Inlens SE and (c) Inlens energy selective backscattered electron detector (ESB). In the latter case, a negative grid voltage > 200 V was applied to suppress collection of secondary electrons. The red arrow marks the same feature in all three images. The Kerr-image shows grains with differently shaped and oriented magnetic domains at the surface (stripe domains, closure-type domains) which are also visible in both SEM images. Additionally, a different sample region was investigated in the SEM using the same instrument settings and imaging conditions, Figure 1 (d-e). The two modes (d) Inlens SE and (e) Inlens ESB with an applied negative grid voltage > 200 V are shown. White arrows mark differences in the observed domain patterns, which are caused by detecting the stray or internal magnetic field. This information is solely obtainable with the SEM. A morphology study is performed on a commercial Co-Sm magnet. This material shows a three-phase nanostructure, which develops in a self-organized process during a complex annealing procedure [2]. Figure 2 (a-c) shows a correlative image sequence of the material microstructure. (a) was acquired with the ETD and shows hard magnetic grains (main phase) and bright particles of a Sm rich phase, probably Sm-oxide. (b) and (c) are recorded by Inlens SE and visualize the materials morphology of the main phase. By changing the recording parameter from (b) higher to (c) lower dwell times, the contrast of the Sm rich particles can be inverted. Here, the brightness of the particles is also induced by less electric conductivity, thus, presenting a potential contrast. High-resolution SEM (HRSEM) delivers unique insights in the material delicate nanostructure at large fields of view Figure 2 (d-e). There (d) shows the arrangement inside a grain with parallel lamella structures along the crystallographic c-axis and a network of polygonal cells with a small boundary phase in between. Increasing the resolution to the nm scale, (e) small droplets with Cu enrichment (according to EDS) are observed inside the cell boundary phase. Grain boundaries phenomena can also be easily studied, e.g. (f) shows the enlarged interface between two grains. Here, a zone without lamellas and differently formed large Cu, Zr enriched phase appears. Application of Inlens detection and HRSEM enables imaging of magnetic contrast and delivers new unique insight in the morphology of magnetic

material, which cannot obtained by competing methods [3].

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[3] The authors gratefully acknowledge the German BMBF for financial support.

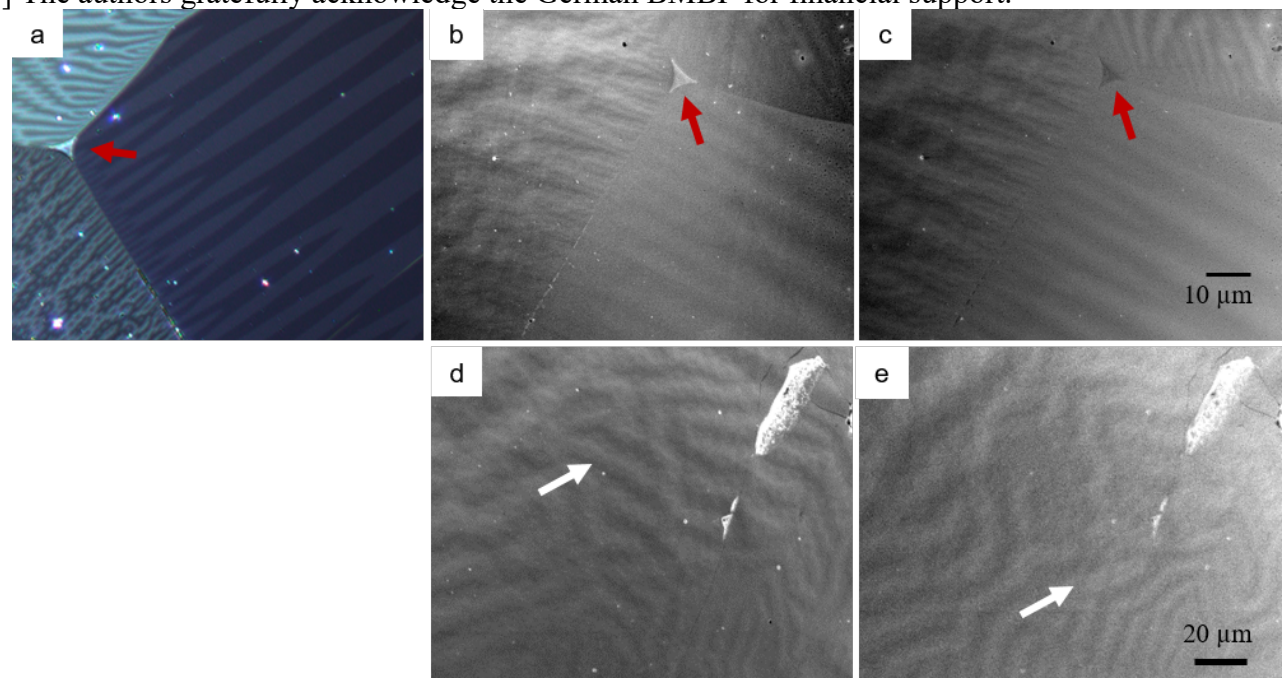

Figure 1. Correlative Kerr-Light microscopy and SEM applied on NdFeB magnet (a, c, e). (a) LM image (b, d) SEM image recorded with the Inlens SE and (c, e) with the ESB, which reflects the differences of the stray and internal magnetic field.

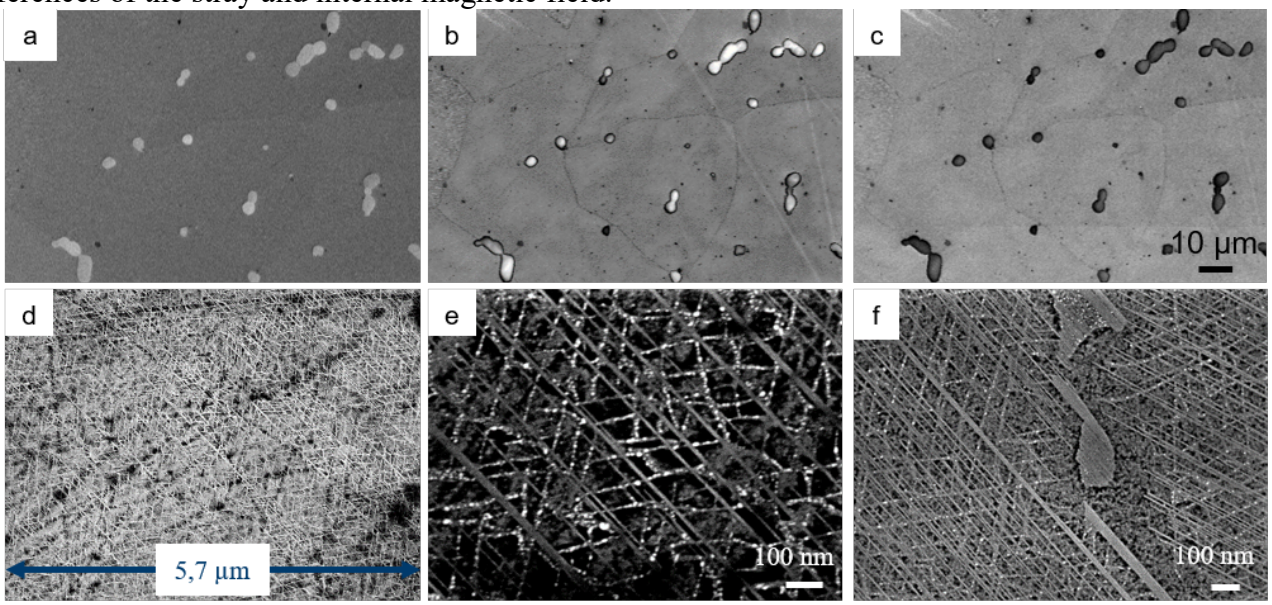

Figure 2. Morphology study applied on a CoSm magnet. (a-c) Identical image area recorded with the (a) ETD and (b-c) Inlens SE. (d) Large field of view of the polygonal network inside a grain (e-f) HRSEM imaging the structure inside a grain and the grain boundary, respectively.

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