Hierarchical Architecture and Coherence of Cores in Multi-core Iron Oxide Nanoflowers Investigated by Correlative Multiscale Transmission Electron Microscopy

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Multi-core iron oxide nanoparticles, often called iron oxide nanoflowers (IONFs), exhibit a combination of excellent properties including superparamagnetic behavior, high saturation magnetization and a good biocompatibility. Therefore, IONFs have found widespread biomedical application, for example as heat mediator for hyperthermia cancer treatment. While the magnetic properties of mono-core iron oxide nanoparticles are controlled mainly by their size, the magnetic properties of IONFs are add-itionally affected by the interaction of magnetic moments between neighboring cores. However, a detailed description of the com-plex internal structure of multi-core IONFs has not been provided so far.

The aim of this study was to reveal the hierarchical structure of multi-core IONFs, including the orientation relationships between individual cores, their internal structure and crystallographic coherence of the core fragments, and to relate these phenomena to the magnetic properties of the multi-core IONFs. The IONFs investigated here were commercially available, dextran-coated multi-core IONFs (synomag-D, micromod Partikeltechnologie GmbH, Rostock, Germany), which were synthesized using a polyol method [1]. Their structural characteristics were investigated using transmission electron microscopy (TEM) that was applied in high-resolution and low-resolution modes and networked by a correlative multiscale approach [2], and correlated with the magnetic properties concluded from the magnetization curve measured using alternating gradient magnetometry (AGM).

High-resolution TEM (HRTEM) revealed that the IONFs under study consist of several cores with specific orientation relation-ships. This alignment is stimulated by neighboring cores sharing lattice planes having the same interplanar spacings. HRTEM in combination with geometric phase analysis [3] disclosed that larger cores are fragmented into small domains that have mutual misorientations of less than 1°. The fragmentation of the cores was confirmed by XRD that recognized the cores as agglomerates of slightly misoriented, partially coherent nanocrystals [4]. The size distributions of the IONFs and the cores were determined in a statistical manner by applying a multi-stage semi-automatic segmentation routine to several low-magnification high-angle annu-lar dark-field scanning TEM images [2], and correlated with the magnetic properties of the IONFs that were obtained from AGM measurements.

References

1. H Gavilán *et al.*, *Part. Part. Syst. Charact.* **34** (2017), p. 1700094.
2. S Neumann *et al.*, *Micros. Microanaly.* **29** (2023), p. 118.
3. M Hÿtch *et al.*, *Ultramicroscopy* **74** (1998), p. 131.
4. D Rafaja *et al.*, *J. Appl. Crystallogr.* **37** (2004), p. 612.