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Synthesis of Cobalt-Doped Ferrite Nanoparticles by Green Hydrothermal Synthesis: From Shape Anisotropic Particles to Chain-like Structures

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In hyperthermia applications, magnetic nanoparticles with high saturation magnetization values and Brownian relaxation behavior are exposed to an alternating magnetic field, whereby heat is generated in the surrounding media to destroy tumor cells locally. Among different types of ferrites, magnetite has the highest magnetic moment, which results in high saturation magnetization values. However, iron oxide tends to oxidize and is a soft magnetic material, and therefore, relaxes according to the Néelian mechanism for particle diameters up to 20 nm. On the other hand, cobalt ferrite nanoparticles (CFNPs) have shown promise as they exhibit a higher magnetocrystalline anisotropy than iron oxide and show hard magnetic properties. Due to that, the Brownian relaxation mechanism is possible for CFNPs larger than 7 nm.

Therefore, our research focuses on the synthesis of cobalt-doped ferrite nanoparticles, in which reduced concentrations of Co^{2+} ions yield high saturation magnetization values accompanied by a Brownian relaxation mechanism. By using a two-step method involving akaganeite nanorod precursors and an aqueous hydrothermal reaction without harmful surfactants or solvents, we synthesized cubic and spherical $Co_xFe_{3-x}O_4$ nanoparticles ($0.25 < x < 0.45$). However, by upscaling this synthesis and varying the reaction parameters, such as pressure, molar ratio, temperature, and basicity, the particle shape and polydispersity can be influenced.[1,2] Moreover, chain-like structures are observed by exchanging the precursor system (Figure 1), which demonstrate reversible chaining in a magnetic field.[3]

We will summarize the parameters that influence the particle shape and cobalt content, as well as show their magnetic and magnetothermal behavior, thereby demonstrating their suitability for a range of applications.

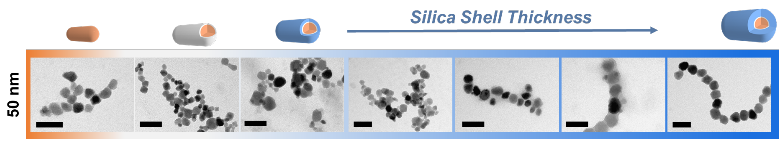

Figure 1: Top: Schematic illustration of the precursor used for the cobalt-doped ferrite synthesis. From left to right, pure akaganeite particles (orange), particles with a polyacrylate shell (white), and the precursors with increasing silica shell thickness (blue). Bottom: Transmission electron microscopy (TEM) images of the resulting cobalt-doped particles using the different precursor systems under the same hydrothermal conditions (modified from Ref. 3).

References

[1] M. Weißpflog, N. Nguyen, N. Sobania, B. Hankiewicz, *J. Phys. Chem. C* 2024, 128(37), 15598–15612. doi:10.1021/acs.jpcc.4c03589.

[2] M. Weißpflog, J. Kabelitz, B. Hankiewicz, *Communications Chemistry* 2025, 8, 305, 1–25. doi:10.1038/s42004-025-01730-9.

[3] M. Weißpflog, D. Eberbeck, B. Hankiewicz, *RSC Advances* 2025, 15, 23007–23024. doi:10.1039/d5ra02233a.

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