

Structural and magnetic properties of praseodymium-doped magnetite nanoparticles

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Magnetite nanoparticles doped with praseodymium, $\text{Pr}_x\text{Fe}_{3-x}\text{O}_4$ ($x = 0.15$ and 0.45), were synthesized via co-precipitation and characterized by powder X-ray diffraction (XRD), Mössbauer spectroscopy (MS), and vibrating sample magnetometry (VSM). The study investigated the effect of rare-earth substitution on structural and magnetic properties. XRD analysis showed that $\text{Pr}_{0.15}\text{Fe}_{2.85}\text{O}_4$ retained a pure magnetite spinel phase with a lattice parameter of $8.392(1)$ Å and a mean crystallite size of $24.3(3)$ nm. The higher-doped sample exhibited a smaller crystallite size ($17.1(5)$ nm), a slight lattice contraction ($8.388(1)$ Å), and a trace amount of hematite (2.7%). Rietveld refinement suggested the Pr^{3+} distribution between tetrahedral (8a) and octahedral (16d) sites as 25%/75% for $x = 0.15$ and 33.3%/66.7% for $x = 0.45$. Based on room-temperature MS measurements, a trace contribution of a superparamagnetic doublet is observed for the sample with $x = 0.15$, whereas a pronounced superparamagnetic component is clearly visible in the sample with a higher praseodymium concentration. An analysis of the hyperfine magnetic fields indicates a predominant occupation of praseodymium ions at the B-sites in the $x = 0.15$ sample, in contrast to the mixed A–B site occupancy observed for the $x = 0.45$ sample. VSM measurements at 300 K revealed a significant decrease in saturation magnetization (66.3 emu/g \rightarrow 31.6 emu/g) and coercivity (100 Oe \rightarrow 50 Oe) with increasing Pr content. At 2 K, both samples showed enhanced magnetic properties (73.3 emu/g and 370 Oe for $x = 0.15$; 38.7 emu/g and 410 Oe for $x = 0.45$). The reduction in magnetization is attributed to preferential occupation of octahedral sites by Pr^{3+} ions, which weakens Fe–O–Fe super-exchange interactions, affecting magnetic ordering [1, 2]. These results demonstrate that praseodymium doping tunes the magnetic properties of magnetite nanoparticles. Lower doping levels preserve superior room-temperature magnetization, while higher doping levels reduce crystallite size and alter magnetic behavior, suitable for applications such as magnetic filters.

References:

[1] M. Zeng, et al., RSC Advances 11 (2021) p. 37246

[2] R. M. Kershi, et al., Journal of Advanced Ceramics 7 (2018) p. 2018

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