Characterization of Pd-decorated cobalt ferrite nanoparticles for magnetic ferrofluid hyperthermia application

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Magnetic ferrofluid hyperthermia has been proposed as a new efficient therapeutic method for treating different types of cancer, as it can enhance the efficiency of common therapeutic methods such as chemotherapy and in particular radiotherapy. $CoFe_2O_4$ (CFO) nanoparticles with significant magnetic crystalline anisotropy are promising candidate for this application. The CFO nanoparticles can then be activated for parallel applications such as photothermal therapy, cell marking, and drug tracking for example by decorating their surfaces with ultra small Pd nanoparticles to enhance surface plasmon resonances.

Pd-decorated CFO nanoparticles were synthesized as a hybrid platform using a two-step coprecipitation method, which resulted in the formation of both bare and Pd-decorated nanoparticles. X-ray absorption near-edge structure (XANES) and its associated x-ray magnetic circular dichroism (XMCD) were measured at the Fe and Co $L_{3,2}$ absorption edges as well as at the O K and Pd $M_{3,2}$ absorption edges in order to investigate electronic and magnetic properties element-specifically and even site-specifically. In addition, elemental and microstructural analyses were carried out using HRTEM, HAADF STEM, EDS and ICP-OES. The characterization was complemented by magnetometry (VSM) and XRD. To account for possible medical applications, magnetic heat generation abilities of different samples were identified using ($\Delta T/\Delta t$) measurements in the presence of an AC magnetic field.

Experimental results confirm that the CFO nanoparticles are highly crystalline with uniform sizes and morphologies, and with a homogeneous decoration of Pd on their surfaces. Cations distribution inferred from XANES and XRD measurements show similar trends and suggest the presence of considerable cation disorder, which increases with decreasing particle size for all samples while Pd decoration has only a slight influence on the degree of disorder. Intriguingly high-field XMCD reveals significantly enhanced total magnetic moments for both Fe and Co ions after Pd decoration. Magnetometry results show a considerable enhancement in magnetization and crystalline anisotropy (by more than 50%) for the Pd decorated samples. The calculated specific absorption rate (SAR) shows a strong dependence of the measured magnetic heating on the sizes and size distributions of the magnetic nanoparticles, while the dominant mechanism of heat generation varies from Neel and Brownian relaxation loss to frictional and hysteresis loss with increasing particle size. Pd-decoration affects the loss mechanisms and SAR of the samples differently depending on particle size.

The Pd decoration process therefore has a significant influence on the structural and magnetic features of CFO nanoparticles. . The optimization of parameters such as particles size, cations distribution, and magnetic anisotropy promises to provide improved magnetic hyperthermia performance of the CFO nanoparticles.