Tuning the structural and magnetic properties of iron oxide nanoparticles

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Due to their biocompatibility and magnetic properties, iron oxide nanoparticles (NPs) are especially interesting for applications such as targeted drug delivery and hyperthermia therapy [1–3]. According to its oxidation states, iron may form various crystal structures and thus show different magnetic properties. Divalent FeO is a bulk antiferromagnet with a rock salt crystal structure at room temperature. When Fe^{2+} is oxidized towards the trivalent state, as found e.g. in Fe_3O_4 and Fe_2O_3, one encounters a spinel structure and ferrimagnetic (FiM) behavior. The FiM to paramagnetic phase transition for bulk magnetite and maghemite occurs at TC = 858K and 948K, respectively. However, they may show different magnetic properties in nanoscale due to the finite size effect. Synthesis of single-phase oxide NPs is challenging. An oxidized layer is often found at the surface of the NPs. This leads to an exchange bias effect.

We observe a shift in the hysteresis loops of various sizes of iron oxide NPs (5-20nm). This is due to an exchange interaction between the magnetite core and a shell with disordered surface spins. By comparing hysteresis loops cooled at different magnetic fields, a hardening effect is observed, i.e. the squareness and hardness of hysteresis loops is significantly enhanced with increasing magnetic cooling field. This indicates that an anisotropy axis is induced due to the exchange bias effect.

In order to understand the origin of the exchange bias effect, we studied their crystallographic structure using X-ray powder diffraction, total scattering experiments with pair distribution function analysis. The ratio of different phases of iron oxide (wustite, magnetite and maghemite) was obtained using X-ray absorptions spectroscopy. The morphology of the particles was characterized using scanning electron microscopy and small angle scattering. The relationship between the composition of the NPs and the exchange bias effect is studied. Furthermore, the magnetic properties of the samples can be tuned by oxidation or reduction via different annealing procedures. These results provide important information for the manipulation of the exchange bias in oxide NPs.

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