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Assessing the Self-assembly of Synthetic and Biogenic Magnetite Nanoparticles

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Highly ordered arrangements of magnetic nanoparticles exhibit anisotropic magnetic properties. These properties can be exploited for applications in information storage and processing, nanoelectronics, spintronics, sensors, and various functional hybrid materials. Previous studies aligned magnetic nanoparticles (NPs) on Si-substrates with an external magnetic field applied in a direction parallel to the surface of the Si-substrate, and characterized the aligned particles using TEM, measuring angular dependence of magnetic hysteresis loops, isothermal remanent acquisitions (IRM) and first order reversal curves (FORC). In this study, we aligned synthetic and biogenic magnetite NPs on the surface of silicon (Si) substrates by applying a magnetic field, parallel and perpendicular to its surface. Samples were also prepared in the absence of a magnetic field as a reference. The degree of anisotropy was determined using the anisotropy of magnetic susceptibility (AMS) measured in low field on a AGICO MKF1a susceptibility bridge. High-field AMS was measured on a torque magnetometer to differentiate between contributions to the magnetic torque, e.g., shape anisotropy and magnetocrystalline anisotropy. Hysteresis loops, acquisition of isothermal remanent magnetization (IRM) and first order reversal curves (FORC) were also measured parallel and perpendicular to the direction of alignment. The low-field AMS indicates that the highest degree of anisotropy is achieved during the application of the external magnetic field parallel to the Si-surface. Samples with highest anisotropy on the Si surface show particles that have self-assembled into a distribution of elongated clusters with a predominant orientation along the field direction. High-field AMS results show a dominance of 2θ torque response with a minor contribution from a θ- and 4θ-terms. The 2θ signal indicates for the presence of uniaxial anisotropy, which arises due to the alignment of the NPs along their easy axis under the application of the external magnetic field. Weak contribution from θ and 4θ signals suggests the presence of a small degree of remanence and biaxial anisotropy, respectively. Biaxial anisotropy can be due to the crystallographic orientation of NPs other than that of easy axis. Magnetic measurements parallel and perpendicular to the alignment direction indicates a decrease in the ratio of saturation remanent magnetization (M_{rs}) to saturation magnetization (M_s) and an increase in remanent coercivity (H_{cr}). We demonstrate how torque magnetometry can be used to evaluate the efficiency of nanoparticle alignment in materials.