

Ferrite nanoparticle chains studied using electron holography combined with magnetic force microscopy

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Nanoparticles are attractive advanced materials due to the dependence of their physical properties upon their shape, size, composition, magnetic and interfacial characteristics. Therefore, uniform nanoparticles (NPs) with a narrow size distribution, precise composition and magnetic properties are now being considered for applications in areas such as spintronics and recording media, which are based on the miniaturization of devices.[1-3] Chains of permanent nanomagnets would provide a very efficient pathway towards materials exhibiting increased data storage densities. The use of magnetic nanoparticles would reduce the size limit of one bit of information from multigrain to one single nanoparticle. Nevertheless the main current limitation is the thermal stability of nanostructures below a given size. Indeed when the size of magnetic NP's decreases, they become superparamagnetic, i.e. the orientation of their magnetic moment becomes unstable against the thermal fluctuations.[4,5] While superparamagnetic nanoparticles are well-suited for biomedical applications,[6] they cannot fulfil the requirements necessary for the development of applications related to spintronics and magnetic recording. This behaviour may be circumvented by the synthesis of chains of nanoparticles to generate a local coupling and an enhancement of magnetic anisotropy. Therefore, the investigation of nanoparticle chains has become an appealing research topic to push back the superparamagnetic limit. The determination of the magnetic configuration in relation with the precise crystallography of each particle is necessary to understand the observed configurations. In this study, we combine off-axis holography with magnetic force microscopy and high resolution transmission electron microscopy on the same chains to enlighten this relation.

Ferrite nanoparticles have been prepared using the protocol described in [7]. They were deposited on a carbon membrane in a magnetic field gradient to form isolated long chains. The same chains have been observed by off-axis holography, magnetic force microscopy and high resolution transmission electron microscopy. Off-axis holograms of the same zones have been recorded before and after reverse of the sample. The holography gives access to the magnetic component in the grid plane, whereas the magnetic force microscopy gives access to the perpendicular component. The 3D-magnetic configuration of the individual magnetic configurations is so determined. The crystallographic orientations of the same particles were deduced from high resolution electron microscopy images. Some micromagnetic calculations were finally performed to understand the results.

Magnetic force microscopy showed a non-uniform magnetization component perpendicular to the plane. The electron wave phase was calculated from holograms using the GPA packing. The in-plane magnetic components, deduced through derivation of the phase difference, were also rotating along the chain.

Using HRTEM, the individual particles were found to be truncated octahedral with (111) facets close to a regular hexagon. They share in majority (111) facets with their

neighbours and have their axis perpendicular to the membrane either [110] or [11-2]. Few of them are [111]-oriented and induce defects in the chains.

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