Synthetic Antiferromagnetic Nanoparticles As Contrast Agents In MRI

R. Van Roosbroeck[1,2], T. Stakenborg[1], W. Van Roy[1], J. Lammertyn[2], L. Lagae[1],
[1]Imec, Kapeldreef 75, Leuven, Belgium
[2]KUL (Mebios), Kasteelpark Arenberg 30, Leuven, Belgium
Ruben.Vanroosbroeck@imec.be

Abstract

Magnetic nanoparticles show great promise and are widely investigated as agents in various biomedical applications including analyte detection, biosensing, drug delivery and imaging. A particular field of interest is magnetic resonance imaging (MRI) where such particles can serve as T_2 contrast enhancers. Most of the reported research related to MRI is focussing on superparamagnetic nanoparticles, synthesized by bottom-up wet chemistry methods[1]. These magnetic particles are, however, restricted to the superparamagnetic limit to avoid magnetic remanence and aggregation in the absence of a magnetic field. This restriction therefor implies a size limit (20-25 nm) and consequently a limited magnetic moment per particle. The ideal particle diameter for contrast agents in MRI-experiments unfortunately exceeds this limit[2]. Moreover, bottom-up synthesis often results in polydisperse particle suspensions.
To overcome these issues, synthetic antiferromagnetic (SAF) particles are proposed here as alternative T_2 contrast agents for MRI applications. These particles are composed of two ferromagnetic layers, separated by a non-magnetic layer (Figure 1). Using the interlayer exchange coupling effect, synthetic antiferromagnetism can be produced which mimics superparamagnetic behavior (i.e. no magnetic moment in the absence of a magnetic field). Size and shape can be controlled through a range of litohgraphic methods to produce highly magnetic and monodisperse particle suspensions. To fabricate the SAF particles, we used colloidal lithography with monodisperse polystyrene beads (60-200 nm) serving as an etch mask. By controlling the size of the polystyrene beads, the final SAF particles could be fine-tuned in size. After synthesis on wafer scale and a lift-off step, the particles were suspended in aqueous solution and chemically stabilized.
As intended, the particles showed no magnetic remanence despite the fact that they are composed of ferromagnetic materials (Figure 2). To show the performance of the SAF particles as contrast agents simulations were performed and experimental relaxivities were determined. Using simulations the effect of size, composition and shape of the particles on the relaxivity was demonstrated. Second, experimental relaxivities r_2 up to 350 $s^{-1}mM^{-1}$ were achieved for NiFe-based particles which is competitive with conventional superparamagnetic nanoparticle suspensions[3]. These proposed SAF particles, behaving like superparamagnetic particles without being restricted in size, show a great potential for MRI applications.

References

[1] Hilgner I, Kaiser WA, Nanomedicine **7** (2012) 1443-1459.
[2] Vuong QL, Gillis P, Gossuin Y, Journal of Magnetic Resonance **212** (2011) 193-48.
[3] Vuong QL, Berret JF, Fresnais J, Gossuin Y, Sandre O, Advanced Healthcare Materials **1** (2012) 502-512.

Figures

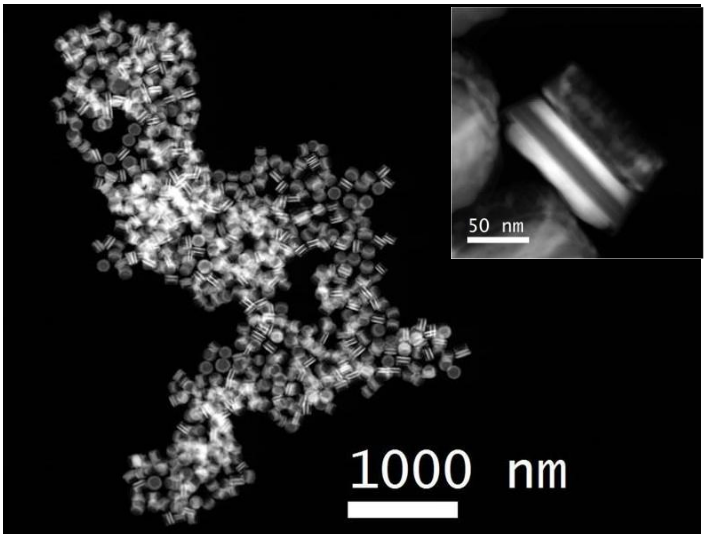

Figure 1: Electron microscopic image of the fabricated synthetic antiferromagnetic nanoparticles with a mean diameter of 100nm. The inset (upper right) shows a magnification of a single particle. The SAF particle is composed of two NiFe layers (black) in the center separated by a thin Ru-spacer (bright). A gold layer on top and bottom (thick bright layers) surround the SAF stack.

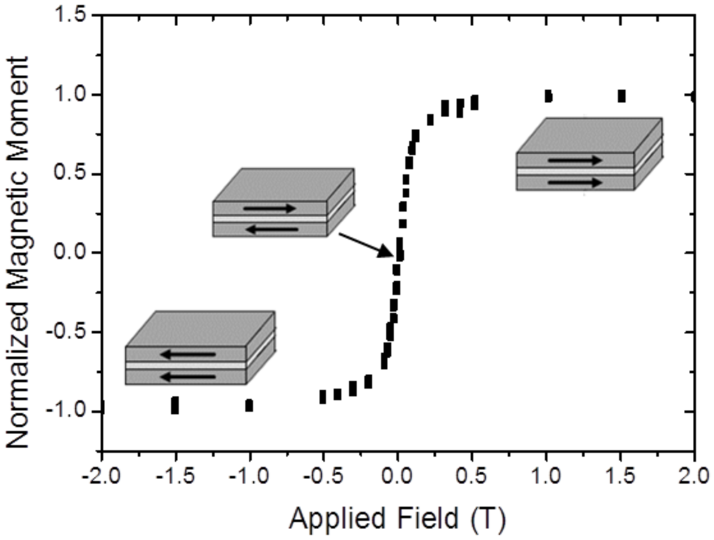

Figure 2: SQUID-measurement of suspended synthetic antiferromagnetic nanoparticles with a mean diameter of 100 nm. The schematics show the magnetization of the magnetic layers inside the particle. At zero field no magnetic remanence is observed due to the SAF-coupling of the magnetic layers.