Self-polarization phenomenon and control of dispersion of synthetic antiferromagnetic nanoparticules for biological applications

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Using a top-down approach, synthetic antiferromagnetic micro/nanoparticles [1] usable for biological applications were prepared. They are made of magnetic multilayers consisting of ferromagnetic layers antiferromagnetically coupled between them through a thin ruthenium spacer. These particles exhibit “superparamagnetic-like” properties. Their magnetic susceptibility can be accurately controlled by the thickness of the constituting layers. We focused on particles of composition $(NiFe/Ru0.7nm/)_n/NiFe$ with a total NiFe thickness kept constant at 120nm and varying the number of repeats n between 1 and 7. The size of particles that we investigated was 1μm*1μm*120nm. These particles have much higher moment and susceptibility than conventional magnetic oxide based nanoparticles prepared by chemical routes. This allows manipulating them with lower magnetic fields. The preparation technique is illustrated in Figure 1 with various examples of realization. The technique benefits from all the knowhow in microelectronic technology in particular nano-imprint lithography. Particles as small as 30nm could be prepared. The interest of this approach is that both the shape and composition of the particles can be optimized depending on the foreseen biotechnological applications. Besides, these particles are not spherical. They exhibit some shape anisotropy or intrinsic magnetic anisotropy which opens new possibilities to manipulate them with magnetic fields rather than gradients of magnetic field. This may allow controlling their motion at much longer distance than with conventional approach. Indeed gradients of magnetic field decrease very rapidly as a function of distance from field source whereas field can be produced over much longer distance.

When dispersed in solution, striking differences in the interactions between these synthetic antiferromagnetic particles are observed depending on their susceptibility [2]. Above a susceptibility threshold, a phenomenon of self-polarization is observed in zero applied field resulting in a gradual agglomeration of the particles. In contrast, below this susceptibility threshold, the particles get redispersed in zero field. For practical use, this second situation is of course preferable. It is therefore possible to optimize the magnetic susceptibility to keep it much larger than in conventional magnetic nanoparticles but still avoiding their magnetic agglomeration. This control of agglomeration.dispersion is illustrated in Fig.2. This phenomenon was interpreted by a self-consistent model taking into account dipolar interactions between particles and their magnetic susceptibility [2]. The model is similar to the mean field theory of ferromagnetism wherein the mean field is due to the dipolar field created by all neighboring particles on a given one.

References

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Figures

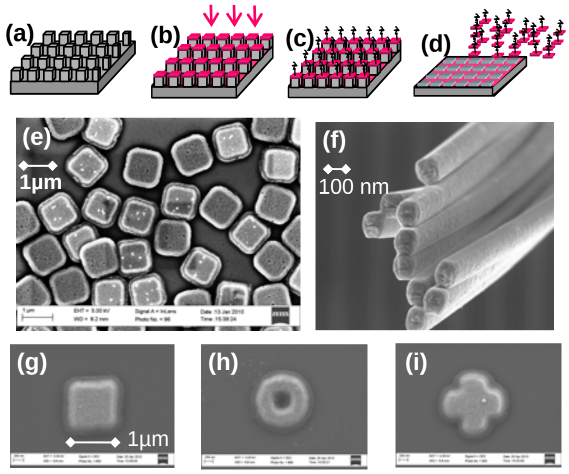

FIG.1. "Top-down" approach: schematic steps of the nanoparticles fabrication. (a) Prestructuration of wafer (nanoimprint or lithography) (b) Deposition of magnetic stack (c) Functionalization of surfaces (d) Release in solution by lift-off. SEM Photos: (e) SAF "superparamagnetic-like" particles, NiFe/Ru/NiFe, 1µmx1µmx120nm (f) Multilayered magneto-resistive nanowires 100nm in diameter, 100 m long, prepared by this top-down approach. (g) Square (h) Ring (i) Cross.

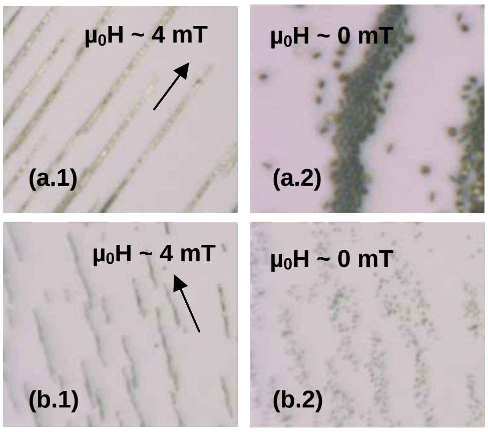

FIG.2. Optical microscopy images of SAF particles in acetone, after lift-off. (1µmx1µmx120nm) of $(NiFe/Ru/)_nNiFe$ *(a) n=1,* μ_0H_{SAT} *~4 mT. (b) n=7,* μ_0H_{SAT} *~32 mT. (a.1) Chains in* μ_0H*~4 mT (a.2) Self-polarization in zero external H~0 (in earth field) (b.1) Chains in* μ_0H*~4 mT (b.2) Dispersion in external H~0 (in earth field).*