Sampling the structure and chemical composition of ferromagnetic nanoparticles with wide size distributions by Ferromagnetic Nuclear Resonance

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Assemblies of nanoparticles are investigated in many research fields. One of the problems for understanding their properties arises from the difficulty in producing mono-dispersed particles. Therefore, the identification of the key parameters at the origin of their properties is blurred by wide size distributions. In this work we report on the new method we have developed in ^{59}Co Nuclear Magnetic Resonance (NMR) which allows the sampling of the structure and chemical composition of ferromagnetic nanoparticles within their size distributions.

Nuclear Magnetic Resonance is commonly used in chemistry or biology but it is much less popular for studying ferromagnetic systems. However recent developments have shown that NMR can give unique information on the structure, stacking faults, chemical order or interface morphology of magnetic thin films, multilayers [1], or nano-particles [2]. When used for studying ferromagnetic samples, NMR is also called Ferromagnetic Nuclear Resonance (FNR, acronym we favour but it is also sometime called Internal Field NMR, IFNMR). In this present work, we report on a new FNR methodology that provides unique insights into the study of ferromagnetic nanoparticles.

In this new methodology we introduce the concept of Temperature Differential Ferromagnetic Nuclear Resonance (TDFNR) spectra. These spectra are obtained by first measuring FNR spectra for different temperatures. Differences between spectra obtained at adjacent temperatures are then computed resulting in the so called Temperature Differential Ferromagnetic Nuclear Resonance (TDFNR) spectra. These TDFNR spectra have the advantage over all the other investigation methods to allow analysing the structure and the chemical composition of particles for selected size ranges [2] within the particles size distribution. Therefore the TDFNR spectra allow one to sample simultaneously the crystallographic structure, the chemical composition and the chemical order of ferromagnetic nanoparticles within the size distribution of the particles. In addition from the TDFNR spectra intensities it is possible to estimate the particle size distribution. Our methodology allows therefore a very complete understanding of the relationship between the structure and the size of the particles even in the case of broad size distributions. In addition no specific sample preparation is required and the method allows analysing the samples in their macroscopic shapes.

The method is first applied to the study of cobalt nanoparticles and allows showing that surprisingly in the studies sample, the smallest Co particles have mostly a hexagonal structure while the largest one have rather a cubic (fcc) structure. In a second example, we extend the field of application of the method by sampling the chemical composition and chemical order within the size distribution of alloyed CoFe nanoparticles. Our method can thus be applied in many research fields, allowing a deeper understanding of the properties of assemblies of ferromagnetic nanoparticles with wide size distributions.

References

[1] P. Panissod, C. Meny,. **Appl. Magn. Reson.** 19, 447-460 (2000)

[2] Y.F. Liu,…, C. Meny, **Nat. Commun.**7, 11532 (2016).