Ferrofluids with High Anisotropy Particles

A.E. Virden[1], S. Wells[2] and K. O'Grady[1]

[1] *Department of Physics, The University of York, Heslington, York, UK, YO10 5DD*
[2] *Liquids Research Ltd, Mentec, Deniol Rd., Bangor, Gwynedd, UK, LL57 2UP*

Introduction

Ferrofluids containing high anisotropy magnetic nanoparticles are of potential interest for new applications of these materials. Potential applications are in areas such as ink jet printing of magnetic inks so as to produce readable characters, hysteresis heating for potential biomedical applications and other possible areas involving dynamic processes in ferrofluids which can be generated by bulk particle rotation within the fluid rather than Neel reversal.

In general ferrofluids are produced using magnetic nanoparticles produced by the well-known co precipitation technique [1]. Particles produced in this way are generally very poorly crystallised due to the fact that the growth takes place at room temperature and the complex crystal structure of a ferrite does not form easily without significant atomic mobility. However recent work on novel preparation techniques has resulted in the preparation of highly crystalline magnetic nanoparticles due to their preparation being undertaken at an elevated temperature [2]. A further advantage of these new preparation routes is that the particle size distribution, resulting from the decomposition of precursor organometallic complexes, is extremely narrow. Furthermore because of the incorporation of the surfactant in the original organometallic material the particles are extremely well separated in a similar manner to those produced by the well-known carbonyl process [3]. Due to these factors ferrofluids produced by this preparation route are expected to show excellent colloidal stability and well defined magnetic properties.

In this work we have taken one example of a material produced by these new routes, cobalt ferrite, and produced a range of particle sizes by decomposition of an organometallic precursor at different particle sizes by heating to a constant temperature for different times.

Experimental

Highly crystalline cobalt ferrite nanoparticles were produced by decomposition of an oleic acid, $FeSO_4$, $CoSO_4$, complexed produced following the basic mechanism described in [2]. The complex was refluxed in dioctyl ether (B.P.=286^{o}C) for periods of time ranging from 6 to 24 hours. The reaction product was precipitated using acetone and redispersed in fresh dioctyl ether after further washing in a ketone. An example of the resulting particles is shown in figure 1 where a transmission electron microscope image with a magnification of approximately 500,000 is shown. This image shows the high uniformity of the particle size and the particle separation produced by the decomposition of the organometallic precursor.

Results

Using images such as that shown in figure 1 we have undertaken particle size analysis using a semi-automated Zeiss particle size analyser. For each sample in excess of 500 particles were measured. Similarly magnetic particle size distributions have been determined using the well established method of Chantrell et al [4]. In the case of these particles a particularly good correlation between the physical and magnetic sizes was obtained due to the expected highly crystalline nature of the particles which is know to extend out to atomic layers very close to the surface [2].

Heating time (hours)	Particle diameter (nm)	σ
6	5.1	0.2
15	9.7	0.2
24	12.5	0.1

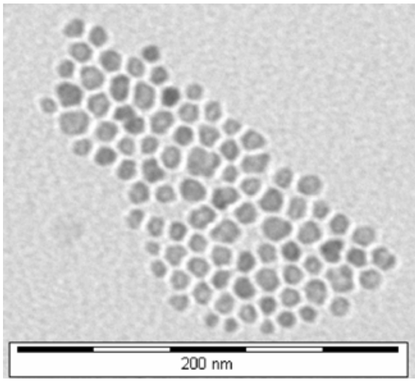

Figure 1: TEM image of cobalt ferrite.

We have also made measurements of hysteretic properties of these materials at low temperatures below the freezing point of the carrier liquid. An example of one such hysteresis loop measured to 10 kOe is shown in figure 2. This shows a remarkably high coercivity at 77K of in excess of 5 kOe and a very high remanence to saturation ratio M_r/M_s. However it should be noted that in the magnetic fields available to us on our vibrating sample magnetometer we are unable to fully saturate these materials.

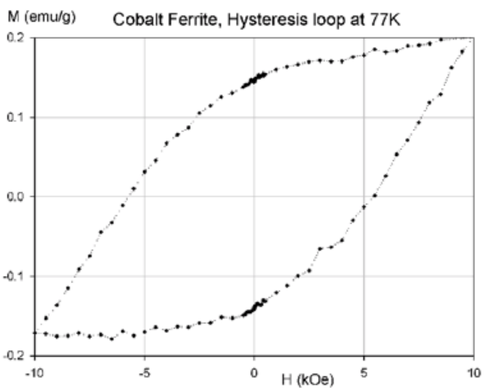

Figure 2: Cobalt ferrite hysteresis loop at 77K.

In the full paper we will show hysteretic data for these materials at a range of temperatures obtained using a magnetometer with a maximum applied field of 90 kOe. Furthermore the origins and magnitude of the anisotropies will be discussed in the context of a model of the behaviour of particles with cubic anisotropy originally developed by Walker et al [5, 6].

Acknowledgments

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