LT 21 Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S4 - LT Properties of Solids 1: Magnetism (experiment)

Single Crystal Silicon Oscillator Studies of Spin Glasses with Reduced Dimensionality

Robert D. Biggar and J. M. Parpia

Materials Science Center, Cornell University, Ithaca, NY, 14853

We report on the use of a high-Q torsional silicon oscillator as a sensitive magnetometer to study the remanent magnetization of spin glass films. We have observed the spin glass transition in *Cu*Mn (1 at. %) films. We have also observed the saturation of these spin glass systems at high fields. This technique allows us to study large isolated spin glass films and to control film geometry.

1. INTRODUCTION

Systems of dilute magnetic impurities in noble metal matrices exhibit the Kondo effect[1] (an increased resistance at low temperatures) and spin glass behavior[2]. It has been of some interest in recent years how these two effects are modified in samples with reduced dimensionality.

Resistivity measurements of thin films and wires of magnetically doped noble metals have revealed a suppression of the magnitude Kondo effect when observed by some groups,[3, 4, 5] while other groups have been able to explain all changes in low temperature resistivity through processes such as electron-electron interactions, unrelated to the Kondo effect.[6]

Resistivity measurements undertaken by DiTusa *et al*[4] and Lane *et al*[5] of *Cu*Cr show both a reduction in the Kondo effect and a suppression of the spin glass resistance maximum as the width of a thin film of this material is varied. This work is difficult to interpret as the system is in an intermediate regime where interactions between effects prevent their separate analysis.

Motivated by a desire to further study the *Cu*Cr system, we have been developing a way to detect the magnetization of thin films and wires. We utilize high-Q torsional oscillator magnetometers fabricated from single crystal Si wafers. These magnetometers avoid the geometry constraint imposed by SQUID measurements.

2. EXPERIMENT

Two stage torsional oscillators (see inset to fig. 2) are etched from a silicon wafer using a KOH etch.[7] When driven in their anti-symmetric torsional mode, these oscillators have Qs on the order of 10^7. Combined with the ability to make oscillators with small values of κ, the torsional spring constant, oscillator amplitude is very sensitive to changes in drive force or energy dissipation.

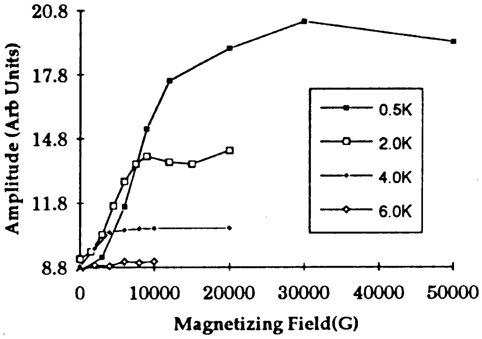

Figure 1: Isothermal remanent magnetization of bulk *Cu*Mn (1 at-%).

Samples of *Cu*Mn are deposited on the head of the oscillator. If the samples are magnetized in a field, and then the field is removed, it is possible to drive the oscillator by using a transverse AC magnetic field at the resonant frequency. Oscillator amplitude (measured capacitively) is then proportional to the magnetization of the sample on the oscillator head. For an AC drive field of amplitude 1 Gauss, we estimate a sensitivity to magnetization of $10^{10}\mu_B$. This should be sufficient to detect magnetization in films down to 1000Å. More sensitive measurements should be possible using thinner oscillators.

After magnetic drive has been established, the sample is warmed and the amplitude recorded. By

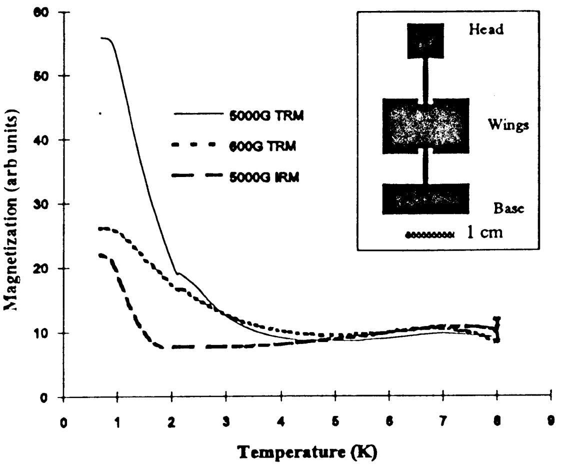

Figure 2: Decay of remanent magnetization with temperature for 1μm thick sample.

repeating this procedure for different magnetizing fields and procedures, it is possible to extract an approximate freezing temperature.

3. RESULTS

We studied a bulk (100mg) sample of *Cu*Mn (1 at-%). Hysteresis was observed, and was seen to disappear at approximately 7K, nominally consistent with other studies of the material. We went on to undertake an isothermal remanent magnetization (IRM) study (see fig. 1). Our results were consistent with previous workers. [8]

We evaporated a 1μm film of the same material onto the head of an oscillator, and found similar behavior. We further studied the difference in thermal dependence of IRM and thermal-remanent magnetization (TRM - the field cooled remanent magnetization). The TRM decayed only slowly on warming, while the IRM showed a much more abrupt drop off (see fig. 2). If TRM was undertaken with fields sufficient to saturate the sample's magnetization (about 5000G) the data again showed the rapid drop off in magnetization with warming, similar to the behavior of the IRM measurements.

Measurements were repeated for films of thickness $4000\mathring{A}$, $2000\mathring{A}$, and $850\mathring{A}$, and similar behavior was observed.

4. DISCUSSION

We observed that the thinnest and thickest films display very similar behavior. Although the thin film sample was significantly noisier (and was magnetized at a lower temperature), the two curves fall more or less on top of each other. However, a minimum at about 4 degrees is much more pronounced in the thinnest sample. No minimum was observed in the bulk sample; apparently there is some sample independent, temperature dependent background which is adding a signal of the opposite sign to the spin glass signal.

A film of intermediate thickness had a distinctly different temperature dependence. This could possibly be due to a change in the relative sign of the sample independent background, or to variations from sample to sample. The zero-field cooled magnetization signal as a function of temperature was quite rich for this sample, with an extra peak at about 6 degrees, indicating that some additional relaxation processes was occuring in this sample.

Although spin glasses are notoriously picky about sample preparation and history, our fabrication technique has not been optimized in terms of reproducibility. Switching to a sputtering deposition processes would increase confidence in the reproducibility of our data. Also, work is need to improve the signal to noise ratio in our thinnest sample. Magnetometer redesign is an on-going process. Vibration isolation should also be improved in the future.

5. Acknowledgments

This research was supported by the National Science Foundation and the Cornell Material Science Center under DMR-9121654. Fabrication was carried out at the Cornell Nanofabrication Facility, supported by the NSF under ECS-8619040.

REFERENCES

[1] J. Kondo, Prog. Theor. Phys., **32** 37 (1964)

[2] See J.A.Mydosh, *Spin Glasses: An Experimental Introduction*, (Taylor & Francis, London, 1993) for an overview.

[3] Guanlong Chen and N. Giordano, Phys. Rev. Lett. **66** 209 (1991), M.A. Blachly and N. Giordano, Phys. Rev. B **51** 12537 (1995)

[4] J.F. DiTusa *et al*, Phys. Rev. Lett. **68** 678 (1992)

[5] K. R. Lane *et al*, Phys. Rev. B **51** 945 (1995)

[6] V. Chandrasekhar *et al*, Phys. Rev. Lett., **72** 2053 (1994)

[7] R.N. Kleiman *et al*, Rev. Sci. Instrum. **11** 2088 (1985)

[8] J. L. Tholence and R. Tournier, J. de Physique **35** C4-229 (1974)