STUDY OF MAGNETIC ANISOTROPY OF GaMnAs

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GaMnAs is a ferromagnetic semiconductor that is drawing increasing interest among researchers because of possible developments in spintronics technology it can bring. It has recently been discovered that magnetization vectors of ferromagnetic semiconductors can be controlled through electrical and optical means, without the use of an external magnetic field. This allows the emergence of novel spintronic devices that are not only smaller, faster and energy efficient, but also compatible with existing semiconductor technologies. Knowledge of GaMnAs's anisotropic behavior is crucial to design an effective optical or electrical method of controlling the material's magnetization vectors. Here, we present a temperature-dependent study of GaMnAs's magnetic anisotropy. In particular, we provide an in-depth quantitative analysis of the spin reorientation transition (SRT) present in GaMnAs. We measured the temperature (*T*) and magnetic field (*H*) dependences of a $Ga_{1-x}Mn_xAs$ ($x = 0.02$) sample's magnetization (*M*) using a superconducting quantum interference device (SQUID) magnetometer. From the *M*-*H* plot, we extracted the anisotropy constants, parameters that determine the magnetization direction, through data fitting, and observed how the constants changed with temperature. While both cubic (K_c) and uniaxial (K_u) constants were negatively related with temperature, the rates at which the values changed were significantly different. The cubic constant showed a rapid decline, while the uniaxial constant remained relatively stable. This suggested a rotation of the magnetization direction (SRT), with changing temperature. Plot of the anisotropy constants with respect to temperature showed that K_c would drop below K_u at $T = {\sim}35$ K. The *M*-*T* curve also showed the 'second-step', which indicated the full rotation of magnetization along the uniaxial easy-axis, at a temperature near 35 K. Finally, we conducted the Stomer-Wohlfarth model analysis to visualize the rotation of the easy-axis. At $T = 10$ K, the easy-axis was at 37.34^o, close to the cubic easy-axis direction [100] (45^o). As the temperature increased, the easy-axis rotated towards the uniaxial easy-axis direction [110] (0^o), confirming the spin reorientation transition.

Study of Magnetic Anisotropy of (Ga,Mn)As

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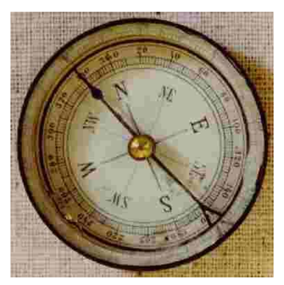
Introduction

•Magnetization direction can convey information.



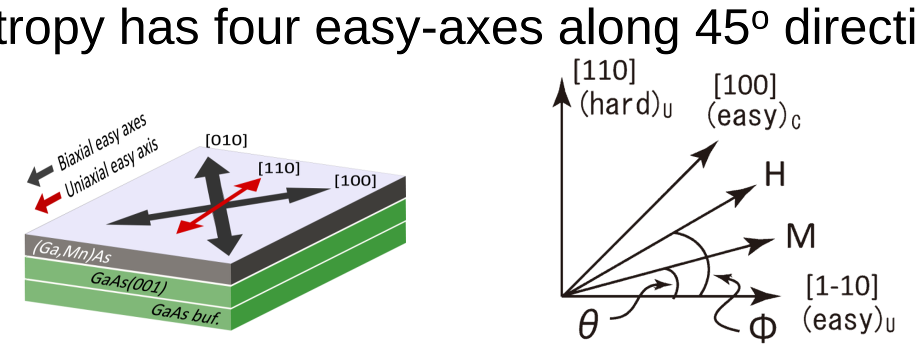
Compass

HDD

•Why Ferromagnetic Semiconductor (FS)?
Magnetization direction of FS, such as GaMnAs, can be manipulated by electrical and optical means. This property can be used to develop new ways of conveying information through magnetization direction.

Project Overview

Background:
•GaMnAs exhibits Cubic and Uniaxial anisotropies
•Uniaxial anisotropy has two easy-axes in 0º and 180º directions, and hard-axes perpendicular to the easy-axes
•Cubic Anisotropy has four easy-axes along 45º direction from Uniaxial easy-axes

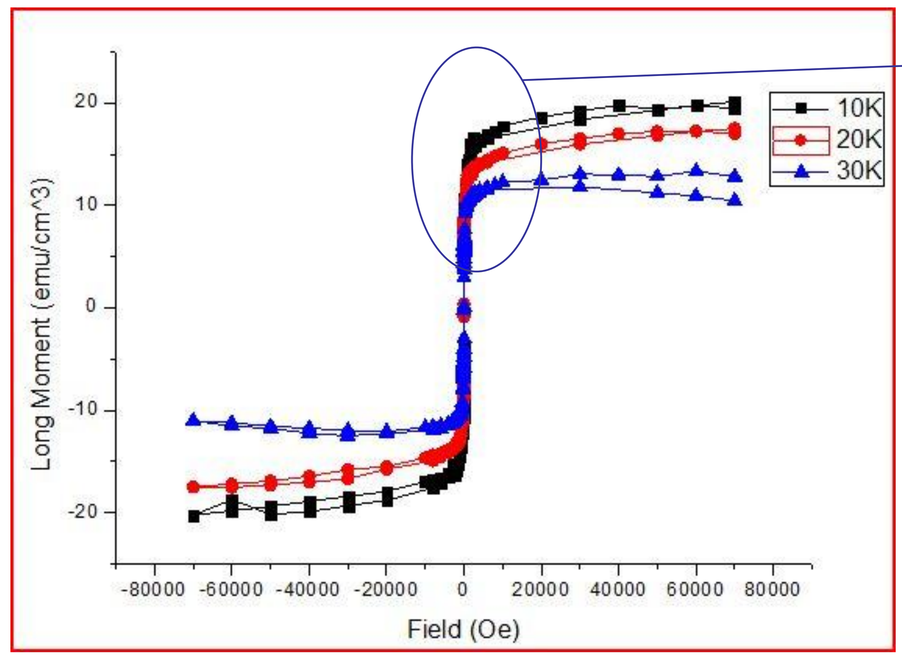


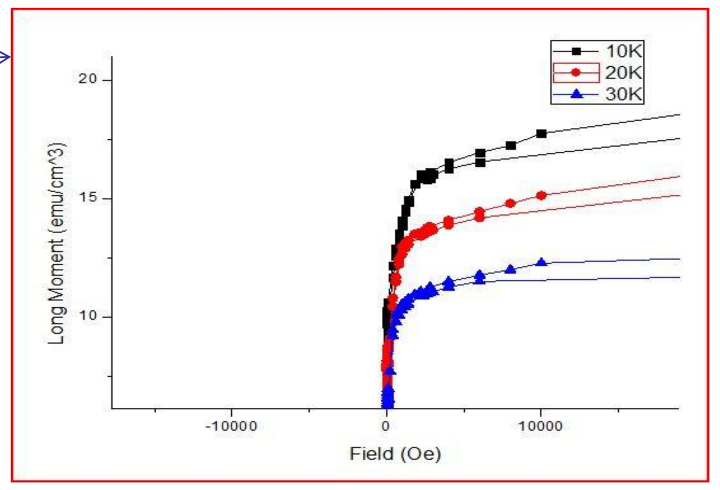
•Cubic and Uniaxial anisotropy constants, K_c and K_u , are the most important parameters that determine the magnetization direction of a sample.
Sample: $Ga_{1-x}Mn_xAs$ (x=0.02)
Equipment used: Superconducting Quantum Interference Device
Objective:
1. To develop a method to accurately extract the anisotropy constants, K_c and K_u
2. To analyze the magnetization rotation behavior in GaMnAs

Approach:
1. Obtain hysteresis plots for the sample at 10K, 20K and 30K using SQUID magnetometer
2. Choose a region of the hysteresis to make the curve fitting. This region should be where coherent rotation is taking place ($H>H_c$)
3. Average the data of the two curves in this region
4. Make a curve fitting using the H-M equation derived from the magnetic free energy equation
5. Check the accuracy of the extracted values of K_c and K_u using the Stoner-Wohlfarth Model and the M-T plot

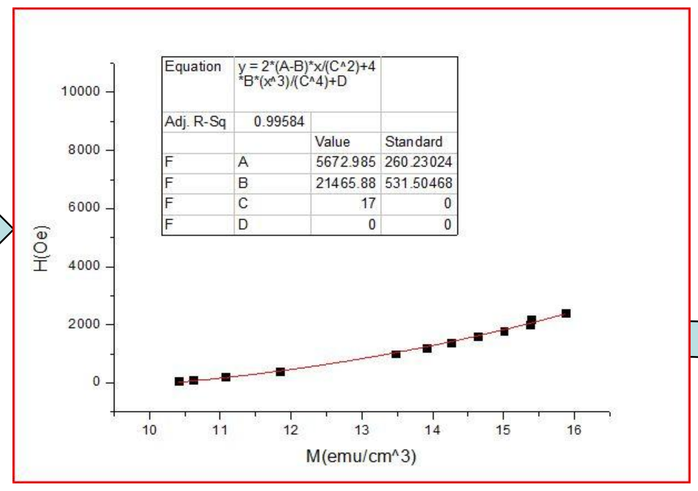
Results

Magnetic Anisotropy Constants obtained through data fitting ($Ga_{0.98}Mn_{0.02}As$)





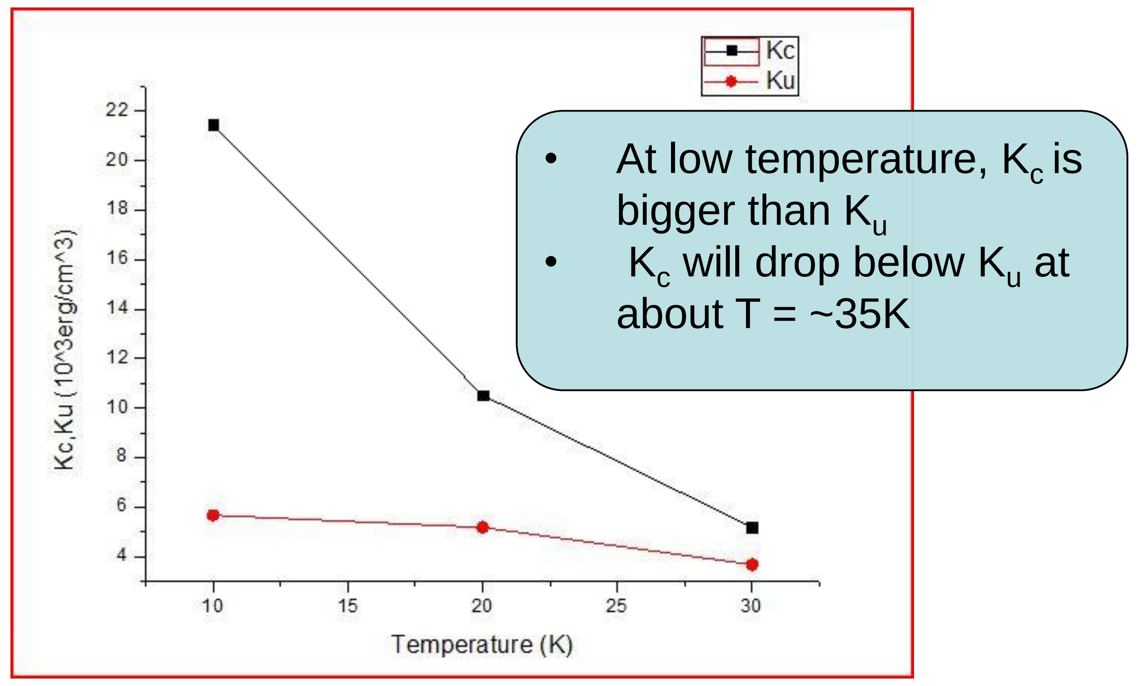
Region of the hysteresis curve which was fitted



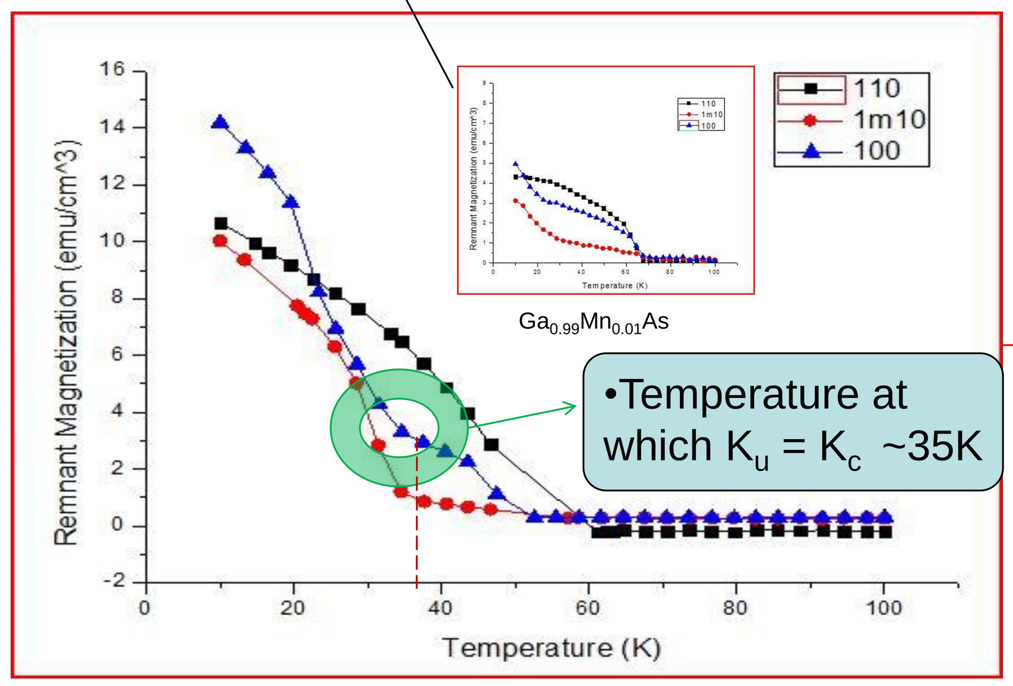
Data fitting on hard-axis at 10K

$$H = \frac{2(K_u - K_c)M_{[1-10]}}{M_s^2} + \frac{4K_c M_{[1-10]}^3}{M_s^4}$$

Accuracy Confirmation

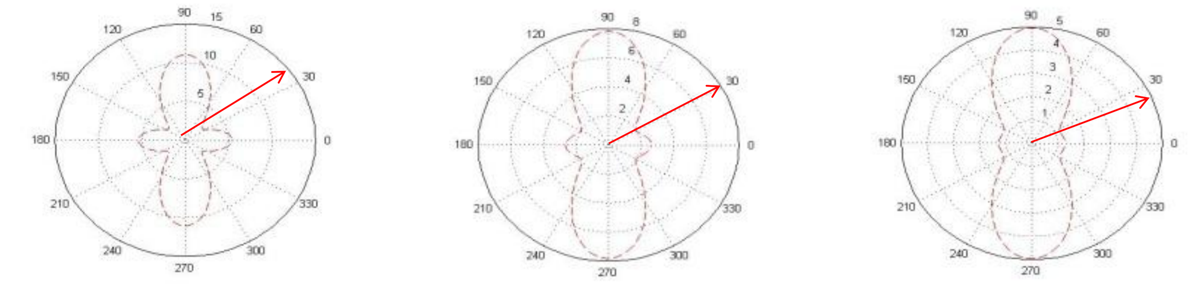


$K_u = K_c$ Temp. at ~24K



Stoner-Wohlfarth Model computed by extracted K_c and K_u values are in reasonable agreement with experimental data

Stoner-Wohlfarth* Model



10K 20K 30K

* Stoner-Wohlfarth model is a magnetic free energy density diagram. It is drawn using the magnetic free energy function:

$$E = -\frac{K_c}{4}\sin^2(2\theta) + K_u \sin^2\theta$$

Conclusion

Achievement: Reliable values of the anisotropy constants for temperature-induced magnetization rotation were extracted through data-fitting along the hard-axis. The computation method has been manualized and can be used as basis of extracting K_u and K_c for light or electric field induced magnetization rotation.
Shortcomings: Unsuccessful in extracting reasonable values in data-fitting along the easy-axis.
Other Observation and Future Interest: While general trend of M-T plots of the samples with differing Manganese concentrations were same, the temperature at which K_u=K_c differed. Relationship between Mn % and K_u=K_c temperature is a matter of interest.

Acknowledgement

Research conducted as participant of NanoJapan 2009 program sponsored by NSF-PIRE grant