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$_x$As ($x = 0.02$) 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 Stommer-Wohlfarth model analysis to visualize the rotation of the easy-axis. At $T = 10$ K, the easy-axis was at $37.34^\circ$, close to the cubic easy-axis direction [100] (45°). As the temperature increased, the easy-axis rotated towards the uniaxial easy-axis direction [110] (0°), confirming the spin reorientation transition.
Study of Magnetic Anisotropy of (Ga,Mn)As

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Introduction

• Magnetization direction can convey information.

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 0° and 180° directions, and hard-axes perpendicular to the easy-axes
• Cubic Anisotropy has four easy-axes along 45° direction from Uniaxial easy-axes

• Cubic and Uniaxial anisotropy constants, $K_u$ and $K_c$, are the most important parameters that determine the magnetization direction of a sample.

Sample: Ga$_x$Mn$_{1-x}$As ($x=0.02$)

Equipment used: Superconducting Quantum Interference Device

Objective:
1. To develop a method to accurately extract the anisotropy constants, $K_u$ and $K_c$.
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 $K_u$ and $K_c$ using the Stoner-Wohlfarth Model and the M-T plot

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