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Analysis of magnetic anisotropy in epitaxially grown Fe film on GaAs(001)

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1. Introduction

Rapid developments in spintronics, where functionality is based upon the carrier spin, are particularly promising for multifunctional devices. Hybrid heterostructures of ferromagnetic metals and semiconductors can be a prominent construction for spintronics. Among many other combinations between ferromagnetic metals and semiconductors, Fe and GaAs have appropriate structural matching. Besides, the magnetic anisotropic property of Fe thin film on GaAs(001) (Uniaxial Magnetic Anisotropy) is totally different from property of bulk Fe (Cubic Magnetic Anisotropy). We investigate how large is the UMA in comparison to shape anisotropy in Fe thin film on GaAs(001) using Magnetic Force Microscope (MFM).

2. Experiments

Sample which is consisted of GaAs / GaAs 2.5μm (n-doped) / GaAs 15nm (n^+-doped) / GaAs 15nm (n^{++}-doped) / Fe 5nm was prepared by molecular beam epitaxy (MBE) growth. GaAs layers were grown in semiconductor chamber and sample was transported to metal MBE *in-situ*. Fe thin film was grown at 200℃. For MFM measurement, sample was patterned as rectangular shape using E-beam lithography and ion milling. The patterns have various dimensions, aspect ratios and directions.

3. Results and Discussions

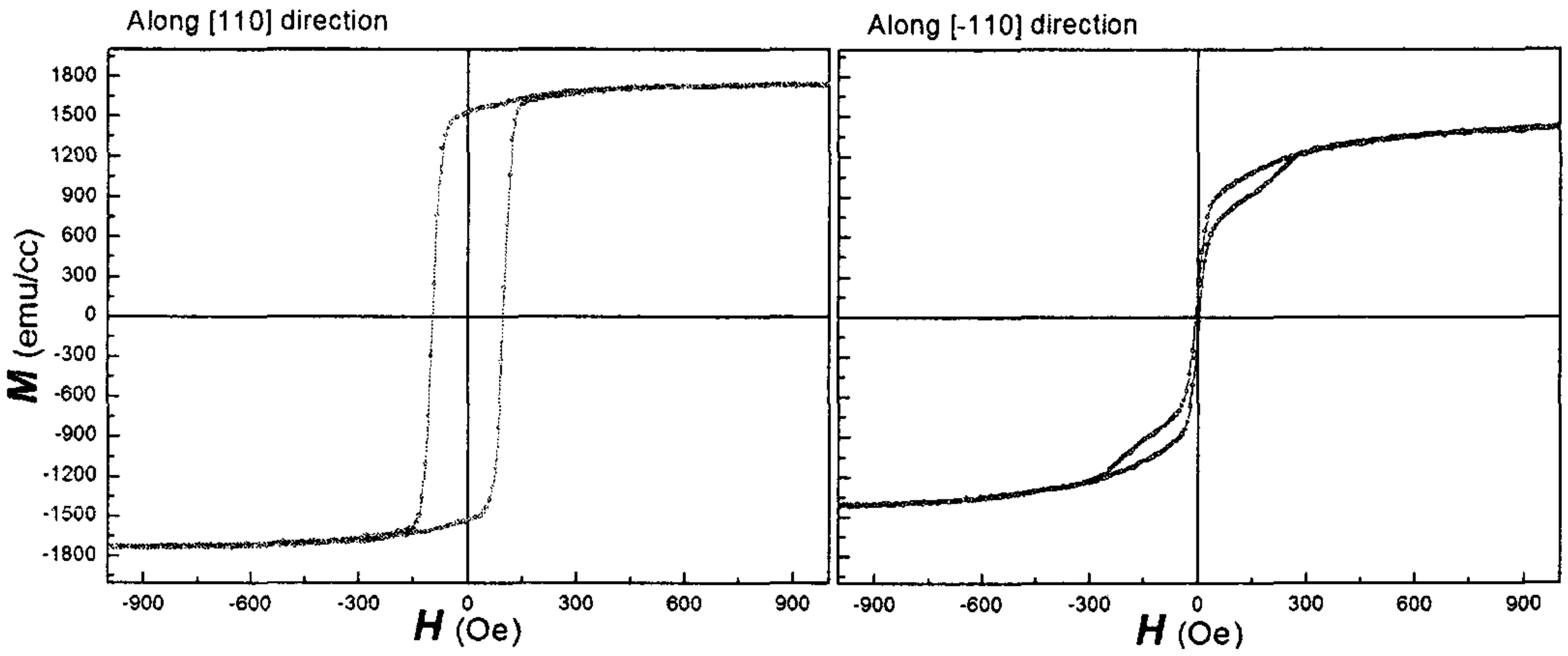

Fig. 1. Hysteresis curve of Fe thin film on GaAs(001) along [110] and [$\bar{1}$10] direction. The data obtained with AGM is showing that [110] and [$\bar{1}$10] directions are magnetically easy and hard axis respectively.

Hysterisis curve of Fe thin film on GaAs(001) obtained with AGM (Fig. 1.) is showing that [110] direction is uniaxial easy axis and [$\bar{1}$10] direction is hard axis. (Although the data along [100] & [010] directions is not shown, it indicates [100] & [010] are magnetically intermediate directions in Fe thin film on GaAs(001).) This data is not in accordance with the case of bulk Fe exhibiting CMA where [100] & [010] directions are easy and [110] & [$\bar{1}$10] directions are hard axis.

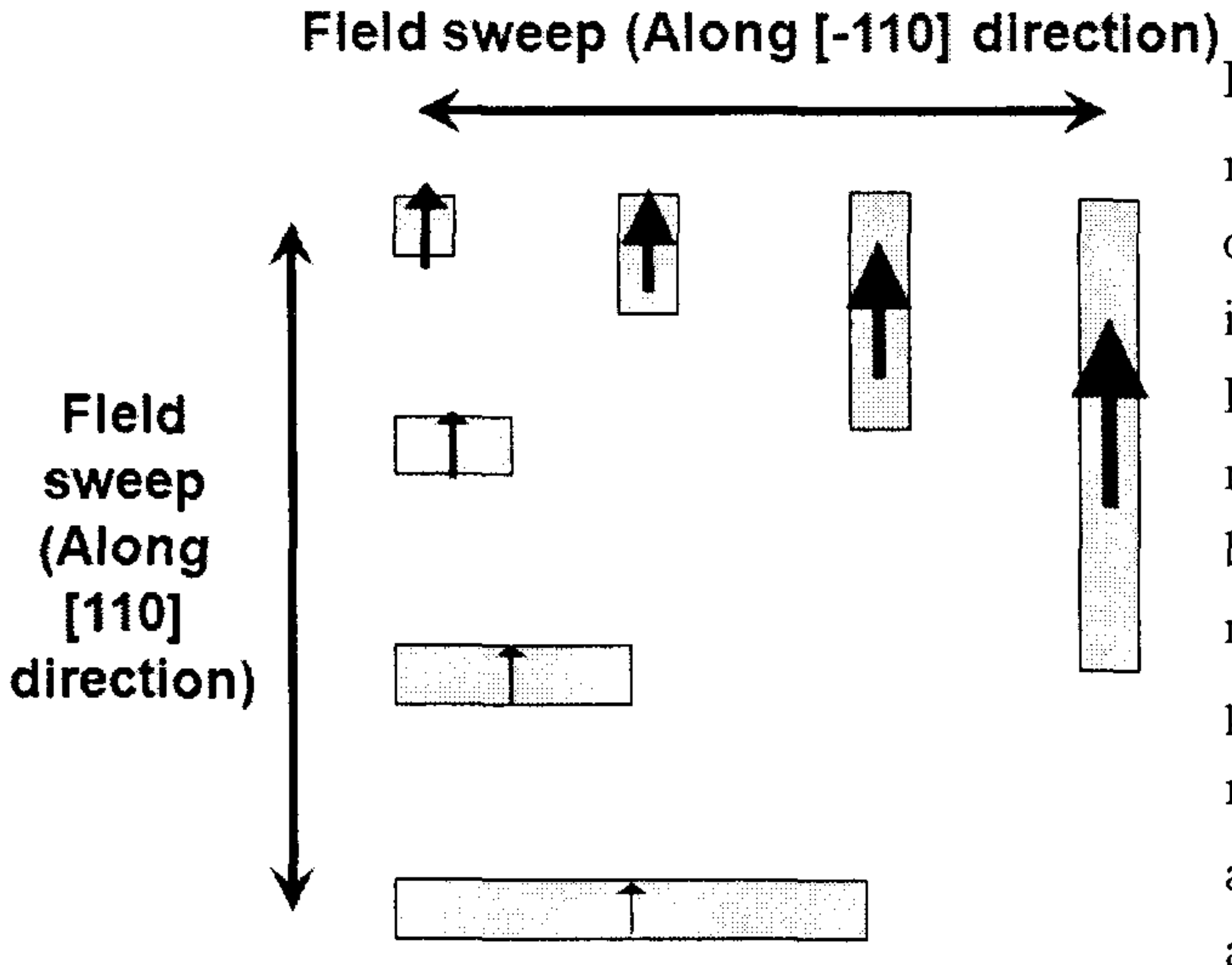

Fig. 2. Schemes of various patterns with aspect ratio from 1:1 to 1:8, [110] & [$\bar{1}$10] directions and dimensions from 500nm to 16μm. The arrows are indicating expected remanent magnetization state. Patterns along [110] direction reveal a large remanent magnetization along [110] direction because the UMA and shape anisotropy affect magnetization along same direction. However, patterns along [$\bar{1}$10] direction reveal a weak remanent magnetization along [110] direction or along [$\bar{1}$10] direction because the effect of the UMA and shape anisotropy are in competition each other.

For analyzing the magnitude of UMA, sample was patterned as Fig. 2. The patterns have various dimensions(from 500nm to 16μm), aspect ratios(from 1:1 to 1:8) and directions(along [110] and [$\bar{1}$10]). We investigate the magnetization configuration in these patterns while magnetic field is swept along [110] and [$\bar{1}$10] directions. Information which can be acquired from this result is whether UMA is larger than the shape anisotropy of each patterns, and the uniaxial anisotropy constant(K_u) from measured coercivity field(H_c). First, from the remanent state of the patterns along [$\bar{1}$10] direction, we can compare the magnitude of UMA with the magnitude of shape anisotropy. For instance, if the remanent state of 1:4 aspect ratio pattern along [$\bar{1}$10] direction is along [110] direction, we can judge the magnitude of UMA is larger than shape anisotropy at 1:4 aspect ratio pattern. For the second, from the coercivity field, we can acquire the mixed anisotropy constant K which can be expressed as $K_u - K_S$ where K_S is the shape anisotropy constant (equation [1]).

$$K = K_u - K_S = \frac{H_c M_S}{2} \qquad [1]$$

with M_S being the saturation magnetization. Then K_S can be obtained with aspect ratio in each patterns. As a result, we can estimate the magnitude of K_u quantitatively.