The Effect of Growth Conditions on Magnetic Properties of Single Crystal Iron Films on Magnesium Oxide

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Abstract

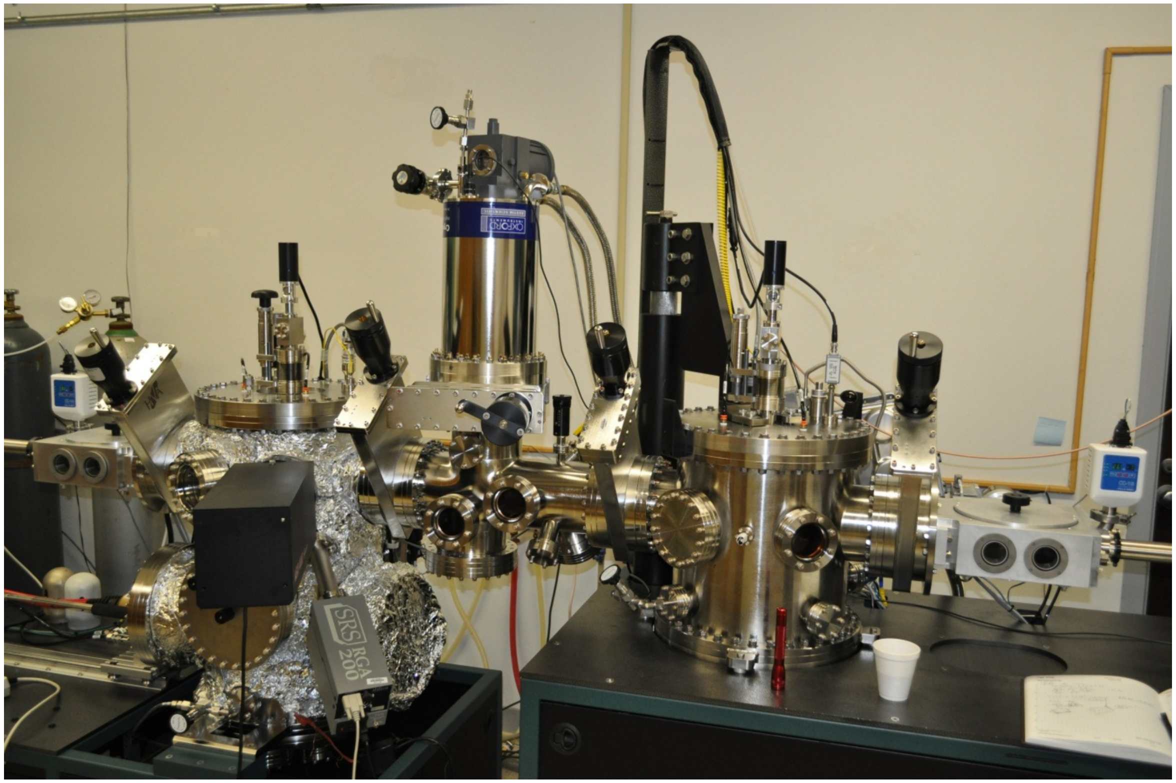
Iron (Fe) was grown epitaxially using electron beam evaporation on a (100) MgO Substrate. Its growth was monitored through a Reflection High Energy Electron Diffraction imaging system. Different deposition conditions and post-deposition treatments were employed and their effect on magnetic properties were analyzed afterwards using Ferromagnetic Resonance (FMR) and Vibrating Sample Magnetometer (VSM) systems. The surface roughness was also analyzed through the use of an atomic force microscope (AFM). Results show that annealing the sample at 400° Celsius after deposition improves the crystallinity of single crystal Fe.

Introduction

Single crystal growth strongly depends on the lattice parameter of the substrate and the deposition temperature. Materials with similar structures tend grow epitaxially. The lattice mismatch between Fe and MgO results in stresses between the two materials. With successful growth, these stresses can be manipulated into the creation of complex 3 dimensional structures by etching away a sacrificial layer, and letting the tension between materials naturally shape themselves. Rolled up structures using magnetic materials have not been thoroughly studied, and those that have been tend to be polycrystalline in nature which makes it difficult to understand the stresses needed for rolling. On the other hand the lattice misfit is the major source of stresses in single crystals. This will allow for the creation of rolled up structures and control of their diameters at the sub-micrometer level.

Sample Preparation

Two samples of Fe were grown on (001) MgO substrates using electron beam evaporation. Both samples were 10 nanometers thick and deposited at room temperature. However, one of the samples was annealed after deposition at 400° Celsius for 30 minutes.



Results and Discussion

Reflection High Energy Electron Diffraction system from Staib Instruments was used to observe electron diffraction patterns during growth of the films and the evolution of the patterns during annealing treatment.

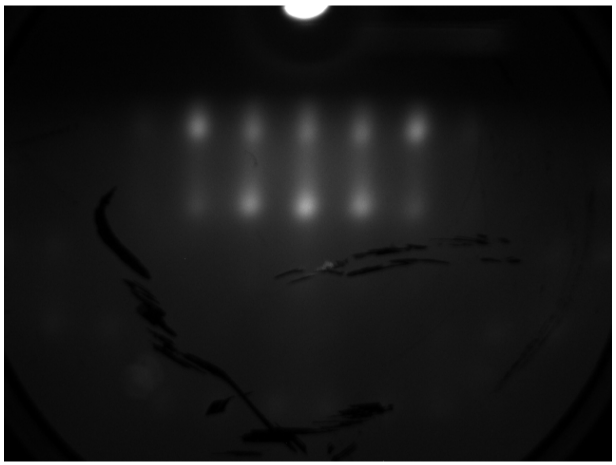


Figure 1: A RHEED image taken right after deposition at room temperature shows streaks that indicate the growth of a single crystal.

Both samples had an average roughness between four and five nanometers. However, the non-annealed sample displayed a grain which may indicate that annealing improves the smoothness of the surface.

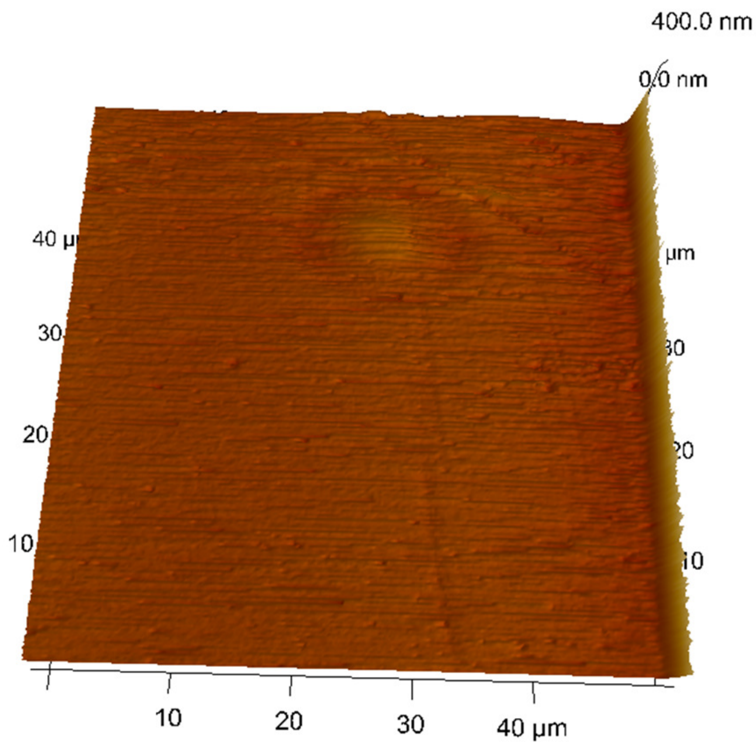


Figure 2: Surface Plot of the as-deposited sample

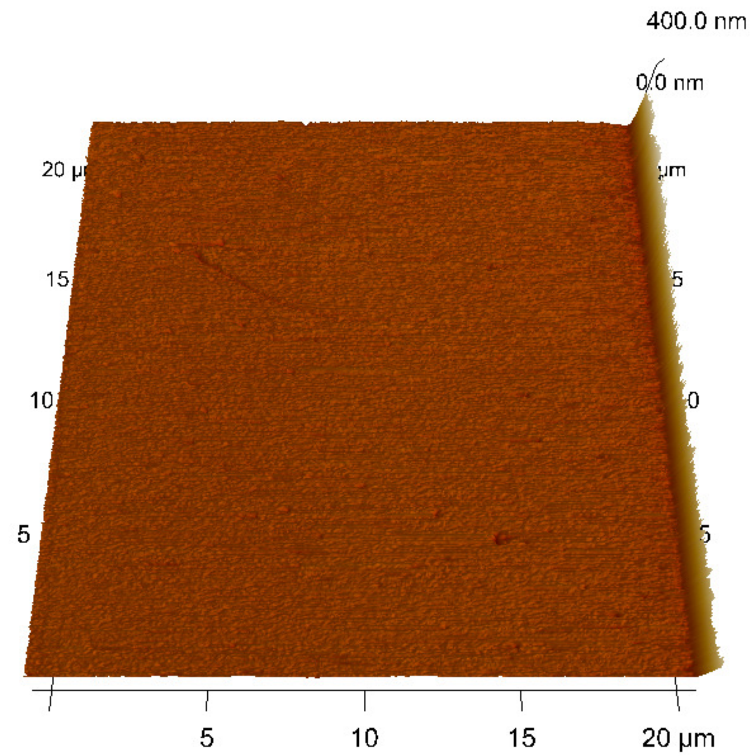
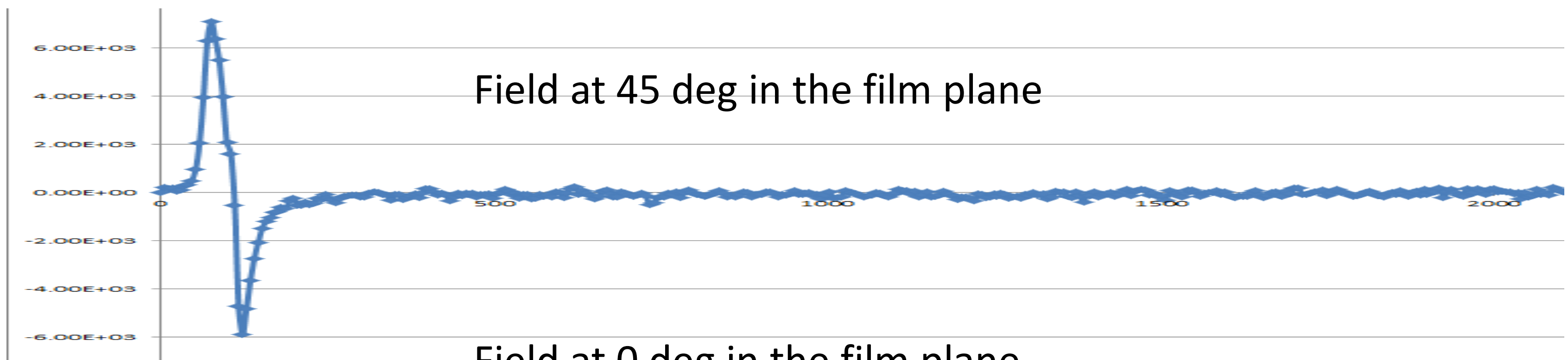


Figure 3: Surface Plot of the annealed sample

Ferromagnetic Resonance (FMR)

An Electron Paramagnetic Resonance Spectrometer from Bruker Inc. was used to measure microwave absorption at ferromagnetic resonance at 9.8 GHz. Because of magnetocrystalline anisotropy the ferromagnetic resonance occurs at different fields for different angles of the applied field. No such angular dependence is expected for polycrystalline samples with randomly oriented grains.



Field at 0 deg in the film plane

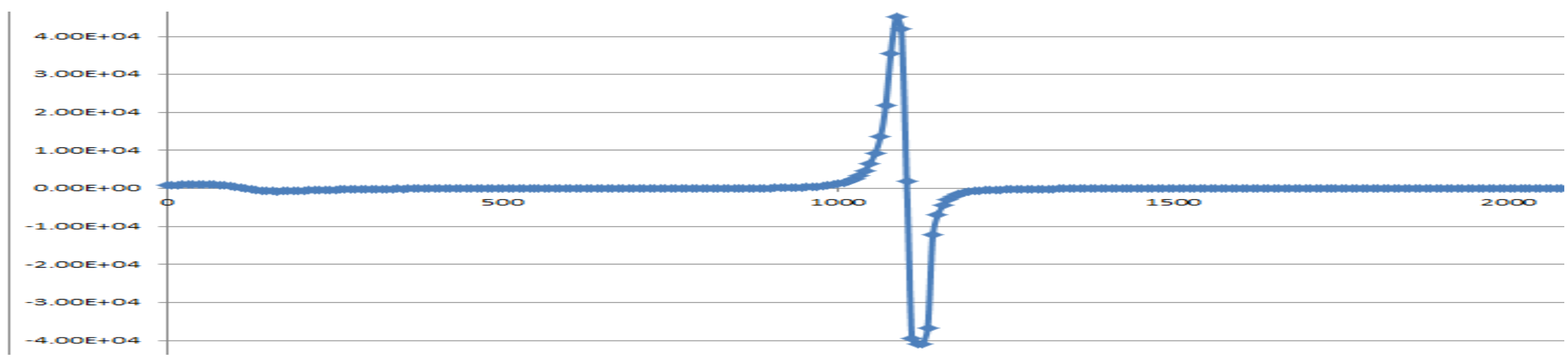


Fig.4. Examples of differential microwave absorption curves vs magnetic field measured for the fields applied in the sample plane at 45^o and 0 degrees

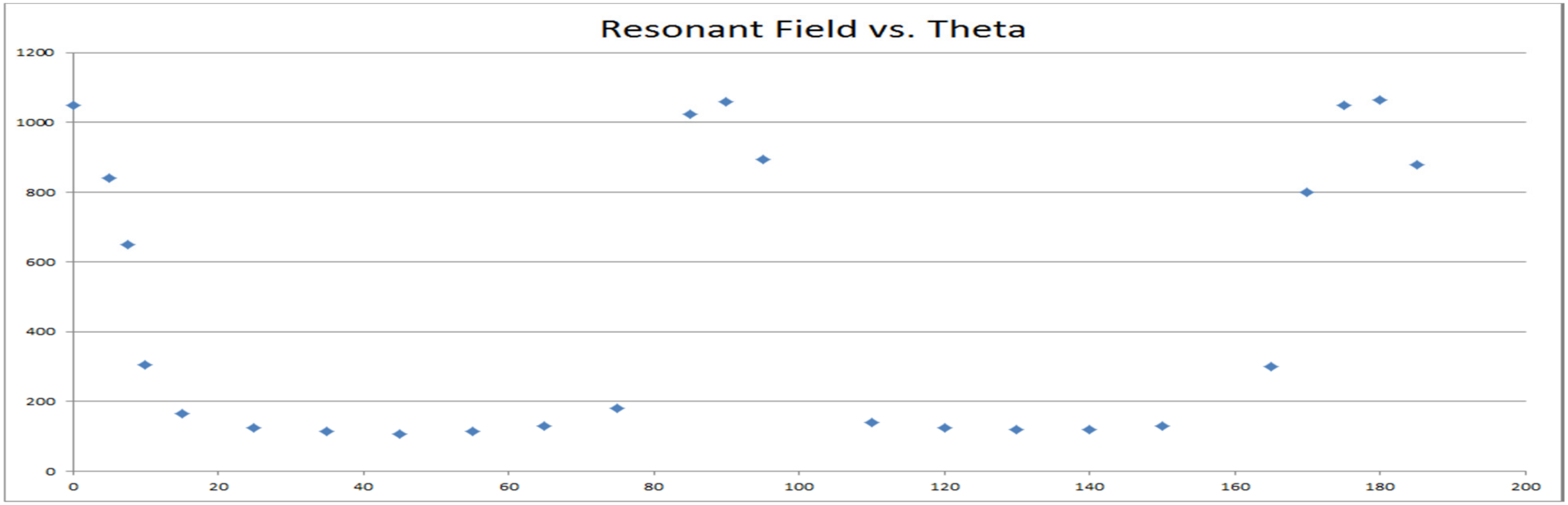


Figure 5: Angular dependence of the resonant field for the single crystal Fe (Magnetic field rotated in the film plane)

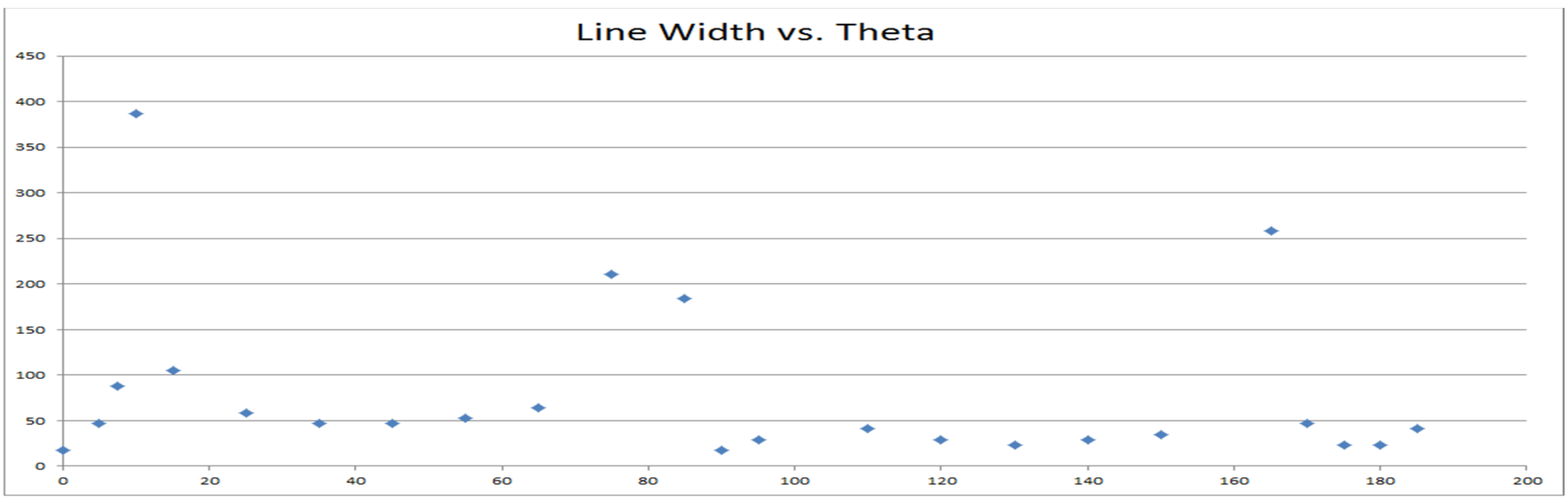


Figure 6: Angular dependence of the resonant curve linewidth

Magnetization hysteresis loops were measured using Vibrating Sample Magnetometer Micromag from Princeton Instruments. Measurements indicate that annealing the sample improves the crystallinity of iron which is evidenced by the change of the hysteresis for different angles of the magnetizing field. Again, the polycrystalline films should not exhibit any angular dependence.

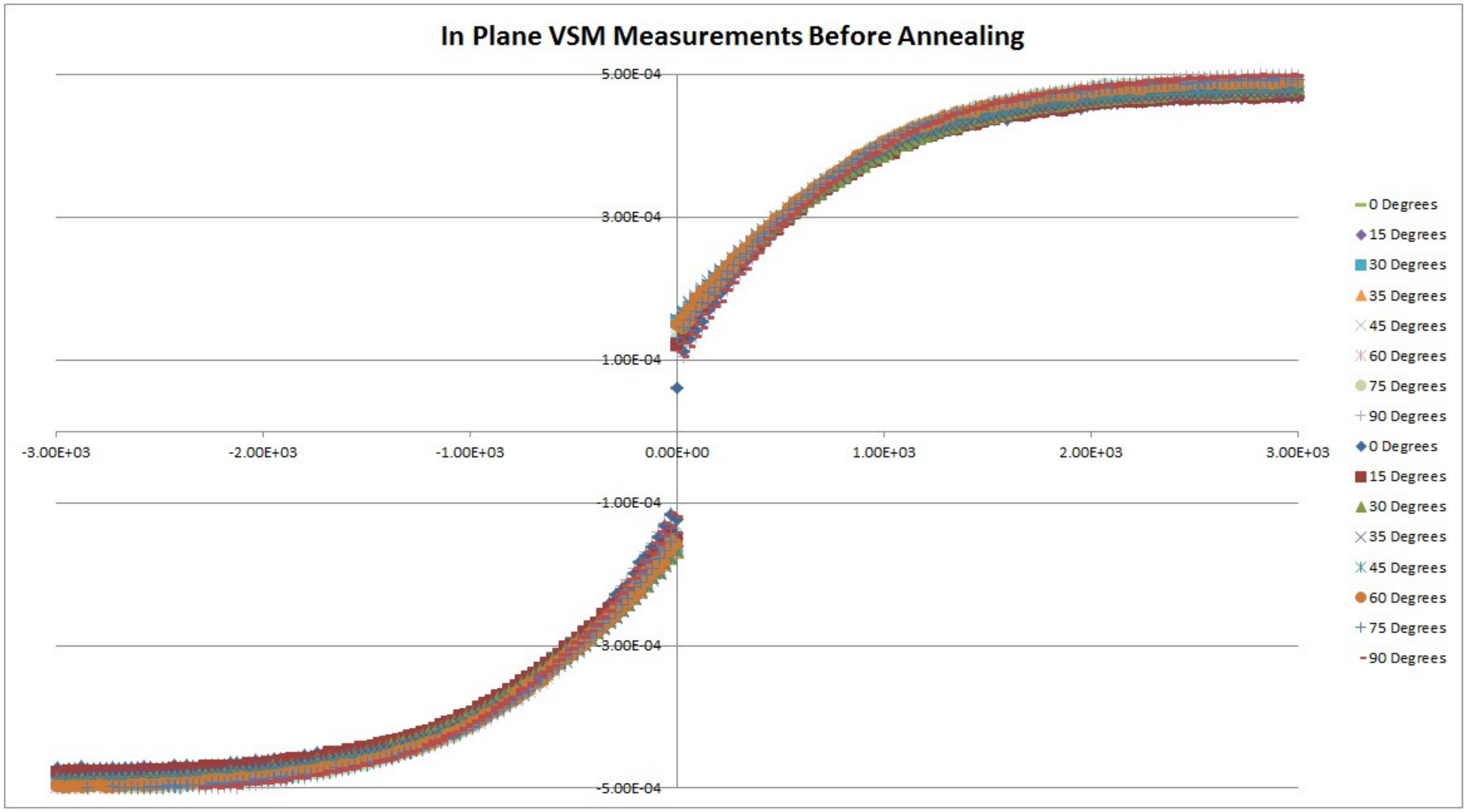


Figure 7: Hysteresis loops for the sample before annealing. The small changes of the hysteresis loop shape were observed as the angle of the magnetic field varied.

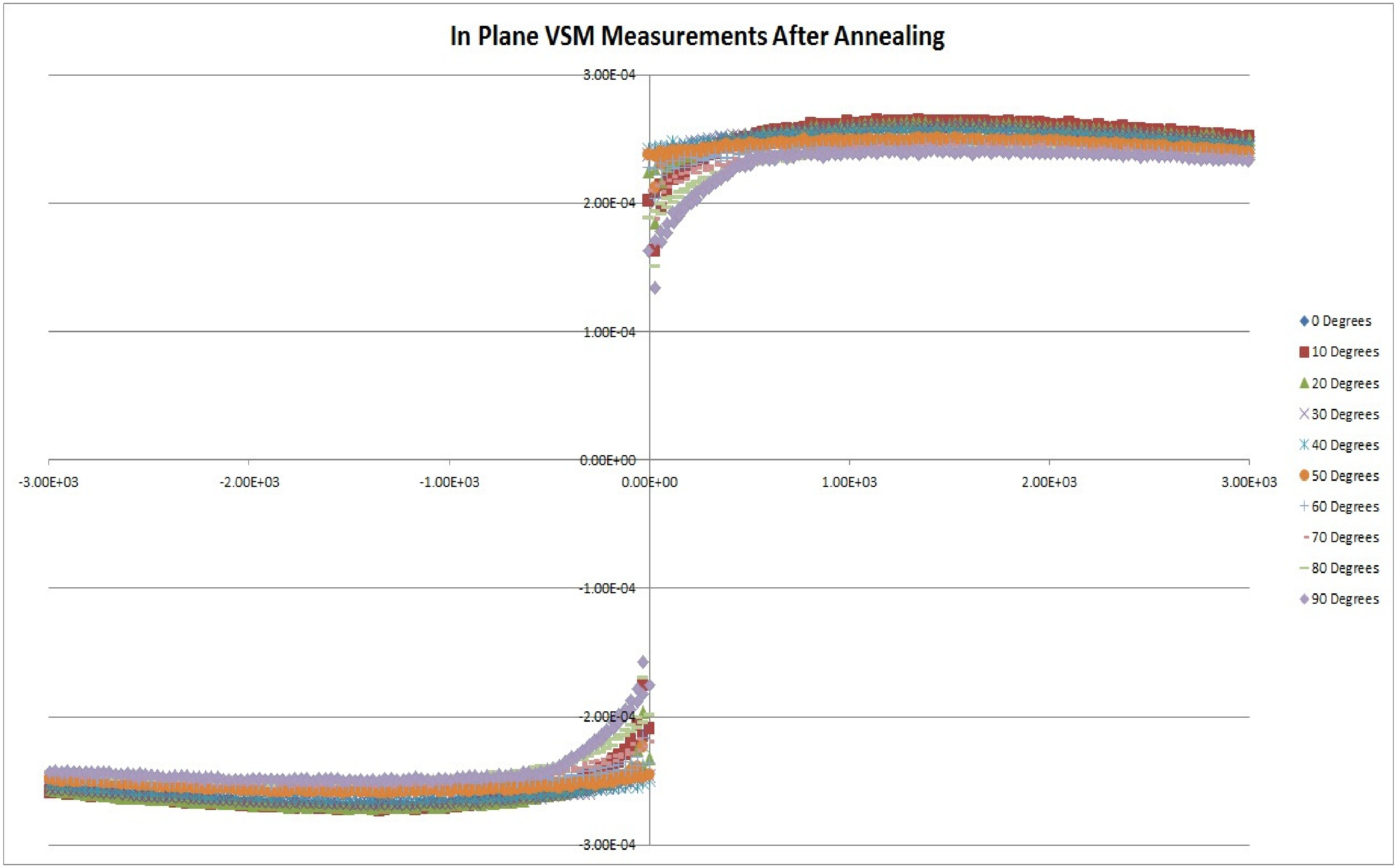


Figure 8: Hysteresis loops for the sample after annealing. The change of the shape and openings of the loop with angle suggest good quality crystalline single crystal film with easy anisotropy axis at 45 deg to the MgO substrate edges.

Conclusions

- It was experimentally found that the growth condition and post-deposition treatment strongly affect magnetic properties of Fe films deposited on top of single crystal MgO substrate.
- Both the RHEED images and FMR measurements suggest the growth of single crystal iron.
- However, it is clear from the increased smoothness of the films and angular dependences of the hysteresis loops and ferromagnetic resonance that annealing the sample at 400° Celsius improves the crystallinity of the Fe films.

Acknowledgements

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