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Imaging the magnetic properties of materials at the 1 μm length scale

G.D. Howells, R.J. Prance *, T.D. Clark, C. Watkins, C. Vittoria [1]

ENGG, University of Sussex, Falmer, Brighton BN1 9QT, UK

Abstract

We describe a new type of scanning magnetic microscope capable of imaging magnetic properties of materials with, at present, 1 μm resolution. We use carefully machined, nearly closed magnetic circuits to restrict the dimensions of the fringing field of a sense head to approximately 1×1 μm^2.

1. Introduction

Novel gyrator circuitry has been developed to enable the sense head to be resonated at audio frequencies (kHz) with the quality factor under external control over a range of 10–100. The complete system consists of the sense head, mounted on a computer controlled *XYZ* stage, above a sample. This allows scanning to be performed at any required height. Frequency shift (and hence sample susceptibility) information is obtained by comparing the phase of the signal from the resonant gyrated sense head with a reference oscillator. Using this instrument we may probe the local (1 μm resolution) susceptibility of magnetic materials.

2. Sense system

A block diagram of the complete system is shown in Fig. 1. The small gap (< 1 μm) sense head is polished to produce approximately a 1 μm long gap region at the tip. The inductance of this head is approximately 1 μH, and this is incorporated into a single op amp gyrator circuit [1]. The resulting impedance behaves like a capacitor of 340 pF. By replacing one of the resistors in the gyrator with a FET we are able to control the effective quality factor (Q) of our gyrator, although extremely stable FET gate voltages (1 ppm/°C) are required to achieve this. The gyrator is now connected in parallel with an inductor of 1.5 H to form a resonant circuit at 7 kHz with an adjustable Q (10–100). In Fig. 2 we show a typical resonance curve for such a system with a Q of 75. Circuit simulations of this complete resonant system are in good agreement with experimental results.

The principle of operation of the system is the measurement of the phase shift induced by magnetic samples placed close to the sense head gap. This phase shift arises from the change in the effective inductance of the head due to the magnetic susceptibility of the sample. Since we drive the system on resonance, the phase shift is proportional to the resulting frequency shift and hence to the susceptibility. Finite element analysis [2] of the region around the head gap indicates that the sensitivity of a head with a 1 μm gap falls by a factor of ten at a perpendicular distance of 3 μm from the gap. In addition, on axis the sensitivity falls by a factor of ten at a distance of 4 μm from the centre of the gap. These calculations confirm that the region of the sample being probed by this system is of the order of a few microns at the current level of development.

3. Measurements

All that is required now to produce magnetic images of samples is to mount the sense head/gyrator on an *XYZ* scanning table with appropriate data acquisition software. This allows us to perform raster scans with any desired

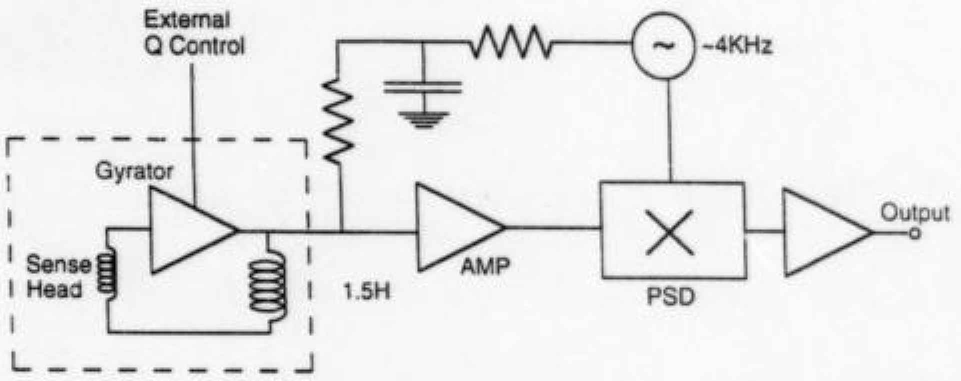

Fig. 1. Block diagram of the scanning magnetic microscope system.

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[*] Corresponding author. Fax: +44-273-686-670.

[1] Present address: Department of Electrical Engineering, Northeastern University, Boston, MA 02115, USA.

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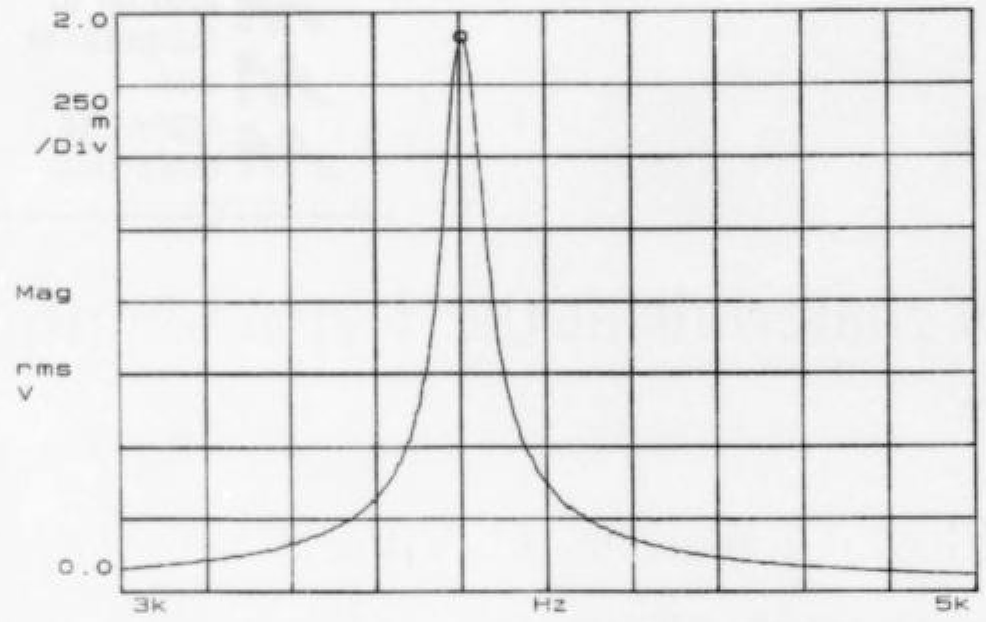

Fig. 2. Measured frequency response of resonant sense head and gyrator with $Q = 75$.

step size from 0.5 μm upwards and at any desired sample to sense head spacing. The phase shift output is recorded as a function of position using National Instruments' LabView software.

The purpose of creating this scanning magnetic microscope is to provide a non-contact method of imaging the magnetic properties of materials. In Fig. 3 we show a scan over the surface of a sheet of silicon–iron (Si–Fe) alloy. This clearly shows the magnetic domain structure of the material at large scale. In Fig. 4 we see the result obtained from a scan over an amorphous thin film of $Fe_{80}B_{15}Si_5$. The sample was fabricated to include defined dots with diameters from 40 μm down to 10 μm with a film thickness of 0.2 μm.

4. Conclusions

The ability to create images of the microscopic magnetic properties of materials is of obvious importance, and this capability has been demonstrated above. Currently, we are able to resolve magnetic susceptibility information at the level of a few microns and we are developing the sensor to improve both stability and resolution. Increased stability will allow for longer scan times and result in enhanced resolution. In addition we have incorporated an integral pair of Helmholtz coils in order to apply a bias field to the sample. The feasibility of measuring sample B–H curves as a function of position is now being investigated using this apparatus.

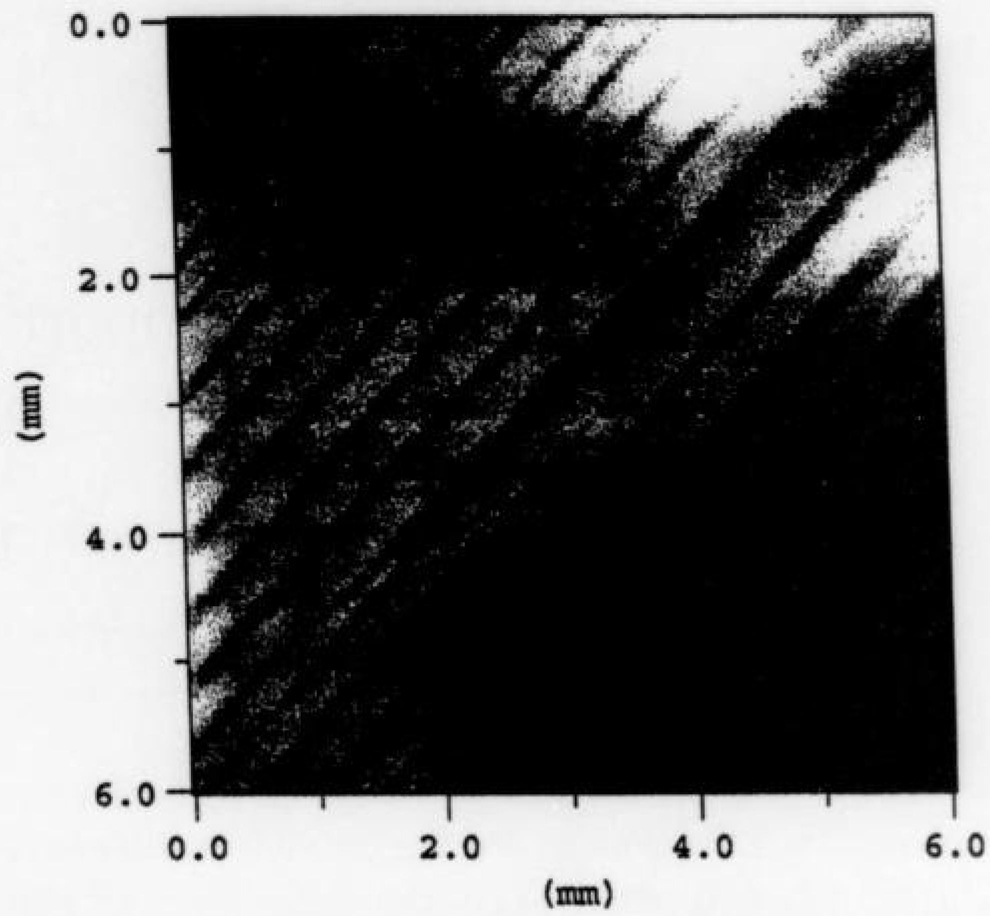

Fig. 3. Magnetic microscope scan over the surface of SiFe sheet showing magnetic domain structure.

References

[1] P. Horowitz and W. Hill, The Art of Electronics (Cambridge University Press, Cambridge, 1989) p. 266.

[2] PC-OPERA, Finite Element Analysis Programme, Vector Fields Ltd, Oxford.

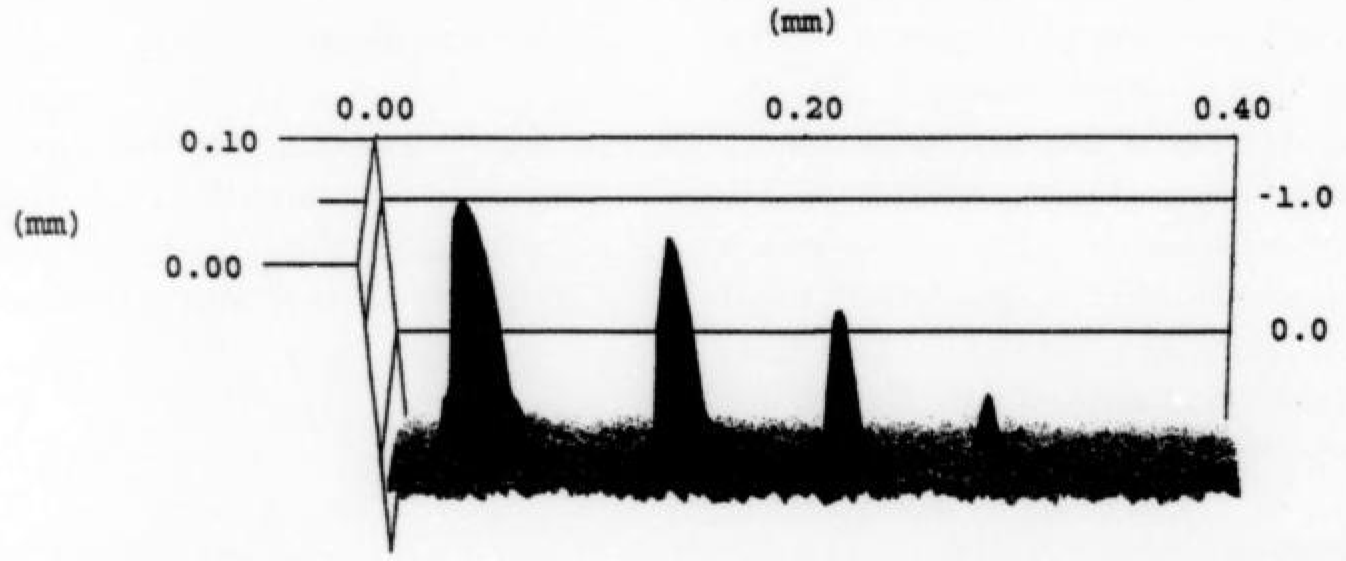

Fig. 4. Magnetic microscope scan over the surface of a thin film of $Fe_{80}B_{15}Si_5$ showing dots of 40, 30, 20 and 10 μm diameter.