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Room Temperature Scanning Hall Probe Microscopy in External Fields

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A new versatile room temperature scanning Hall probe microscope system (RT-SHPM) was developed and used for the magnetic imaging of longitudinal magnetic recording media, low coercivity perpendicularly anisotropic iron garnet epitaxial layers, and demagnetized strontium ferrite permanent magnets placed in externally applied magnetic fields. The RT-SHPM incorporates an ultra-high sensitive sub-micron GaAs Hall probe (active area of ~ 0.8x0.8 μm^2; room temperature Hall coefficient of 0.3Ω/G; field sensitivity of 0.04 G/√Hz) with an integrated scanning tunnelling microscope tip for vertically positioning the probe in very close proximity to sample surfaces. The Hall probe is not magnetized by magnetic fields hence enabling the real time (~1frame/sec) measurments in external magnetic fields. Results described include the observation of otherwise sharp magnetic transitions in written floppy disks to coalesce into small islands under external fields greater than 1300 Oe and the transformation of magnetic bubble lattices into striped-maze patterns in Bi-substituted iron garnet epilayers in cycled external fields.

Keywords: scanning Hall probe microscopy, magnetic recording, garnets, magnetic domains, permanent magnets

1. Introduction

A fundamental knowledge of the physical properties of magnetic domains is important for the development of magnetic information storage technology [1], high coercivity permanent magnets [2] and the next-generation of magneto-electronic devices where operation is based on control of electron spin [3]. The experimental observation of such magnetic domain structures has historically been an extremely active area of research with early reports of the visualization of silicon-iron reported by Williams and Shockley as far back as in 1949 [4].

In this paper we demonstrate the versatility of a new room temperature scanning Hall probe microscope system (RT-SHPM). The system enables the quantitative and non-invasive imaging of magnetic structures even in the presence of externally applied magnetic fields. The RT-SHPM offers tremendous practical advantages over other methods used for monitoring magnetic domains such magnetic force microscopy, SQUID technology, Kerr and Faraday effect microscopy. The magnetic structures studied included commercially available written floppy disks, ZIP media, single crystal Bi-substituted iron garnet epilayers and demagnetized strontium ferrite permanent magnets.

2. Room Temperature Scanning Hall Probe Microscope System

Fig.1 shows the main components of the RT-SHPM. The system was specifically designed for use at room temperature with a maximum scanning range of 50x50 μm^2. A GaAs/AlGaAs heterostructure micro-Hall probe sensor (HP) was mounted onto a piezoelectric scanning tube (PZT) at a tilt angle of 1.5° with respect to the sample. A scanning tunnelling microscope (STM) tip integrated adjacent to the HP was used for its precise vertical positioning. Magnetic imaging was carried out by first using a combination of high resolution stepper motors (coarse) and the PZT (fine) to

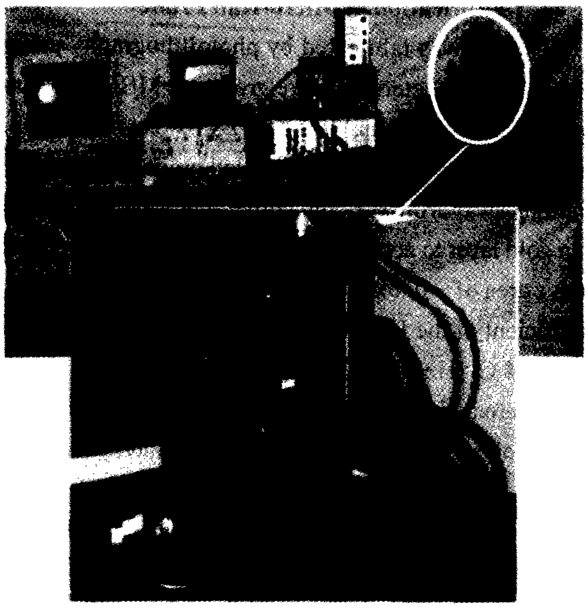


Fig. 1 Room Temperature Scanning Hall Probe System

position the HP into close proximity to the sample surface until a tunnel current was detected at the STM tip. Next, the HP was scanned over the surface while simultaneously measuring changes in Hall voltage that are proportional to fluctuations of the perpendicular component of the magnetic field emanating from the surface.

The system was designed to be easy to use with the following features: (i) the tilt angle between the Hall probe and sample surface was precisely adjusted using an electronic angle sensor coupled to the PC control software; (ii) coarse sample approach was achieved by a high resolution motorized z-stage with a 25 mm range; (iii) the use of electrodes on the reverse-side of the Hall probe chip carrier for electrical connection of the Hall bar and STM tip to the control and biasing electronics; (iv) data acquisition with a choice of 3 modes including the *STM/SHPM mode* where scanning is carried out while simultaneously monitoring STM tip tunnel current and the real time mode where a 128 x 128 pixel scan is possible in aproximately 1 second; (v) an electronic control system incorporating an ultra stable dc current source and low noise amplifier circuits.

2. 1 Fabrication of Micro-Hall Probe

The HP was fabricated by photolithography using a GaAs/AlGaAs heterostructure grown by MBE with a two dimensional electron gas density of 2×10^{11} cm^{-2} and mobility of 400,000 cm^2/Vs, at 4.2K. The Hall probe was located 13 microns away from the chip corner that was coated with a thin gold layer to act as the STM tip. The Hall probe had an active area of ~ 0.8 x 0.8 μm^2. The room temperature Hall coefficient of the HP was 0.3Ω/G and the field sensitivity was 0.04 G/√Hz. The STM tip was not coupled to the Hall bar thus reducing noise during measurement. A Hall drive current of 3 mA was used for all the measurements.

2.2 Data Visualization

The raw two-dimensional gray-scale image data of RT-SHPM scans was stored as either a bit-map or ASCII format. In some cases, a three dimensional visualization of the SHPM image can be more informative for interpreting results. For such purposes, we developed unique program routines for the static and animated 3D visualization of SHPM data using Interactive Data Language (IDL v.5.3) [5].

3. Results

3.1 Longitudinal Magnetic Recording Media

Figs.2 is a typical 25μm x 25μm RT-SHPM image of a written 3.5-inch floppy disk clearly showing the transitions adjacent to a gap between two tracks. This image was obtained using the *STM/SHPM mode* of the RT-SHPM system where the surface was scanned whilst simultaneously monitoring the tunnel current at the STM tip.

Figs. 3(a-f) are representative 25 μm x 25 μm images taken in the *real time SHPM mode*, showing the coalescence of floppy disk transition regions under perpendicular fields upto 3460 Oe. The graph below shows the variation of the measured magnetic fields along the lines on the images.

Fig. 4 shows a 50μm x 50μm *STM/SHPM mode* image of a ZIP disk where the field variations along the line shown.

3.2 Bi substituted single crystal iron garnet crystals

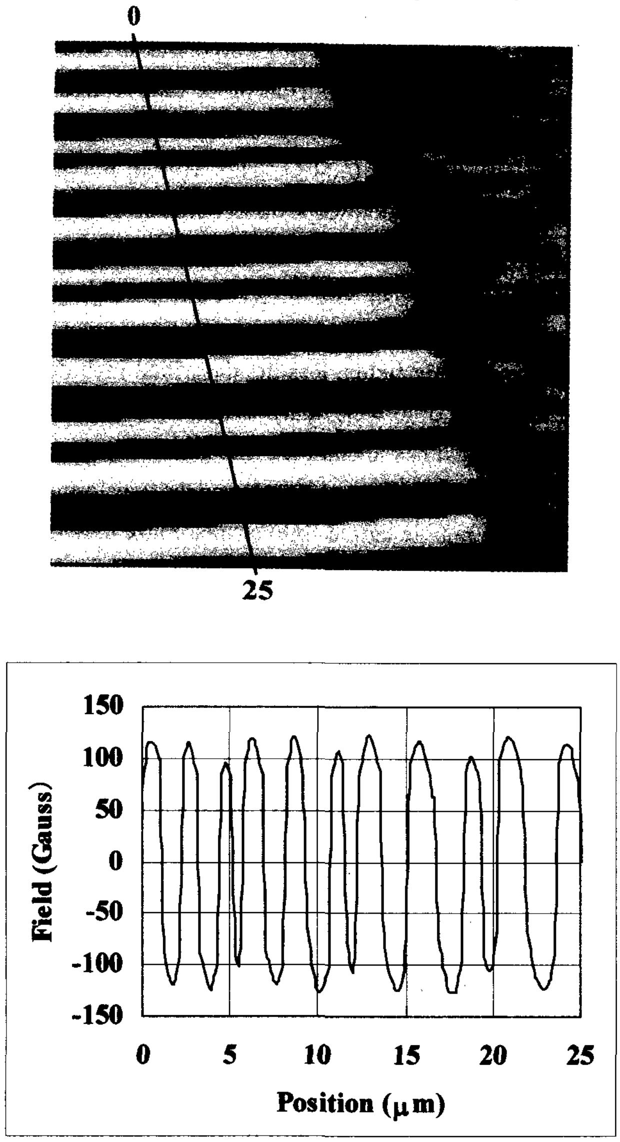
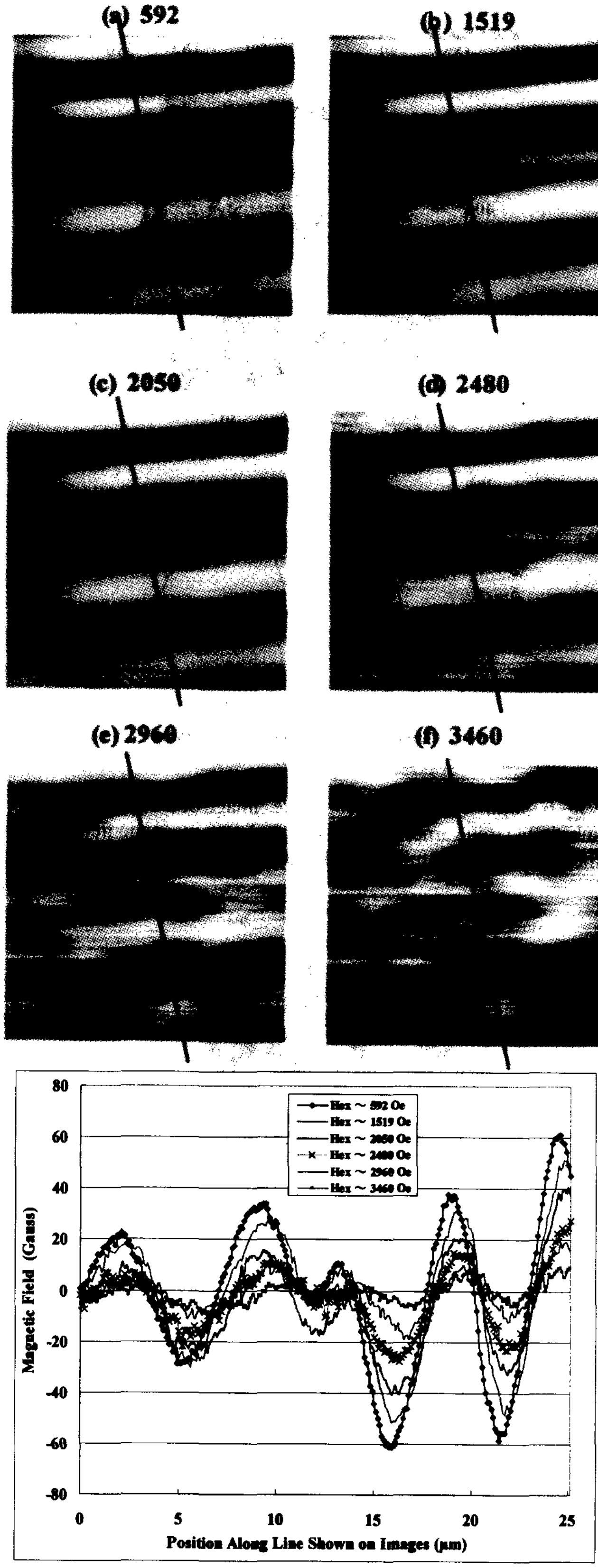


Fig.2 A 25μm x 25μm RT-SHPM image of a written track on a 3.5 inch floppy disk. The graph below shows the field variation along the line.



Figs. 3(a-f): Typical 25 μm x 25 μm images showing the coalescence of floppy disk transition regions under perpendicular fields u to 3460 Oe .The graph below shows magnetic field variations along lines.

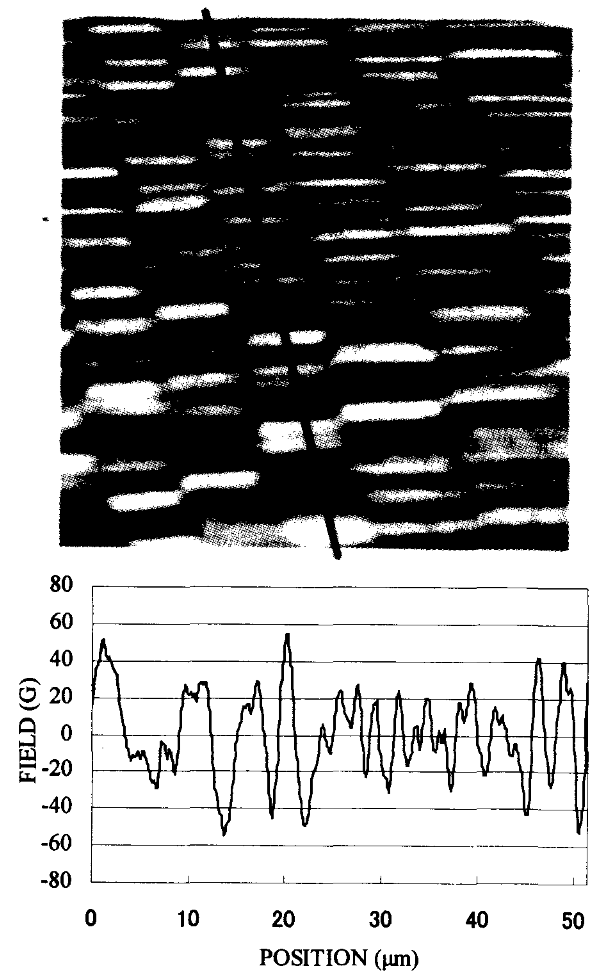


Fig.4. 50μm x 50μm *STM/SHPM mode* image of a ZIP disk . Graph below shows the variation of magnetic field along line shown.

Fig.5 shows representative 25μm x 25μm SHPM images of a 5.5 μm thick single crystal bismuth substituted iron garnet epilayer measured in the *real time SHPM mode* with the garnet placed in a cyclic external perpendicular field as indicated. A total of 25 images were taken at 25 Oe intervals. The images clearly show the initial hexagonal bubble lattice to expand and transform into a maze pattern. The measured field ranged between ±59G. These results show the configurational hysteresis of domain structures in low-coercivity films with strong perpendicular anisotropy[6].

Fig. 6 shows a 50μm x 50μm image of a 360μm thick Bi substituted iron garnet epilayer. The image resembles 'fujitsubo' (barnacles) as observed in the gray scale inset image. The RT-SHPM image reveals a very complicated spatial magnetic field distribution that is not observed using conventional optical techniques often used for characterization of garnets. The graph shows the variation

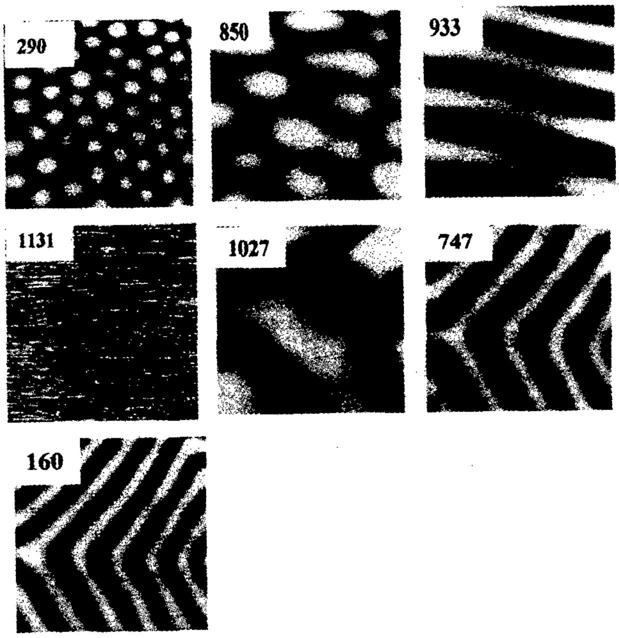


Fig. 5 Typical 25 μm x 25 μm images of a 5.5 μm thick single crystal bismuth substituted iron garnet epilayer garnet

of magnetic field along the line [A-B] across one of the 'fujitsubo-like' domain structures.

3.3 Sr Ferrite Permanent Magnet

Figs. 7(a) and 7(b) show the RT-SHPM images of a demagnetized Sr ferrite magnet without and with (1760 Oe) an external perpendicular field, respectively. Domain structures are clearly imaged and are seen to increase in size on application of the external field.

4. Summary

A new versatile room temperature scanning Hall probe microscope system was used for the quantitative magnetic imaging of storage media, garnets and demagnetized strontium ferrite permanent magnets. The RT-SHPM system is expected to find a wide range of applications in the development of information storage media and permanent magnets as well as new technology related to 'spintronics', where semiconductor/ferromagnetic hybrid structures are being studied for the next generation of magneto-electronic devices.

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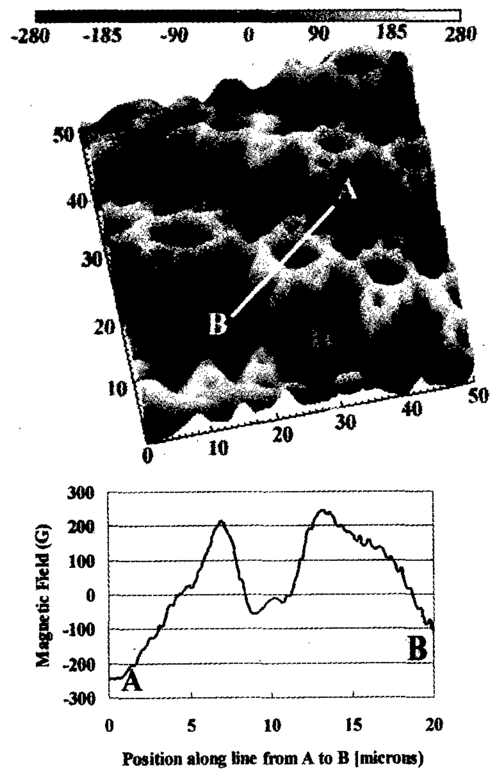
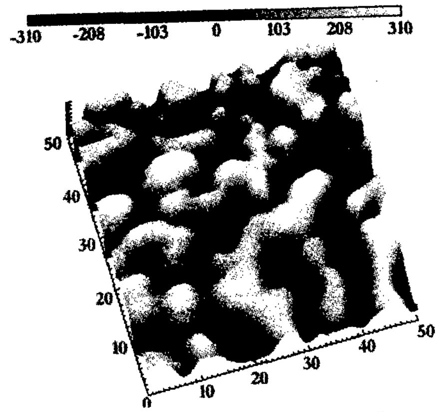
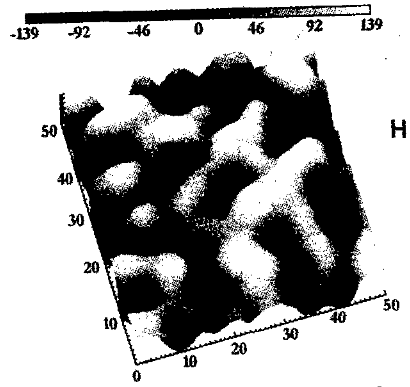


Fig. 6 50μm x 50μm 'fujitsubo-like' image of a 360μm thick Bi substituted iron garnet epilayer. Graph shows magnetic field along the line across the 'fujitsubo-like' domain.



7(a)
H_{ex}= 0



7(b)
H_{ex}=1760 Oe

Fig. 7(a) 50μm x 50μm RT-SHPM image of a demagnetized Sr ferrite magnet without external field

Fig.7 (b) 50μm x 50μm RT-SHPM image of demagnetized Sr ferrite magnet placed an external perpendicular field of 1760 Oe.