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Room temperature scanning Hall probe microscopy of localized magnetic field fluctuations on the surfaces of magnetic recording media, permanent magnets and crystalline garnet films in external bias fields

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Abstract

A sub-micron room temperature scanning Hall probe microscope (RT-SHPM) was used for real-time imaging of surface magnetic domains of floppy disks, Sr ferrite magnets and Bi-substituted iron garnets placed in large external bias fields. Domain wall nucleation was observed in the garnets where bubble lattices expanded, collapsed and transformed into stripe domains in cyclic bias fields. Evolution of RT-SHPM images was compared with conventional vibrating sample magnetometer measurements.

Keywords: Microdomains; Ferromagnets; Garnets; Magnetic recording media; Hall effect

The development of ferromagnetic materials used for high performance permanent magnets, recording media and garnets requires a fundamental understanding of the behavior of magnetic domains in the presence of external bias fields [1].

In this paper, we demonstrate the versatility a new room temperature scanning Hall probe microscope (RT-SHPM) system for the direct, non-invasive, and quantitative imaging of domains on the surfaces of floppy disks, strontium ferrite permanent magnets (SFM) and crystalline Bi-substituted iron garnet thin films in the presence of large external magnetic fields.

A detailed description of the RT-SHPM system, as schematically shown in Fig. 1, has been previously reported [2–3]. It is based on a low-temperature SHPM system [4] and consists of a GaAs/AlGaAs heterostructure micro-Hall probe (HP) mounted onto a piezo-electric scanning tube (PZT) at a tilt angle of 1.5° with respect to the sample surface. A scanning tunnelling microscope (STM) tip was integrated adjacent to the HP for precise vertical positioning and the coil used for calibrating the HP. Magnetic imaging was carried out by scanning the HP over the surface of the sample while simultaneously measuring changes in Hall voltage that are proportional to fluctuations of the perpendicular component of the stray magnetic field emanating from the surface. All measurements were made at a height of ~0.27 μm above the sample surfaces.

Some pertinent features of the RT-SHPM include: (i) scan range up to $50 \times 50\,\mu m^2$; (ii) data acquisition with a choice of 3 modes including the *real time mode*, where a 128×128 pixel scan is possible in about 1 s. The HP had an active area of $\sim 0.8 \times 0.8\,\mu m^2$, a room temperature Hall coefficient of $\sim 0.3\,\Omega/G$ and a field sensitivity of $0.04\,G/\sqrt{Hz}$. The STM tip was not coupled to the Hall bar thus reducing noise during measurement. The room temperature series resistance (longitudinal) of the HP was $\sim 70\,k\Omega$ enabling a maximum Hall drive current of

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$\sim 3\,\mu A$. The noise level (Johnson noise) could be reduced further by using probes with a smaller series resistance.

The FD samples were commercially available 1.4 MB disks that were written prior to measurements. The SFM samples were cut from a block and surfaces normal to the easy axes polished until the roughness was $< 0.2\,\mu m$ as measured by the STM tip integrated with the HP. Typical dimensions of the resulting samples were 5×5 mm with a thickness of 400 μm. The garnet samples were Bi-substituted iron crystalline 5.5 μm thick films grown on non-magnetic (GGG) substrates by liquid phase epitaxy [5].

External bias fields (H_{ex}) were applied using a neodymium iron boride permanent magnet enabling magnitudes of up to 3500 Oe to be applied perpendicular to the sample surfaces. The magnitude of H_{ex} was varied by changing the distance between the sample and permanent magnet. The external fields were applied in regular steps and the RT-SHPM scan carried out in synchronization at 1 frame/s thus enabling almost real-time measurements. Sample hysteresis loops measured using a vibrating sample magnetometer (VSM).

There was no observable correlation between the STM-tip topography and the magnetic images for any of the samples studied. Figs. 2a–f are typical 25 μm × 25 μm

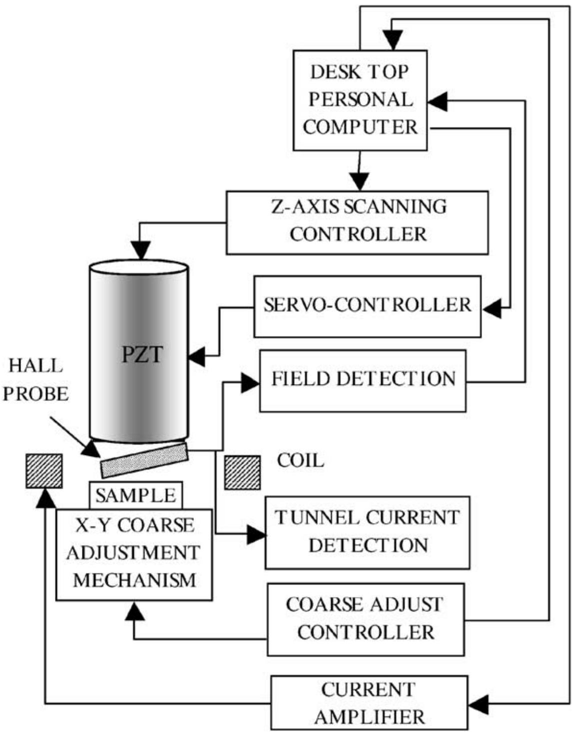

Fig. 1. Diagram illustrating the main components of the room temperature scanning HP system (RT-SHPM).

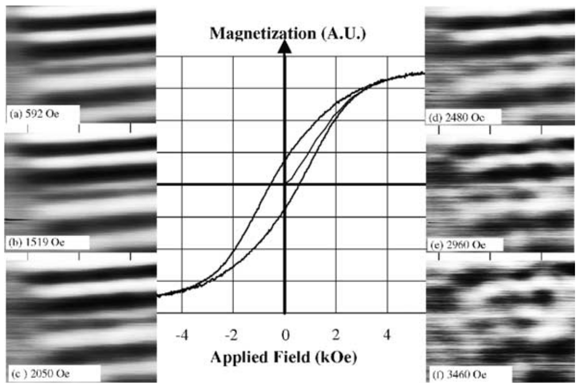

Fig. 2. The variation of RT-SHPM images (25 μm × 25 μm) of a 1.4 MB written floppy disk with external bias fields applied perpendicular to the disk surface. The corresponding VSM magnetization curve is also shown.

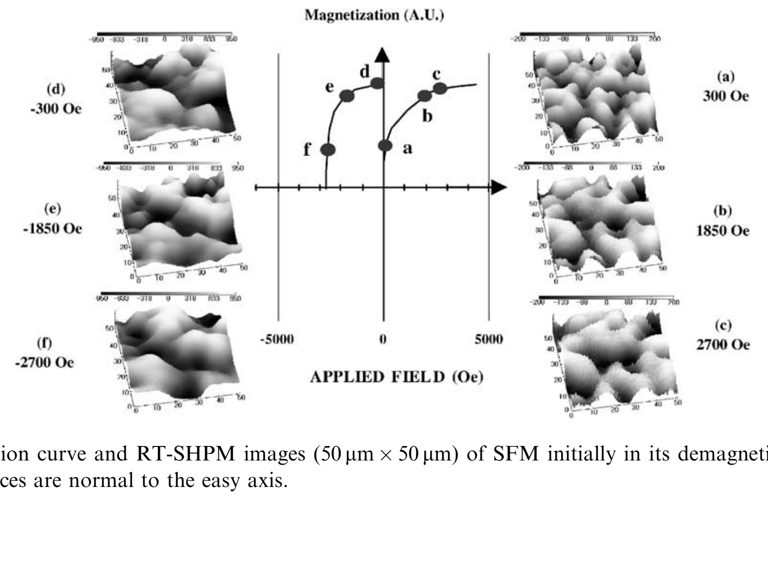

Fig. 3. VSM magnetization curve and RT-SHPM images (50 μm × 50 μm) of SFM initially in its demagnetized (a–c) and remanent (d–f) states. Image surfaces are normal to the easy axis.

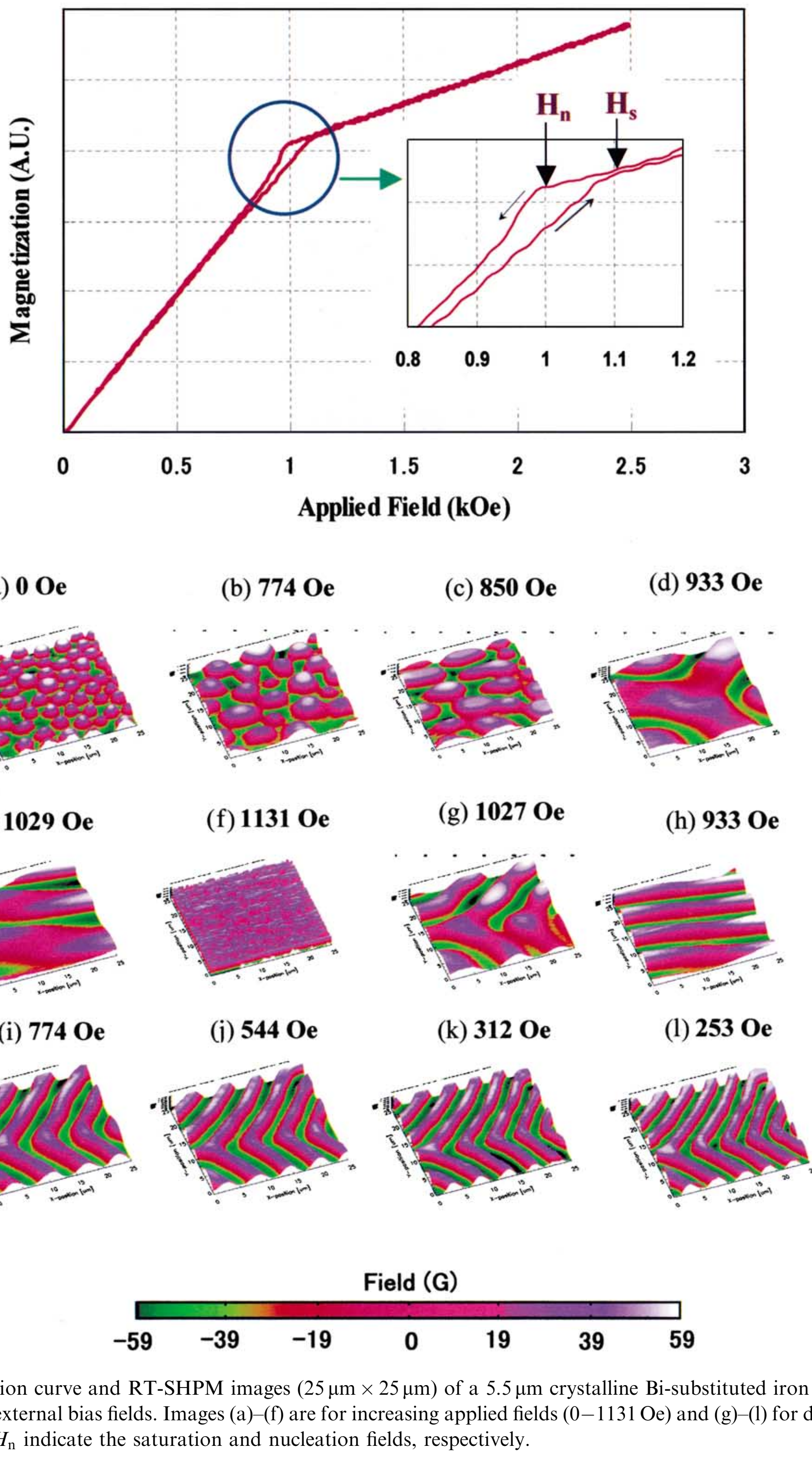

Fig. 4. VSM magnetization curve and RT-SHPM images (25 μm × 25 μm) of a 5.5 μm crystalline Bi-substituted iron garnet thin film placed in perpendicular external bias fields. Images (a)–(f) are for increasing applied fields (0−1131 Oe) and (g)–(l) for decreasing values (1027–253 Oe). H_s and H_n indicate the saturation and nucleation fields, respectively.

RT-SHPM images of the written FD placed in an increasing external magnetic field applied perpendicular to the disk surface. The FD surface was imaged continuously as the external field was increased from zero to a maximum of 3460 Oe in 150 Oe steps. The black and white regions in the RT-SHPM images represent magnetizations into and out of the plane of the paper. The initial distinct magnetic transitions are seen to deform and coalesce into island-like regions at fields approaching the saturation field of 4000 Oe as measured by the VSM with H_{ex} applied perpendicular to the disk surface. The stray surface fields measured by the RT-SHPM decreased from ± 60 G to $< \pm 10$ G as the external applied field was increased from 593 to 3460 Oe. The reason for these observed field variations are unclear and are being investigated.

Fig. 3 shows typical $50 \times 50\,\mu$m images (surface normal to the easy axis) of the variation of surface magnetic field fluctuations with increasing H_{ex} applied along the easy axis of an SFM initially in a demagnetized state (3a–c) and remanent state (3d–f). The results of the corresponding VSM measurement are also shown. The RT-SHPM images show magnetic regions on the sample with magnetization perpendicular to its surface due to the existence of clusters of multi-domain grains. The SFM samples used in this study were produced by a process involving sintering with grain sizes ranging between 2–10 μm as observed by SEM measurements. It can be seen that at $H_{ex} = 300$ Oe the size of the domains on the SFM in the demagnetized state are 5–10 μm with those in the remanent state being larger. Inspection of the RT-SHPM images shows domain movement followed by rotation with increasing external bias fields. A detailed micro-magnetic evaluation of these results is in progress and the results will be reported elsewhere.

Fig. 4 shows $25\,\mu\text{m} \times 25\,\mu$m images of a 5.5 μm thick crystalline Bi-substituted iron garnet thin film in external perpendicular bias fields and the corresponding VSM loop. Images (a) –(f) are for increasing applied field (0−1 1 3 1 e) and (g)–(l) for decreasing values (1027–253 Oe). The initial bubble lattice is seen to expand and ultimately transform into a maze pattern. The measured fields varied between ± 59 G. A comparison of the VSM magnetization results and RT-SHPM results shows good agreement between the saturation field (H_s), where bias field causes a change from a multi-domain to single domain structure and the nucleation field (H_n) where a single domain transforms into a multi-domain structure. These results are direct evidence of configurational hysteresis of domain structures in low-coercivity films with strong perpendicular anisotropy [6]. The control of such domain structures is important for operation of optical devices such as optical isolators.

The RT-SHPM system was demonstrated to be a valuable tool for the direct, quantitative and non-invasive observation of localized stray magnetic field fluctuations at the surface of ferromagnetic materials in the presence large external bias fields. We are currently working on the fabrication of Hall probes with a higher spatial resolution and the incorporation of magnets for applying external fields > 1 T.

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