

Nanoscale microscopy of magnetic materials

The density of data-storage on magnetic media, –the common hard-disk–, has increased by more than 60% per year over the past two decade. In 1995, the data density was about 0.25Gb/in² (gigabit/square inch of disk), in 2003 it is expected to reach 100Gb/in². The individual magnetic data bits are reaching dimensions in the range of tens of nano-metres. The requirements on the magnetic materials become very severe, and extreme optimisation is essential. This is true especially for the read-heads as smaller magnetic bits produce smaller signals, leading to signal-to-noise problems.

Advanced magnetic materials serve not only the magnetic storage industry, but also other industrial sectors, notably sensors. A crucial condition for the continued development of these materials is the ability to visualise the magnetic domain structure. The behaviour of magnetic domains are key to the understanding of the overall magnetic properties of the systems. However, the shrinking magnetic structures have reached the limits of classical magnetic imaging techniques.

It is therefore necessary to develop novel magnetic imaging methods, which will provide resolutions around the 40 nano-metre and below. This is the field of magnetic nano-microscopy. There are a variety of basic approaches, of which three are explored in this project: **magnetic force microscopy (MFM)**, **magneto-optic near-field scanning microscopy (MO-SNOM)**, and **spin-polarised scanning tunnelling microscopy (SP-STM)**. The parallel development of different techniques allows a realistic assessment of their specific sensitivity and practicality.

The current market for magnetic data storage products is in the range of 50 billion euros annually. Most of this consists of hard disks for personal computers. This is a volatile and very technologically competitive market, dominated by a handful of global players.

The Technology

Magnetic Force Microscopy is derived from atomic force microscopy. In MFM, a nano-sized magnetic particle is attached to the tip of an atomic force cantilever. The particle experiences a magnetic force, proportional to the local magnetic field, as it is scanned in close proximity to a magnetic surface.

Magneto-Optic Near Field Microscopy is derived from near field optical microscopy. The measurement relies on the effect of the local magnetic field on the optical polarisation (magnetic Kerr effect) of a very fine light beam, of about 10 nano-metre (nm) diameter.

Spin-Polarised Scanning Tunnelling Microscopy is a special version of scanning tunnelling microscopy. A scanning probe needle (with a tip radius of some 10 nm) is brought close enough to the surface for quantum tunnelling to occur. The magnitude of the tunnelling current then provides a measurement of the local magnetic field.

The project aims to develop these advanced magnetic imaging techniques to the level of commercial instruments. This includes an exploitation strategy targeting the mass production of MFM tips.

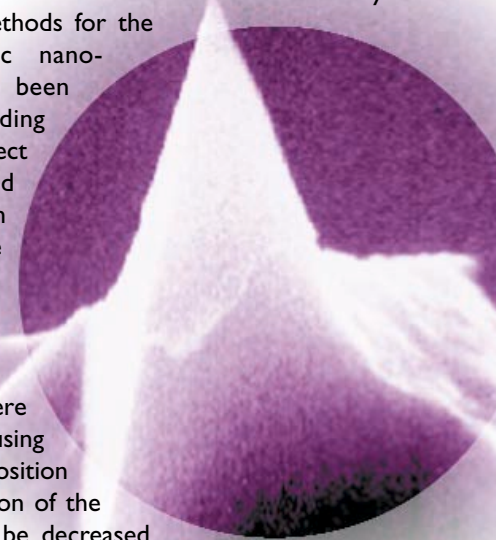
The current market for MFM probes may be estimated to 0.7 million euros annually, with a growth of some 15% per year.

Achievements

The project is now in its third year, and the work is progressing well. Key milestones have been reached.

Some highlights are:

- **Magnetic test samples.** "Real-life" test samples have been taken from hard disk systems. Various novel methods for the creation of magnetic nano-structures have been explored, including e-beam lithography, direct writing with an MFM, and "cold-atom" deposition in a laser interference pattern.
- **Improvement of the spatial resolution of MFM microscopy.** Advanced MFM tips were successfully prepared using an electron-beam-deposition technique. The resolution of the MFM technique could be decreased to about 30 nm, using carbon needles attached to micro-machined silicon cantilevers.
- **Batch fabrication of MFM tips.** A batch fabrication process using focused-ion beam milling is under development.
- **MO-SNOM tips.** A technology was developed for the reproducible production of MO-SNOM tips, based on the drawing of optical fibres under laser illumination.
- **Prototypical microscope.** A modified instrument, based on a commercial non-magnetic unit, has been produced. A key point is the elimination of all magnetic material from the construction.



The Project Team

The partnership structure is based on complementarity, trans-nationality and multi-disciplinarity. The project is co-ordinated by the University of Saarland.

Seagate is a world leading manufacturer of hard disks and magnetic storage products. They are a clear end-user of the technologies developed in this project, as they would use nano-magnetic microscopy both for development and production quality control.

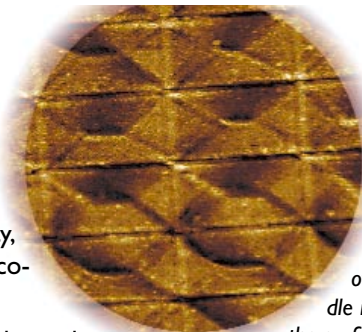
Triple-O is a world-wide supplier of scanning probe microscopes / measurement systems. Their responsibility is for the prototype MO-SNOM system.

Nanoworld Services is a leading manufacturer of tip and cantilever structures for scanning probe microscopy. They are responsible for the development of a mass-fabrication method.

The three universities – **Saarland, Nijmegen and Dublin** – pursue the sometimes complementary, sometimes competing, approaches to the development of the tips and the samples. As the work matures, the most promising ones have to be selected.

An application example

The project will contribute to the development of nano-magnetic microscope systems with 30 nano-meter resolution, which can be used routinely in a production environment. Such instrumentation, equipped with fully automated control, can be integrated in the production process for purposes of production quality monitoring and control.



Glossary

Atomic Force Microscopy: a needle with a tip radius of some nano meters is scanned over the sample surface. Deflection of the needle is measured and provides information about the surface topology, down to atomic level.

Scanning Tunnelling Microscopy: an electrically conducting needle is scanned within a few nano meters of the sample surface. This is close enough for electron tunnelling to take place. The tunnelling current provides information about surface topology and finer details, down to atomic level.

Tunnelling: the quantum-mechanical effect by which electrons can propagate through – very – thin insulating barriers. This is related to the wave nature of the electron behaviour.

Near-field Optical Microscopy: a hollow fibre needle is scanned over the sample surface. Light is shone through a small aperture at the tip. Light reflected from or transmitted through the sample provides information. The key point is that the aperture is so small (nano-metre range) that it generates light only within a few nano meters of the tip (the near field), resulting in a resolution in the nano-metre range. The near field effect is conceptually similar to the electron tunnelling effect.

Scanning probe research on nanoscale magnetism of advanced materials for high resolution recording

Magnetude

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Project co-ordinator:

Uwe Hartmann

u.hartmann@rz.uni-sb.de

University of Saarland

Saarbrücken (D)

University

www.uni-saarland.de/fak7/hartmann/welcome.html

Trinity College

Dublin (IRL)

University

www.tcd.ie/Physics/Nanotechnology

University of Nijmegen

Nijmegen (NL)

University

www.evsf2.sci.kun.nl

Seagate Technology (Ireland)

Derry (UK)

Manufacturer of hard disks and magnetic storage products

www.seagate.com

Triple-O Microscopy

Potsdam (D)

Manufacturer of scanning probe microscopes/measurement systems

www.triple-o.de

Nanoworld Services

Wetzlar (D)

Manufacturer of tip and cantilever structures for scanning probe

microscopy

www.nanoworld.com

Useful links

<http://www.cordis.lu/nanotechnology/home.html>

<http://europa.eu.int/comm/research/growth/>

<http://www.cordis.lu/growth>

growth infodesk: growth@cec.eu.int

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