Permanent magnet micro flux sources

Micro flux sources produce magnetic fields which are spatially modulated at the micron scale. They have many potential applications in the field of magnetic MEMS (Micro-Electro-Mechanical-Systems), as well as for biasing, diamagnetic levitation, the manipulation and trapping of particles and atoms, etc. The magnetic force on a magnetic particle submitted to the field of such a flux source depends on the field and on the field gradient created by the source. Since the field gradient is inversely proportional to the size of the field source, the force per unit volume increases as its size is reduced.

The use of permanent magnets to produce the flux offers a number of specific advantages. It favours autonomy and stability. By comparison, micro-patterned soft magnetic materials require the application of an external magnetic field while micro-coils operating in DC mode produce much smaller fields and field gradients. The challenge in fabricating micro-permanent magnet based sources is first of all to produce hard magnetic films of the appropriate thickness (1-100 µm). We have demonstrated that triode sputtering is suitable for the preparation of high performance hard magnetic films (NdFeB, SmCo) in thick film form. The second challenge is to laterally pattern the films on the scale of 1-100 µm. In a first approach we showed that standard micro-fabrication techniques (lithography, etching, planarization) can be applied to these highly reactive films (collaboration LETI). Here we will present an alternative and very promising patterning technique, namely Thermo-Magnetic Patterning (TMP).

When we heat a hard magnetic film we reduce its coercivity, i.e. the value of external magnetic field required to reverse its magnetisation. TMP (fig. 1(a)) exploits this fact to locally modify the direction of magnetisation, by localised heating through a mask in the presence of a magnetic field which is lower than the film's room temperature value of coercivity. An excimer laser operated in nanosecond pulsed mode at an ultraviolet wavelength is used so as to minimise reflection at the film's surface and lateral heat diffusion through the hard magnetic film. Qualitative magnetic imaging using Magneto-Optic-Indicator-Films (MOIF) (fig. 1b) and Magnetic Force Microscopy (MFM) reveals the magnetic patterns with lateral dimensions of roughly 50 µm and 7µm, respectively, which have been produced by TMP of 5µm thick out-of-plane textured NdFeB films (fig. 1c,d).

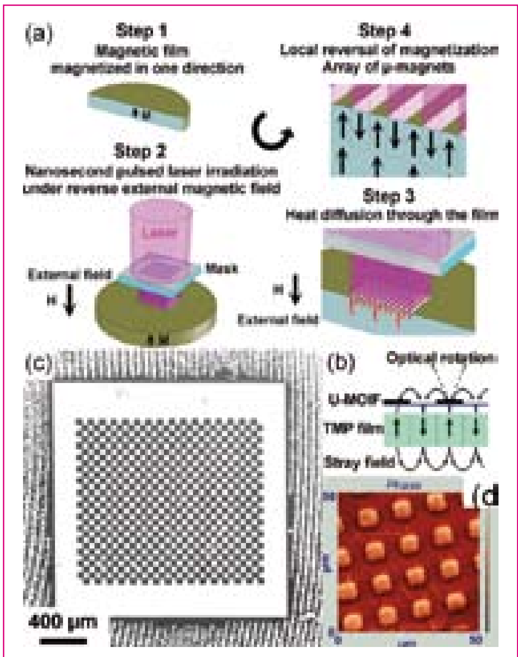

Figure 1:
(a,b) Schematic diagrams of the TMP process and magneto-optic imaging with a uniaxial Magneto-Optic-Indicator-Film (U-MOIF),
(c) Magneto-optic image of aMOIF placed on top of a uniaxially patterned out-of-plane textured NdFeB film irradiated through a mask with features of size 50 x 50 µm,
(d) MFM image of a similar film patterned with a mask containing features of size 7 x 7 µm^2.

The stray field patterns produced by these hard magnet micro-flux sources have been quantitatively characterised using a Scanning Hall Probe Microscope. Comparing these measurements with calculations we have estimated the depth of film over which magnetisation had been reversed by TMP to be of the order of 1.3 µm.

These hard magnet micro-flux sources constitute traps for superparamagnetic (SPM) particles and biological species incorporating superparamagnetic particles (collaboration Ampere Lab. Lyon). Preliminary experiments show that the magnetic field gradients produced at the interface between reversed and non-reversed regions of the hard magnetic films are strong enough (>10^6 T/m) to attract and trap 100 nm sized SPM particles flowing in a micro-fluidic channel above the film (fig. 2a). What is more, bacteria of 1µm in size (escherichia coli) internalised with the SPM particles by electroporation can also be trapped at these regions of high field gradient (fig. 2b). These preliminary results show the great potential for the use of permanent magnet micro flux sources for lab-on-chip applications in biology and medicine.

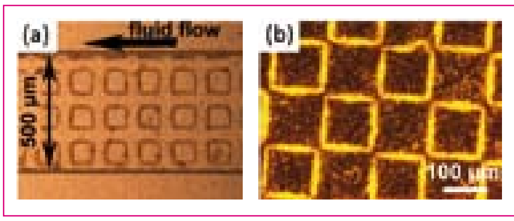

Figure 2:
(a) (collaboration Ampere Lab, Ecole Centrale Lyon). Optical image showing the trapping of superparamagnetic particles within a PDMS micro-fluidic channel (width: 500µm, height: 100µm) above a TMP NdFeB film,
(b) Fluorescent image showing the trapping of bacteria internalised with superparamagnetic particles on a TMP NdFeB film.

TMP can be used to produce complex magnetic field configurations such as linear Halbach arrays, for which flux is maximised on one side and minimised on the other side of the array. A linear Halbach array prepared by TMP of an isotropic NdFeB film is shown in figure 3. This demonstrates the potential for TMP to produce complex patterns at the micro-scale and should allow us to optimise the use of micro-flux sources in identified applications and eventually open the door to new applications.

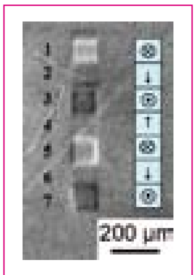

Figure 3:
magneto-optic image of a MOIF placed on top of a thermo-magnetically patterned linear Halbach array and schematic diagram showing the direction of the applied magnetic field during TMP.

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FURTHER READING

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