# Magnetic MEMS

**Nora M. Dempsey**
**Institut Néel, CNRS/UJF, Grenoble, France**

## 1) Why are magnetic MEMS of interest?

Micro-Electro-Mechanical-Systems (MEMS) are devices of sub-mm dimensions integrating various components (mechanical elements, sensors, actuators) and electronics on a common substrate (typically Si). They are progressively permeating our everyday lives, mainly in the form of micro-sensors (pressure, temperature, contact, chemical, gyroscopes etc…) and have applications in many fields including automotive, air-and-space, industrial processing and biotechnology. The potential impact of MEMS actuators has not yet been realised because their output forces, torques and energy densities are much limited by the mainly electrostatic principles upon which today's systems are based. Micro-actuators incorporating magnetic materials and based on magnetic actuation principles provide a number of advantages over electrostatic actuators, namely low voltage and power consumption combined with large actuation forces over relatively long distances. However their emergence has been limited by the non-availability of high quality magnets of the appropriate size.

## 2) Which magnetic materials for MEMS?

A variety of magnetic materials have potential applications in magnetic MEMS including familiar hard and soft materials as well as more exotic magnetostrictive, thermo-reversible and shape memory materials. While soft materials such as permalloy (FeNi) are relatively easy to prepare in film form by electrodeposition and sputtering, the processing of the other materials is more challenging. The core of this lecture will deal with the preparation of high performance hard magnetic materials based on rare-earth transition metal (RE-TM) alloys (NdFeB, SmCo) or $L1_0$ alloys (FePt, CoPt).

## 3) Preparation of µ-magnets

Various routes which have been used to prepare µ-magnets are listed in Table 1.

*Table1.* Techniques used to prepare µ-magnets.

| Top-down Routes | Bottom-up (deposition) Routes |
|---|---|
| Machining of bulk magnets | Electro-deposition |
| Screen printing, tape casting and bonding | Plasma spraying |
| Mechanical deformation | Pulsed Laser Deposition (PLD) |
| | Sputtering |

All routes have their advantages and disadvantages. A number of factors will determine the choice of preparation technique including:

- ***Process-material-compatibility***
- ***integratability into the overall micro-fabrication process***
- ***compatibility of substrates and buffer/capping layers with overall micro-fabrication process***
- ***thermal compatibility*** of the material with the substrate

### 3-i) Top-down preparation techniques

#### *Machining of bulk magnets*

This technique is presently used to prepare magnets for application in milli-systems (wrist watches, flip-dot displays, heart catheters...). There is a lower limit to the magnet thickness achievable by micro-machining (ca 150 µm for RE-TM magnets). High quality RE-TM magnets may suffer surface-degradation during micro-machining, resulting in the loss of coercivity of the surface layer, and thus the overall magnet remanence.

#### *Screen printing, tape casting and bonding*

Screen printing and tape casting are well adapted to fabricate isotropic films with thicknesses in the range of 0.1-1 mm. In the case of screen printing, the permanent magnetic thick film can be deposited directly onto the micro-system components.

#### *Mechanical deformation*

Cyclic mechanical deformation can be used to prepare foils of typical thickness 100 µm. Hot-deformation can be used to die-upset magnets down to thicknesses of several hundreds of microns.

### 3-ii) Bottom-up preparation techniques

#### *Electro-deposition*

Electro-deposition can be used to deposit certain materials at rates of up to a few µm/h over large areas. It is a technique already used in MEMS processing.

#### *Plasma spraying*

Plasma spraying is a rapid solidification technique in which alloy powder is injected into a very high temperature plasma flame and then projected onto a surface. It is suitable for the preparation of thick films ($\leq$ 1 mm).

#### *Pulsed Laser Deposition (PLD)*

PLD can be used to prepare films. However deposition rates tend to be low and deposited surfaces small.

#### *Sputtering*

Sputtering can be used to prepare films. Deposition rates and film surface areas depend strongly on the type of sputtering tool and target size. Triode sputtering is adapted to high deposition rates over large surfaces.

### 3-iii) A case study: high rate sputtering of thick hard magnetic films

Based on encouraging literature reports, and the fact that sputtering is one of the most promising routes for the integration of high quality magnets into MEMS, a high rate triode sputtering chamber was developed at Institut Néel. In our case, Si substrates are used so as to be compatible with local micro-technology platforms. The deposition of three high performance hard magnetic materials, NdFeB, SmCo and FePt has been studied. Thick films (5-50 µm) were deposited at deposition rates of up to 20 µm/h. The influence of deposition temperature on the magnetic and structural properties of films in the as-deposited and post-deposition annealed states will be presented. The extrinsic magnetic properties (coercivity, remanence) depend strongly on the substrate temperature during deposition. NdFeB films can be prepared with out-of-plane texture while the SmCo films can be prepared with in-plane texture.

## 4) Structuring of μ-magnets

A number of different routes which have been used to pattern permanent magnet films are schematized in figure 1. The patterns produced can be categorized as i) *topographic* or ii) *crystallographic*. The topographically patterned films can be further categorized as patterned either *during deposition* or *post-deposition*. The cross section of a 5 μm thick NdFeB film deposited on a pre-patterned substrate is shown in figure 2.

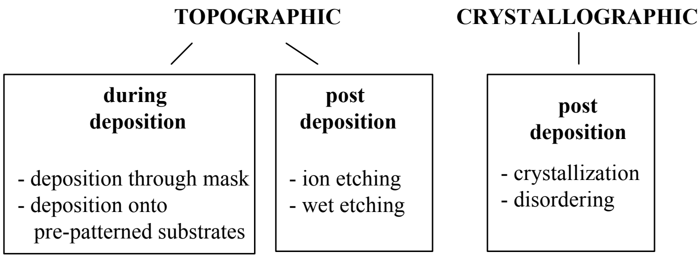


*Figure 1.* Overview of different routes used to pattern permanent magnet films.

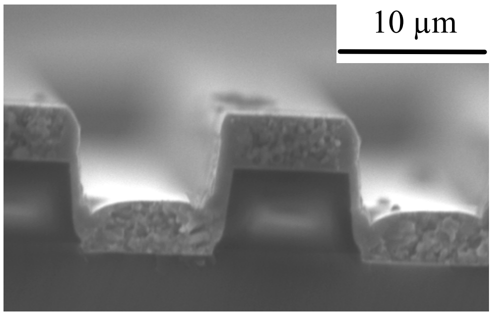


*Figure 2.* Cross sectional SEM image of {Ta(100 nm) / NdFeB (5 μm) / Ta (100 nm)} deposited onto a pre-patterned Si/SiO substrate.

The second, and less conventional type of patterning, involves the local modification of the film's magnetic properties through a change in its crystallographic state. In this case a modulation in the magnetic properties is achieved without a modulation in the film's surface height.

## 5) Proto-type magnetic MEMS

A number of proto-type magnetic MEMS (μ-motors, μ-generators, bistable μ-switches..) will be reviewed. The use of micro-magnet arrays for levitation of small particles, which demonstrates the potential for magnetic lab-on-chip systems, will be presented.