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50. Internationales Wissenschaftliches Kolloquium
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# Technological Aspects of Thin Film Magnetic Heads Manufacturing

## ABSTRACT

The increase of the data recording density by using thin ferromagnetic film structures represents a way of read/write magnetic heads performance improvement.

In this paper there are presented the following important aspects: the structure of a thin film magnetic head, performed by vacuum selective evaporation through contact metallic masks; the thickness distribution of the condensed substance on a substrate executing a simple rotational motion or a planetary motion; the 3D model of the holder-device for the parts under planetary motion, designed by help of a CAD software; the experimental research results regarding the deposition technology of the thin permalloy layers and the conclusions referred to the factors that influence the features of the evaporated ferromagnetic films.

## INTRODUCTION

Thin film magnetic heads are made in a similar way to the semiconductor chips. Thousands of structures can be obtained on the surface of one silicon wafer, the product that results from this being of very small dimensions and of high quality.

Thin film heads have an extremely tight and clean-cut air gap. The head core in this case is made out of Ni-Fe alloy, magnetically four times stronger than the ferrite core.

Thin film heads produce very „sharp" and very well defined magnetic impulses that allow very good write densities. Not having a conventional coil, they are less sensitive at the impedance variations that coils usually have. The very small and light heads can float lower than the ferrite ones; the float height was reduced at only 0.05 μm or even less. The low float height permits collecting a stronger signal when reading; the signal-noise ratio rises, taking to a greater reading accuracy. A ferrite head wouldn't be able to choose the useful signals from the background noise, if it is set to work in a unit with a higher density of the tracks and with a high

linear density. In addition, thin film heads, which are smaller, allow the insertion of some packages with more discs inside of the units.

Their use on high scale made them competitive regarding the costs.

## MAGNETIC HEAD STRUCTURE DESCRIPTION

The integrated multi-layer vertical magnetic head [1] structure under study has the magnetic circuit made from thin permalloy (Ni-Fe alloy) films and a winding (flat coil) of conductive material (copper), isolated by silicon monoxide films. All these ferromagnetic (thickness ≈ 0.2 μm), dielectric and conductor (thickness ≈ 1 μm) layers are deposited by vacuum evaporation using metallic masks on silicon substrate.

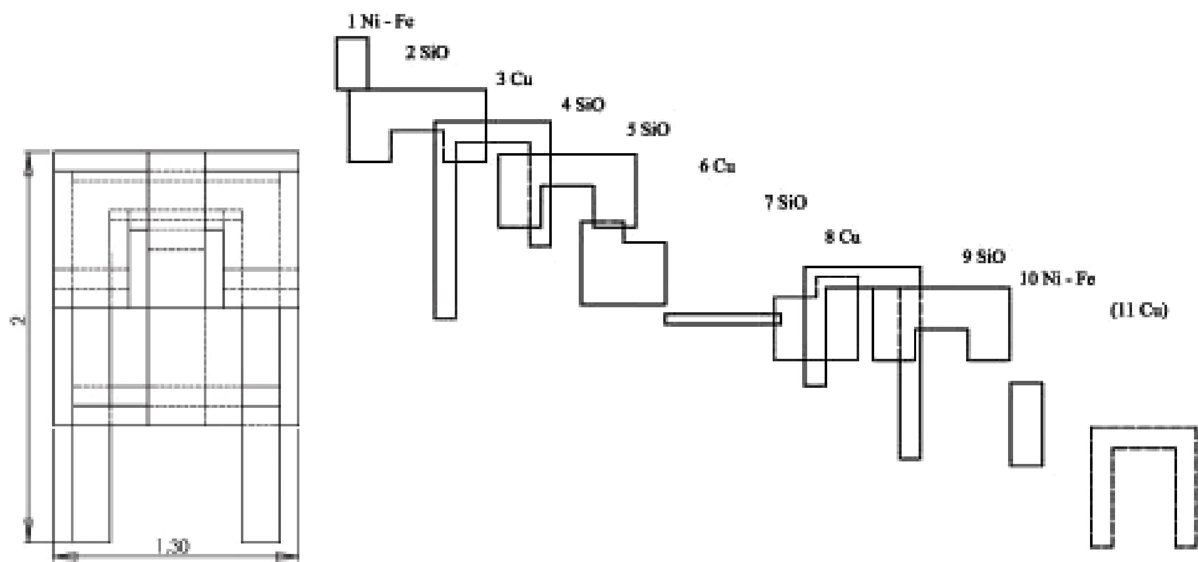



Fig. 1 Integrated magnetic head structure

The magnetic head structure, configuration and succession of the layers are represented in fig. 1.

Mask nr.1 defines the form of a magnetic layer, witch is the first polar part. This shape has an edge at the superior level and a symmetry axis that coincides with the symmetry axis of the zone onto direction of the deposited layer thickness.

Masks nr.2, 4, 5, 7 and 9 define the shapes and the positions of the dielectric layers. The masks 2, 4 and 9 are "U" shaped, and the masks 5 and 7 are the mirror images relative to the symmetry axis of the first masks. When they are superposed, these thorough holes define a central rectangular zone, in which the end sections of the magnetic layers will be in contact.

The first conductor layer is deposited by the hole of the mask nr.3, the right branch making contact with the next conductor layer, which corresponds to the mask nr.6, after the

deposition of two successive dielectric layers, 4 and 5. The winding circuit ends with the conductor layer 8, which represents the mirror image of the conductor layer 3.

Another dielectric layer 9 is deposited on this structure and over this layer is superposed the magnetic layer 10, which represents the second polar part.

The defined structure represents only one turn winding, which is in clockwise direction. For a counterclockwise winding, the deposition sequence will be: 1-2-8-4-5-6-7-3-9-10.

In order to obtain more coils, another turning winding will be added after the dielectric layer 7, using „U" shaped mask nr.11.

## METALLIC MASKS EXECUTION

The method using metallic masks has the advantage of a shorter technological route against the photo-etching method [2]. The last one involves repeated extractions of the structures from the deposition equipment, with the view to etch the layers as the specific pattern through the photoresist mask.

In case of using metallic masks, the whole structure is obtained in a single vacuum cycle, being necessary a very precise device for the displacement of the masks on the substrate, into the vacuum chamber.

Metallic masks are obtained by chemical erosion – photo-cutting version– applied to very thin metallic sheets, supported by a thicker mechanic holder. There are used foils from copper, copper-beryllium, stainless steel, nickel and molybdenum, with 125 - 5 μm thickness. Applying photolithography as a protection method in conjunction with a very thin electrolytic deposition of another material (nickel, chromium) compatible with the mask material, precisions between ±2….±8 μm can be reached. The stages of execution of the masks are depicted below, fig. 2.

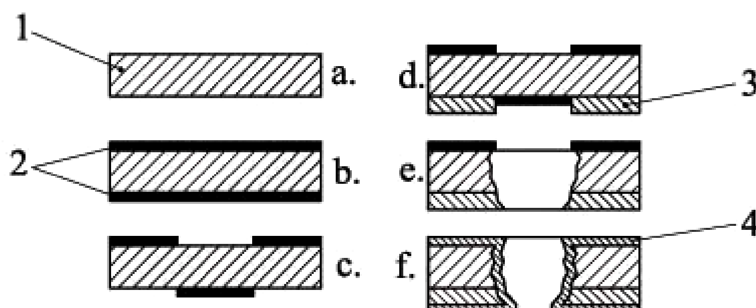



Fig. 2 Execution of the masks by chemical erosion (photo-cutting) and electrolytic deposition: 1 – beryllium-copper foil; 2 – photoresist layers; 3 – nickel galvanic coating; 4 – supplementary deposited nickel layer.

The base material is a metallic sheet from copper-beryllium alloy (a). Both faces are covered with liquid photoresist by centrifuging (b). One of the faces is exposed to UV light through the positive photographic cliché of the configuration that must be obtained, and the other one through the negative cliché. The photoresist is removed, when developing, from the unexposed zone (c). After that, an electrolytic deposit of nickel is being made on the useful face (d). The protecting photoresist mask is removed from this face followed by a chemical selective attack on both sides (e). Finally, after the removal of the photoresist mask from the other face, a last nickel-plating is being made for protection (f). The advantage of this method is that the openings are defined by the nickel layer, and the copper sheet is only support. The material flow over the edges of the photoresist mask, accomplishing an electric insulating material function during the deposition process, compensates the lateral chemical attack after the corroding stage. So, it can increase the resolution and the precision of part configuration. The minimum dimension of the hole/width of lines and apertures represents around 1.5...0.5 of processed material thickness. Following this technological route, we have manufactured masks from foils of beryllium-copper with 100 μm thickness. Cutting-outs of minimum 70 μm width and ± 5 μm tolerance were obtained.

The metallic masks have the advantage of being used for a large number of deposits (with the limit due to the difficulty of keeping them rigid), but in the case of the continuous operating vacuum systems, the exfoliation of the layers deposited on the mask can create cleaning problems.

## PERMALLOY LAYER DEPOSITION PROCESS

The ferromagnetic thin layers samples used for measurements were obtained by vacuum evaporation on oxidized silicon wafers (3000 Å thickness of $SiO_2$ layer). Two deposits of different thickness were made.

The Ni 80% Fe 20% (99.5% purity) alloy was evaporated from a tungsten boat introduced in the circuit of two water-cooled copper electrodes. In order to stabilize the permalloy alloy onto the substrate, first a thin film of chromium was deposited.

The substrates were very well cleaned (ultrasound tank) for obtaining the better adherence of the deposited thin layers. After cleaning, the silicon wafers were dried in a laminar flow niche, class 100.

Thin polycrystalline anisotropic uniaxial ferromagnetic films are obtained applying, during the deposition, a constant and uniform magnetic field (200-250 tesla) generated by two permanent magnets mounted in close proximity of the wafers. The calibration of the permanent

magnets was made with a tesla-meter, measuring the magnetic induction field near the frame-work on which the wafers are mounted.

Working residual pressure, obtained by a diffusion pump, was maintained at a value of $10^{-6}$ torr when the evaporated material molecule propagation could be considered rectilinear and the evaporation source, punctiform. The evaporation was perform under a normal incidence angle, the supporting frame-work being mounted above the evaporation source, and the distance between the silicon wafers being too small to consider oblique incidence deposition. The successive deposition of chromium (intermediary layer of adherence) and permalloy films was executed in the same vacuum cycle, by separate supplying of the evaporation sources.

Due to modification of the evaporation source geometry during the deposition process, the evaporation rate has a tendency to fluctuate; it is maintained constant by modifying the voltage applied to the electrodes.

Technological process stages are the following:

1. fixing the silicon wafers on the supporting frame-work;
2. closing the bell jar;
3. obtaining preliminary vacuum (rotative pump), $p=10^{-3}$ torr;
4. starting the diffusion pump, $p=4\cdot10^{-6}$ torr;
5. cleaning the boat and the wafers in nitrogen plasma;
6. deposition of thin layers:
   a. chromium deposition
   - deposit 1: I=13A, time=1’30’’;
   - deposit 2: I=13A, time=1’30’’;
   
   b. permalloy deposition
   - deposit 1: I=13A, time=5’;
   - deposit 2: I=13A, time=2.5’;
7. deposit control (fig. 3):
   a. measurement of the “square resistance”, depending on the thickness layer, the material and its structure;

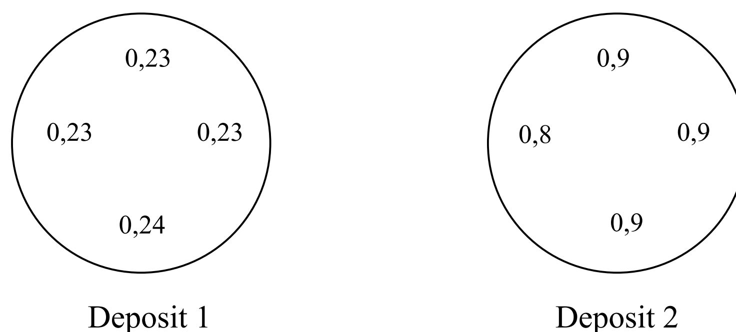



Fig. 3 Results of measuring the specific resistance and $R_{square}$ on the surface of the two wafers

b. photo-etching the layers in a step shape necessary to measure their thickness:
   1°. positive photoresist deposition:
   - lining-up and vacuum fixing,
   - centrifuging at 2500rot/min (photoresist thickness 1.6-1.8 μm),
   - thermal treatment t=30', T=90°C.
   2°. exposure: UV light, 20".
   3°. developing: KOH solution, 30",
   - thermal treatment t=30', T=90°C.
   4°. corroding:
   • $FeCl_3$ solution (for permalloy),
   • $FeCl_3$ - HCl solution at 80°C (for chromium).
   5°. removing the photoresist (acetone).

c. measurement of the deposited layer thickness (electronic roughness-meter with a diamond stylus):
   Deposit 1: $t_1$=2000Å (Cr + permalloy);
   $t_{Cr}$=300Å,
   $t_{NiFe}$=1700Å.
   Deposit 2: $t_2$=800Å (Cr + permalloy);
   $t_{Cr}$=300Å,
   $t_{NiFe}$=500Å.

Unlike the simple substances film obtaining process, in the compound case some difficulties appear as regards the thin layer composition deviation from the initial chemical composition of the evaporated material: every constituent element of a compound has an evaporation rate proportional to its own vapor pressure, and these vapor pressures appreciably differ for the different components of the compound; consequently the vapor composition differs relative to the solid compound and, in most cases, this composition modifies itself in time too.

The vapor pressures for components A and B that form a binary compound are diminished against those in pure state with a proportional value to their concentrations in weight $w_A$ and $w_B$.

In order to assure a stoichiometric composition when evaporating, it is necessary that:

$$\frac{m_{eA}}{m_{eB}} = \frac{w_A}{w_B} \quad (1)$$

that means

$$\frac{p_A}{p_B} = \sqrt{\frac{M_A}{M_B}} \quad (2)$$

where:

$m_{eA}$ and $m_{eB}$ are the evaporation rates for components A and B at the same temperature, $p_A$ and $p_B$ represent the vapor pressures of the pure components, and $M_A$ and $M_B$ are their molecular masses.

The compound dissociation while evaporating is not produced if $p_A \cong p_B$, that means

$$\frac{p_1 \cdot M_A}{p_2 \cdot M_B} = \frac{w_A}{w_B}, \qquad (3),$$ where:

$p_1$ and $p_2$ are the partially pressures of the two components.

On this basis, Holland [3] classified a number of alloys with „constant evaporation rate", that means those alloys which components do not separate during evaporation; they are composed of selected elements from one of the groups: Al, Cr, Sn, Cu and Fe, Au, Ti, Ni.

In practice, maintaining the composition constant during evaporation process depends not only on vapor pressure consideration, but also on the tendency of components A and B to react with the source material or with the residual gases from the bell jar. This way, the nominal composition of the evaporant, necessary to obtain the desired composition for the thin layer, is usually experimental adjusted. For example, for permalloy, a nominal evaporant with the weight ratio of 83% nickel, 17% iron is reproduced in the layer with the ratio of 81% nickel and 19% iron.

Vaporizing only a small quantity of the alloy charge can minimize the composition change during the evaporation.

## THICKNESS UNIFORMITY OF THIN LAYERS DEPOSITED BY VACUUM EVAPORATION

The thickness distribution of the thin layers deposited by vacuum evaporation depends on, excluding the use of masks: geometric form of the receiving surface, placement of the evaporation source regarding the substrate, emissive characteristics of the source, respectively if the evaporation takes place uniformly, in all directions or in certain preferential directions.

When the pressure is low ($<10^{-4}$torr), it is admitted that the evaporation takes place according to Knudsen's laws. These are the gas-kinetic analogy to Lambert's laws for radiation.

The emissive characteristics of the practical sources can be approximated with the presented ones by two types of ideal sources: the punctiform source (with spherical symmetry) and the plane source of small surface (with directional emissive properties).

When using the punctiform source, the substrates have to be placed on a sphere concentric to the source, and sphere radius has to be bigger than the biggest linear dimension of the substrates, in order to obtain uniform layers.

If the substrates are set on a plane support, the $x$ (the distance to the center of the source) / $h$ (the source-substrate distance, in a normal direction on the substrate surface) ratio must be minimized, which requires the placement of the substrates at a high distance $h$, semi-infinite;

only in this case, the finite and plane surface of the support can be considered a portion of the associated concentric sphere.

When using the plane source of small surface, both substrates and the source must be positioned on the surface of a sphere, with a view to obtain uniform layers.

These acknowledgements are the basis of the planetary deposition systems, which are very spread.

The thickness distribution and the maximum thickness deviation for a rotating substrate, executing a simple rotation / planetary motion are represented in fig. 4 and fig. 5.

The study was performed considering the geometrical data of the laboratory installation AV-100.

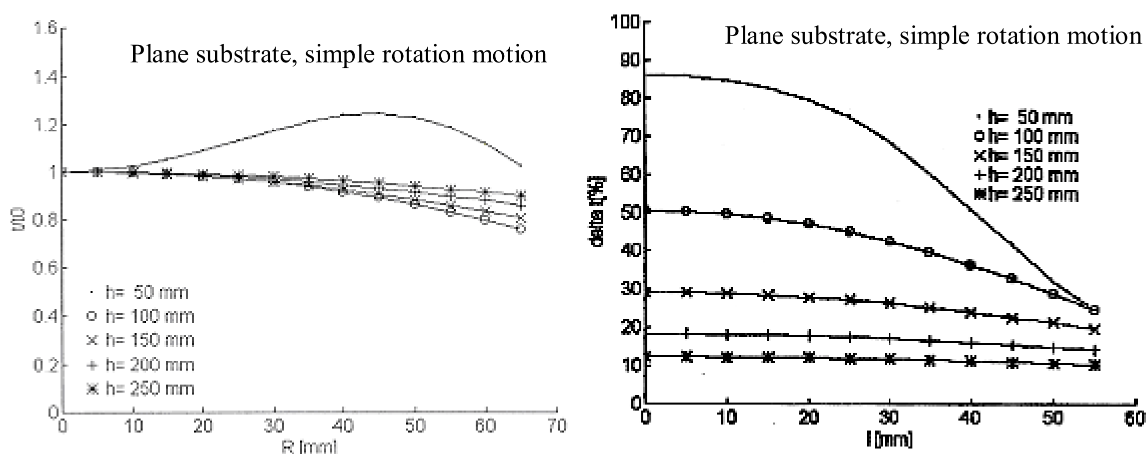



Fig. 4 Thickness distribution ($t/t_0$) and non-uniformity ($\Delta t$) of the deposits on a plane substrate executing a simple rotation motion

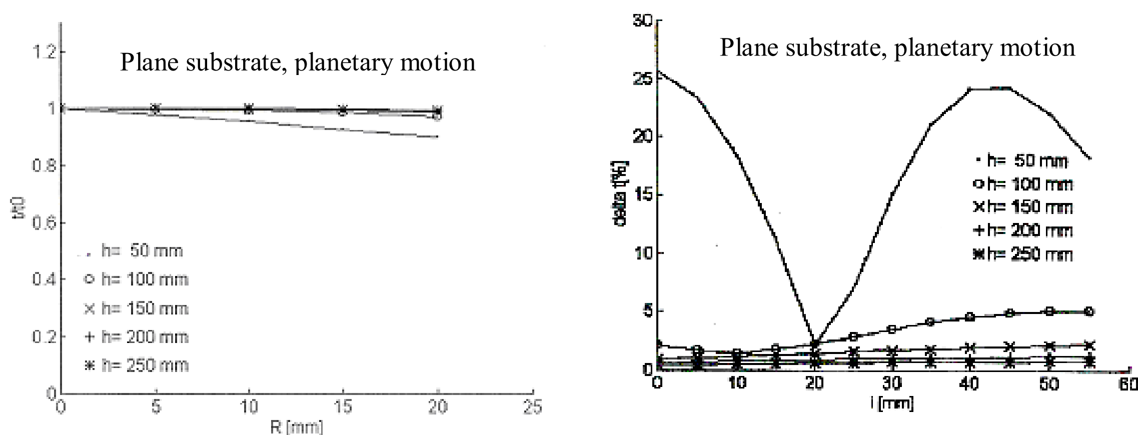



Fig. 5 Thickness distribution ($t/t_0$) and non-uniformity ($\Delta t$) of the deposits on a plane substrate executing a planetary motion

“l” is the distance from the evaporation source to rotation axis of the carrousel; “$t_0$” represents the layer thickness in a point onto surface, in normal direction over the source.

For the same installation, in order to obtain uniform thickness thin layers [2, 4], a planetary motion device was conceived and designed (in Solid Works), fig. 6.

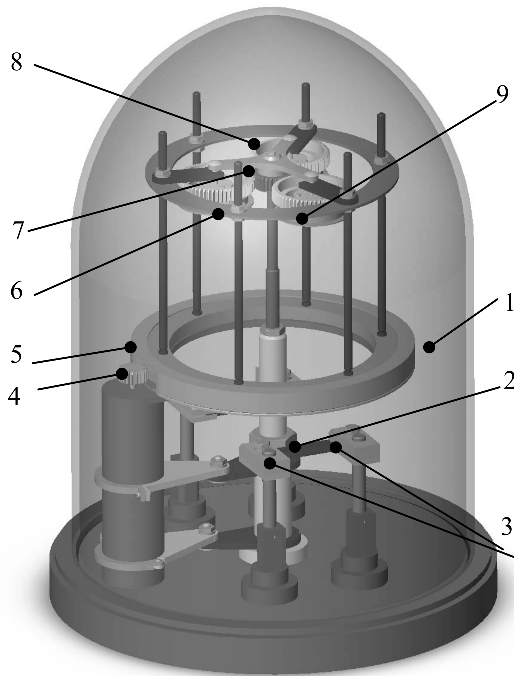



Fig. 6 Device for the planetary motion of the substrates: 1-bell jar, 2-evaporation source, 3-copper electrodes, 4-actuator pinion, 5-crown gear, 6-rotating subassembly, 7-fixed pinion, 8-satellite, 9-substrate (Si wafer)

## EXPERIMENTAL RESULTS, CONCLUSIONS

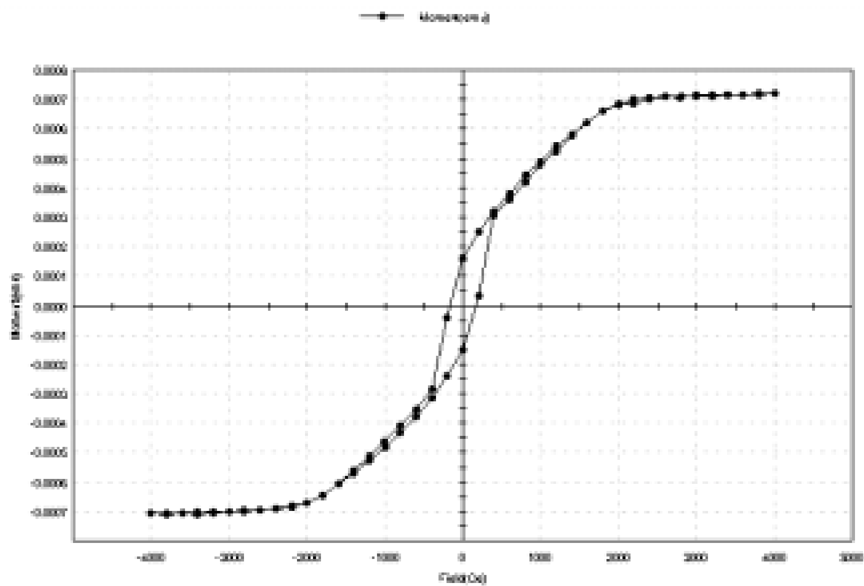
For the two samples of different thickness thin ferromagnetic layers (1700 Ǻ and 500 Ǻ) were recorded their magnetic cycles by help of a magnetometer, fig. 7.

From fig. 7a we find that the first permalloy sample has a very low coercive field (160.03 Oe), and low magnetic losses as a result; the hysteresis loop is very thin, which means that it will be strongly magnetized even at low fields.

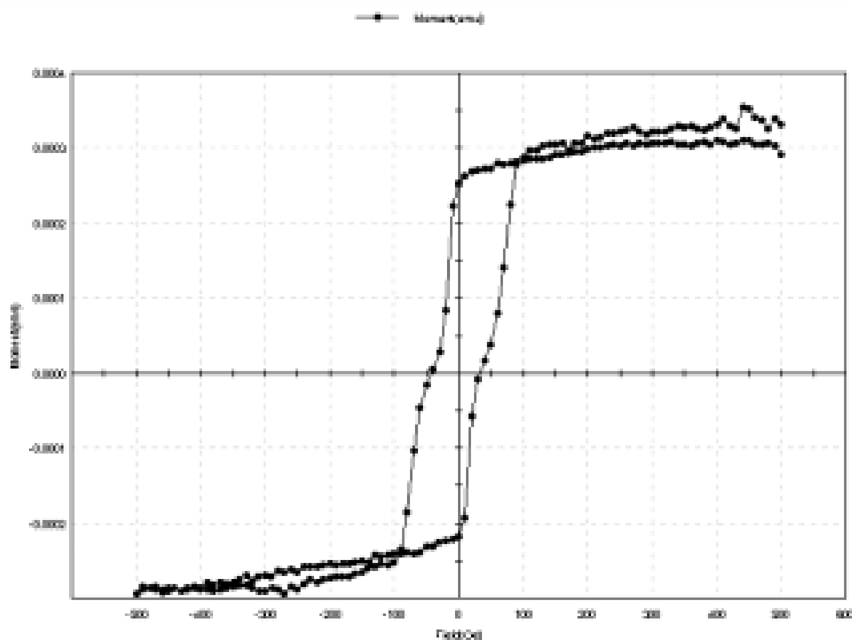
The problem appears at the second permalloy sample (fig. 7.b), which has a very wide hysteresis loop, with high magnetization loss. These losses can be caused by the fact that for very thin layers, the mechanical resistance and the dissipated power are very low. In addition, at a layer thickness lower than a critical thickness, the layer is made up of separate little islands among which the conduction takes place by special effects (tunneling).

Another causes are the impurities that deform the crystalline network of the material, producing internal mechanical tensions. We have to mention that temperature influences the mobility of the atoms that deposit on the substrate. The alloy characteristics and its content of impurities, the contamination of the boat walls or of the substrate can also affect the magnetic

film features [5]. Qualitative and reproducible deposits are performed in advanced vacuum, better than $10^{-6}$ torr, preferable at $10^{-9}$ torr obtained with a turbo-molecular pump.



a. $t_1$ = 1700 Å



b. $t_2$ = 500 Å

Fig. 7 Magnetic cycles of the obtained permalloy layers

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