Flux Gate Magnetometry Applied to RF Cavities

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Work performed under the CARE, number RII3-CT-2003-506395

Outline:

Magnetometry applied to
- Buffered Chemical Polishing (BCP)
- Electropolishing

Eddy Current NDT applied to
- Evaluate of Nb Resistivity
- Detect of defects on Niobium surface

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Typical surface treatment for the RF cavity

In both case of

- bulk Niobium Cavities
- Nb Sputter coated Cu cavities

The surface must be treated to remove sources of rf losses

Mainly two treatments are used to reach a smooth surface:

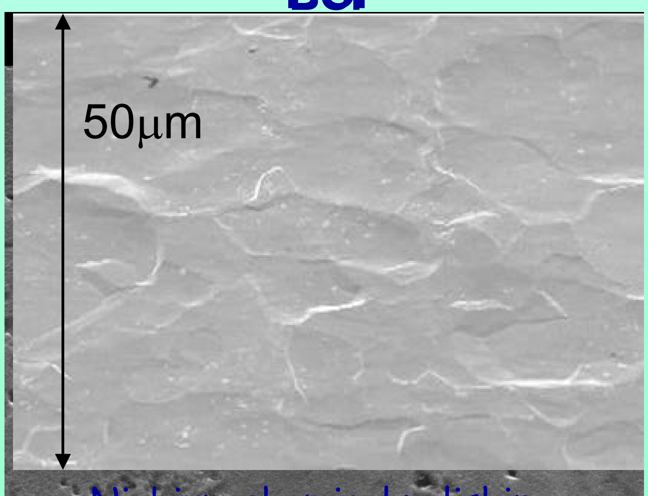
chemical polishing

electropolishing

Niobium

Copper

BCP **BCP**



Niobium chemical polishing (BCP 112, 1 μm/min)

Copper chemical polishing (SUBU5, 1 μm/min)

EP **EP**

Niobium electropolishing ($HF:H_2SO_4$ 1:9, 0.5 μm/min)

Copper Electropolishing (H_3PO_4: butanol 55:45, 0.2 μm/min

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The best surface integrity ⇒ Quality control

Non invasive contact-less Magnetic sensors

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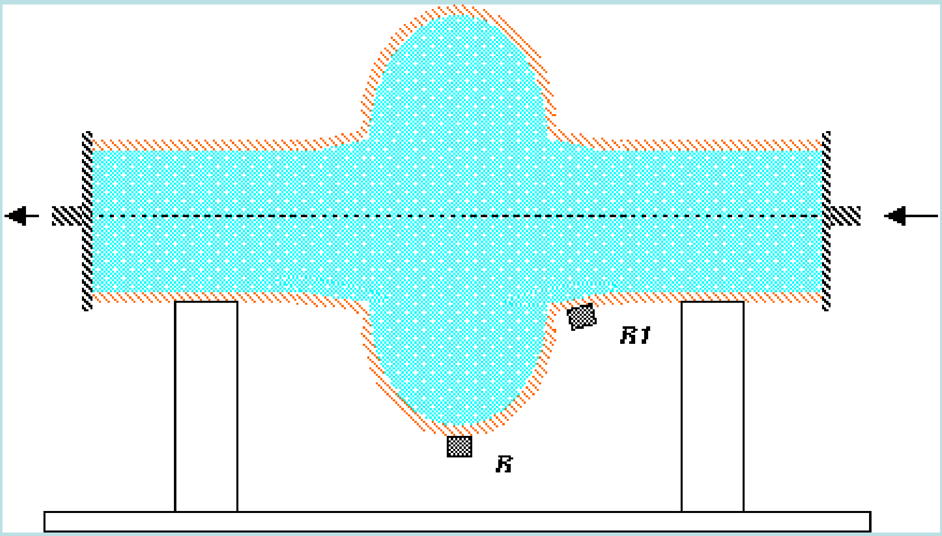
Monitoring the chemical/electrochemical etching



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Typical Magnetic sensors characteristics in unshielded environment

Sensor	Range	Sensitivity
Hall probe	± 10 mT	0.8 μT /√Hz @ 1Hz
Flux Gate	± 70μT	10 pT/√Hz @ 1Hz
GMR	± 50 μT	0.1 μT /√Hz @ 1Hz
SQUID	± 1μT	0.3 pT/√Hz @ 1Hz

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Basic Considerations

In the BCP process there is not metal dissolution … …

The Nb is oxided by HNO_3 → The oxide is reduced by HF in a soluble salt → The H_3PO_4 works as a reaction moderator

All these processes are based on a charge transfer

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If there is a charge transfer a magnetic field is detectable

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The detected magnetic field is proportional to the dissolution rate

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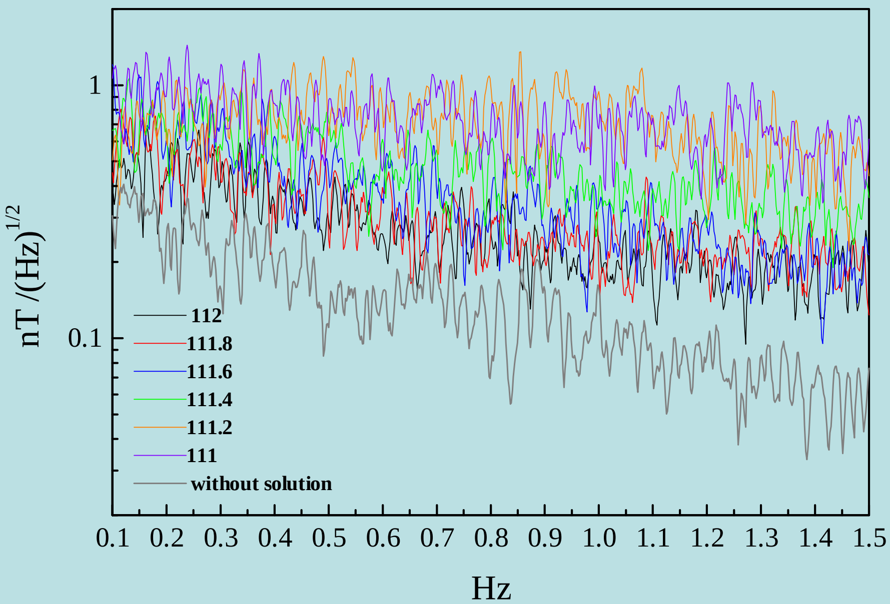
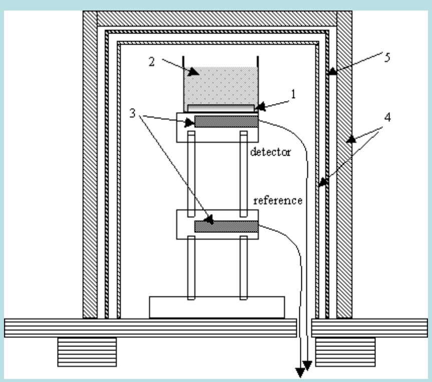
Nb BCP

Passing from Nb BCP 1:1:1 to BCP 1:1:2 (increasing the H_3PO_4 percentage) the magnetic signal detected becomes monotonically stronger

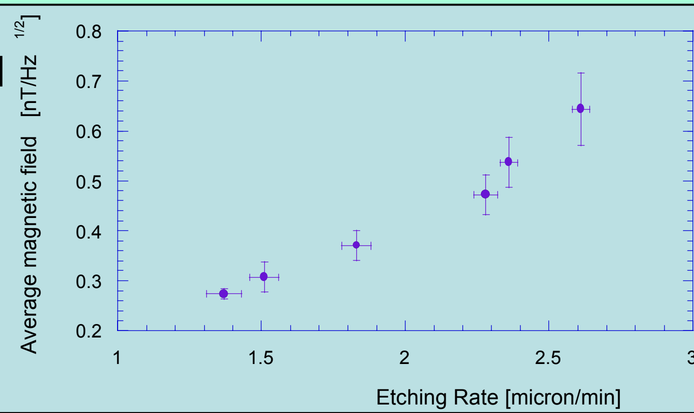


BCP 1:1:1
BCP 1:1:1.1
BCP 1:1:1.2
BCP 1:1:1.3
…
…
BCP 1:1:1.9
BCP 1:1:2

Dissolution rate



Average magnetic field vs etching rate



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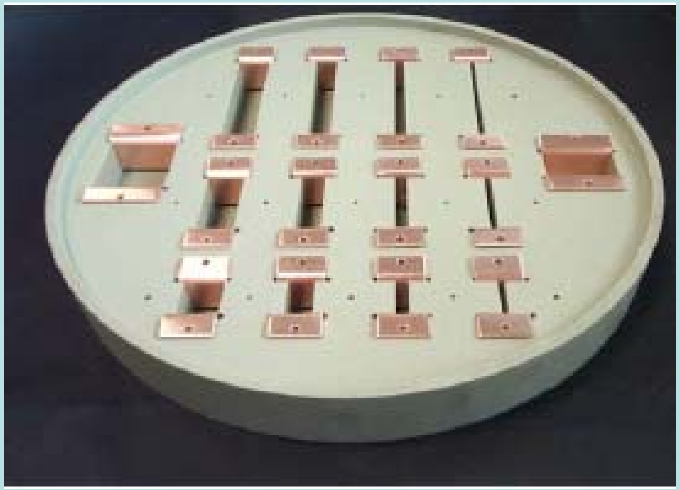
CU Electropolishing



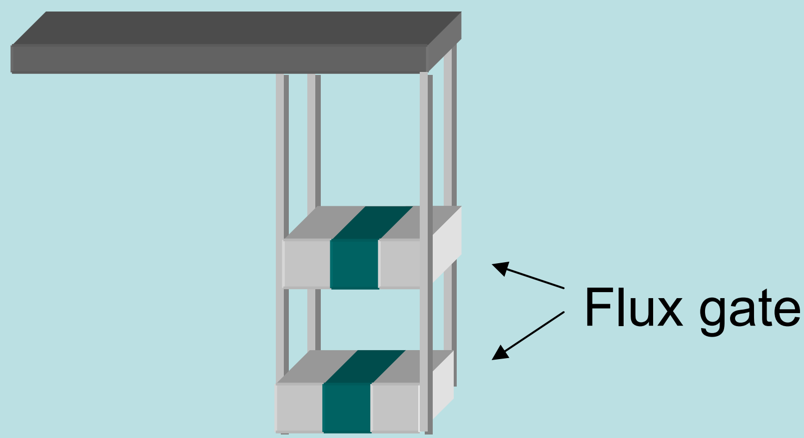
Rectangular electrolytic cells of different dimensions with copper electrodes .

The solution used:

- 55% Phosphoric acid
- 45% n-buthanol

Flux Gate 1st order electronic gradiometer

It detects the "in plane magnetic field" component and is less sensitive to the environmental noise than a magnetometer.



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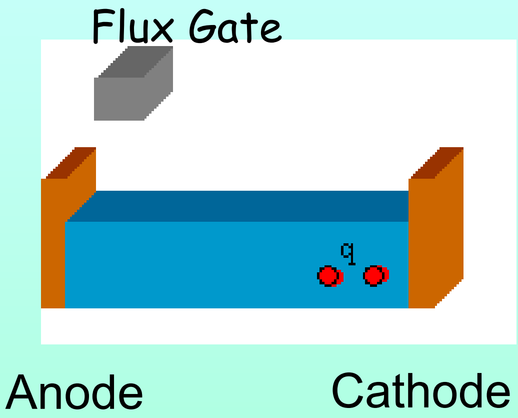
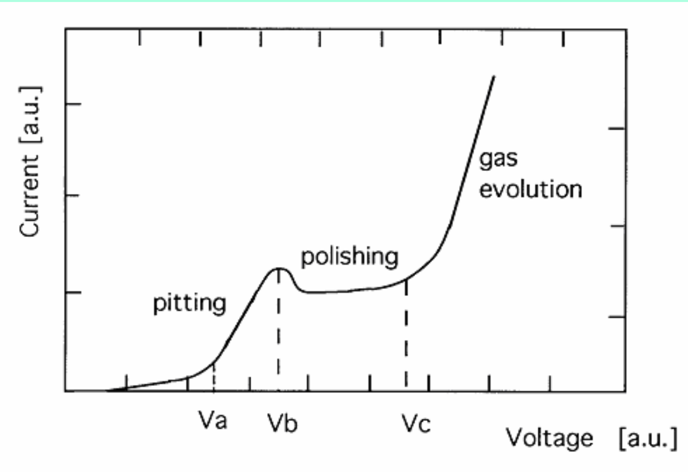
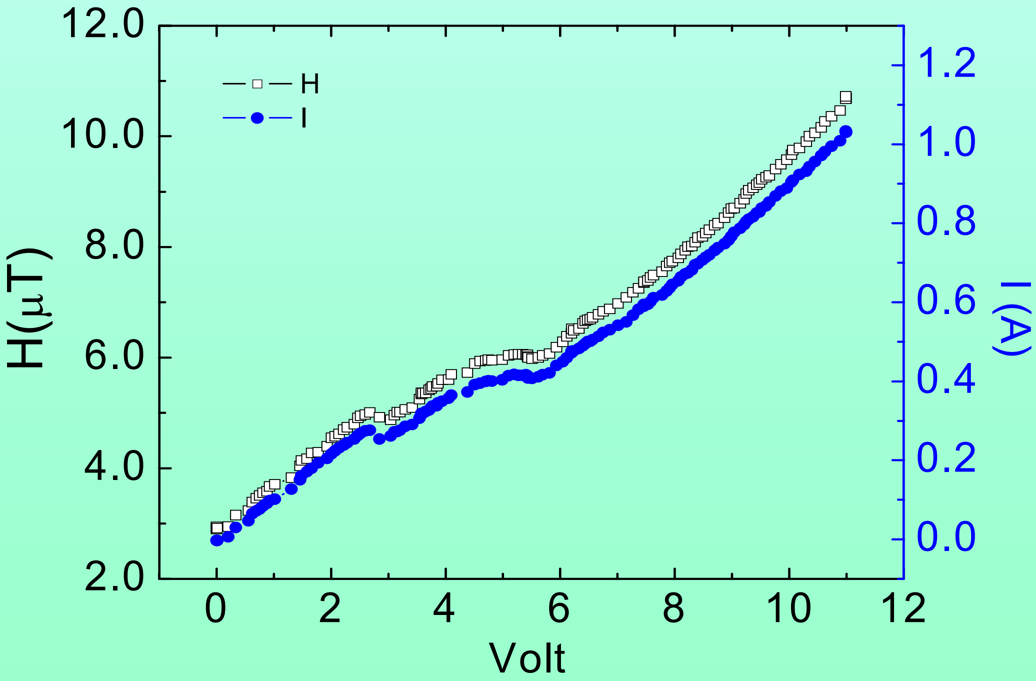
Static measurements

Fixing the probe on the electrode and driving in voltage it is possible to measure:



The H-V Characteristics of Elecropolishing just replies the I-V polarization curve





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Corrosion Rate

Considering the motion of particles, the numbers of carriers is:

$$n = \frac{\mu_0}{4\pi} \frac{jSl}{Br^2}$$

Number of carriers

Faraday law

$$w = \frac{jStM}{nF}$$

Corrosion rate

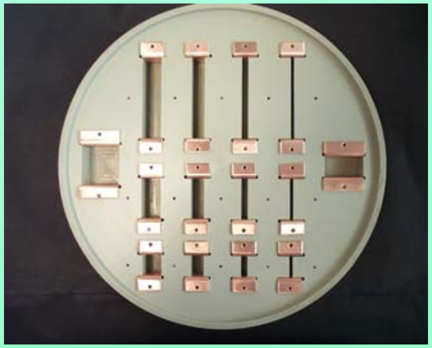
$$\frac{w}{t} = \frac{4\pi BMr^2}{\mu_0 lF}$$

$\mu_0=4\pi 10^{-7}$ Vs/Am

M_{Cu} = 63.456 g/mole

F = 96500 As/mole

In the case of cells 50 mm long and different width:



Cell width (mm)	w[g] at 4V by balance	w[g] at 4V by H	w[g] at 7V by balance	w[g] at 7V by H
8	0,012	0,011	0,025	0,048
16	0,023	0,020	0,035	0,020
24	0,05	0,032	0,13	0,035

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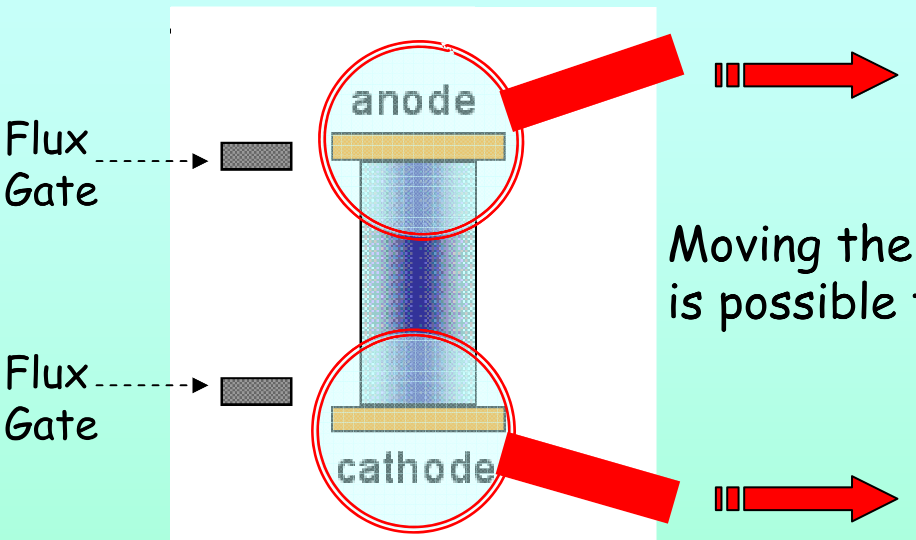
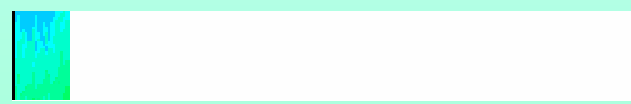
Dynamic measurements



Magnetic field distribution over the anode

Moving the Flux Gate (FG) probe over electrodes it is possible to monitore the electropolishing activity



Magnetic field distribution over the cathode

Starting from the magnetic field distribution the current density across the electrodes can be obtained

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Electromagnetic Inversion

The rectangular cell has been approximated to a finite short wire which generates a magnetic field expressed by Biot-Savart law:

$$B(r) = \frac{\mu_0}{4\pi} \int \frac{J(r') \times (r - r')}{|r - r'|^3} d^3 r'$$

With ***J*** current density and *r* the distance where the magnetic field is measured.

Considering the in plane component of the field

$$B_y(x,y) = \frac{\mu_0}{4\pi} l \cdot z \cdot \iint \frac{J_x(x,y)}{\left(x^2+z^2\right)^{3/2}} dxdy \qquad (1)$$

This formula represents the convolution between the current density J and Green function ***G***

$$G(x,y) = \frac{\mu_0}{4\pi} l \cdot z \cdot \frac{1}{\left(x^2+z^2\right)^{3/2}}$$

By using the convolution theorem it is possible to rewrite the (1) in the Fourier space as:

$$b_y = g \cdot j_x \quad \Longrightarrow \quad j_x = \frac{b_y}{g}$$

Current density in the Fourier space

The inverse Fourier trasformation of j_x gives the current density **J**.

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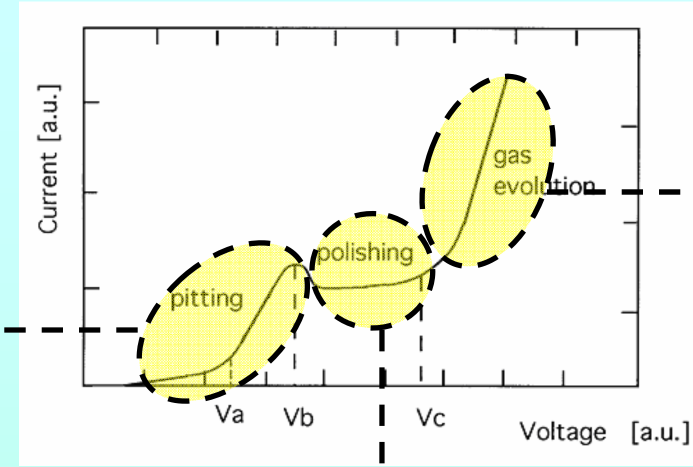
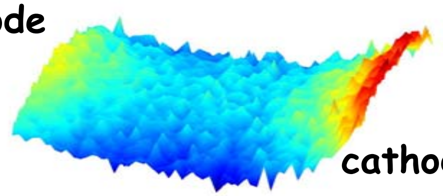


Below the I-V plateau

Magnetic field distribution

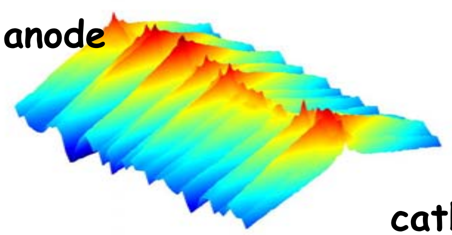
anode



cathode

Current distribution

anode

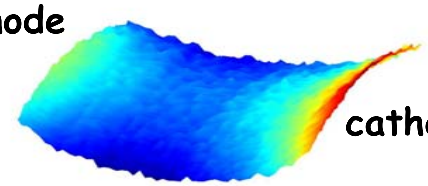


cathode

In the I-V plateau

Magnetic field distribution

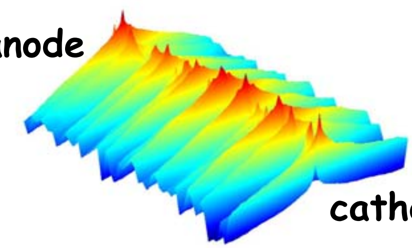
anode



cathode

Current distribution

anode

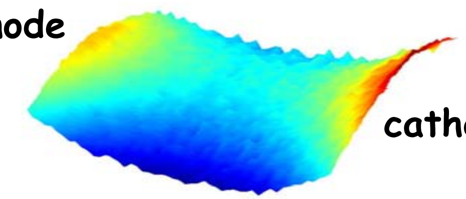


cathode

Above the I-V plateau

Magnetic field distribution

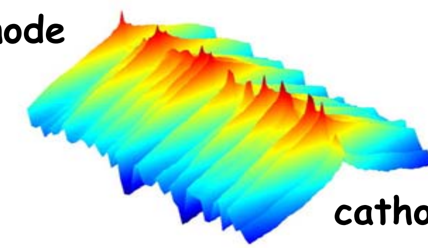
anode



cathode

Current distribution

anode



cathode

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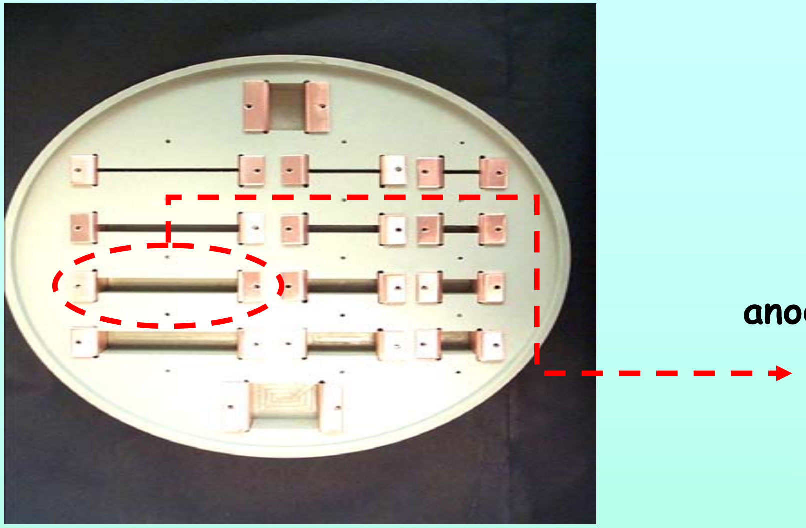
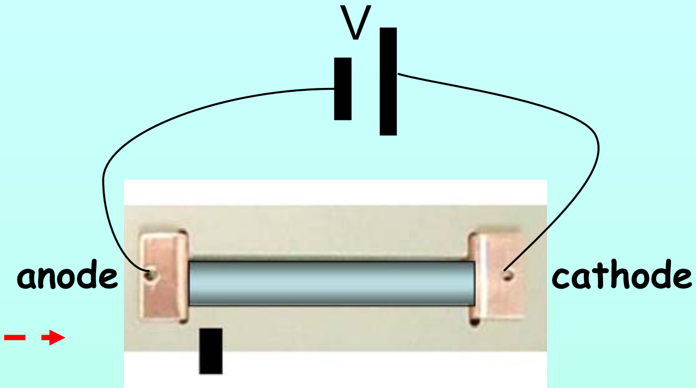
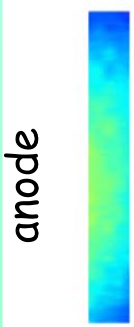
Real time Magnetic Field imaging

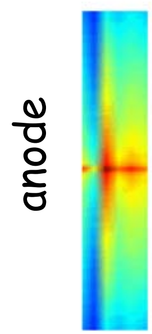




Magnetic field distribution



Current density distribution



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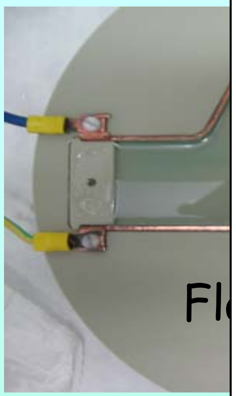
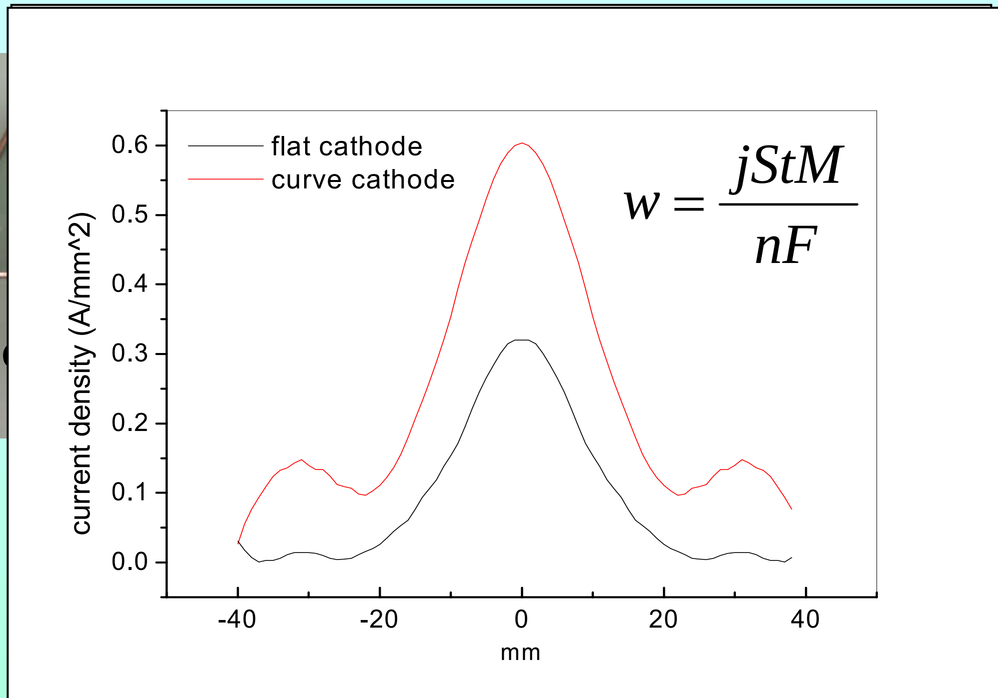
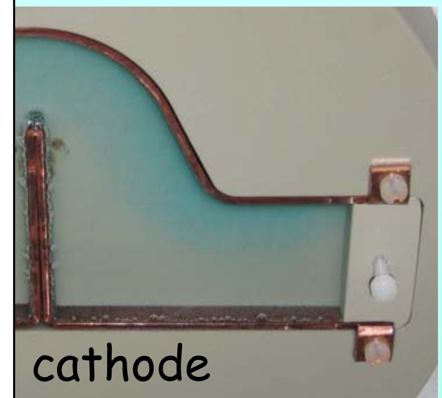
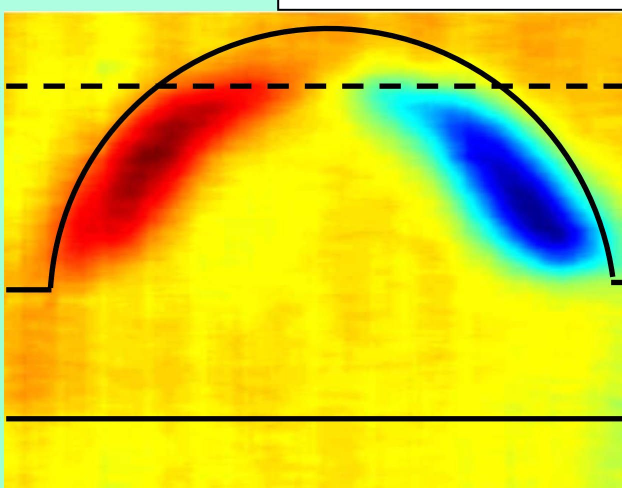
Cells with different cathode geometries

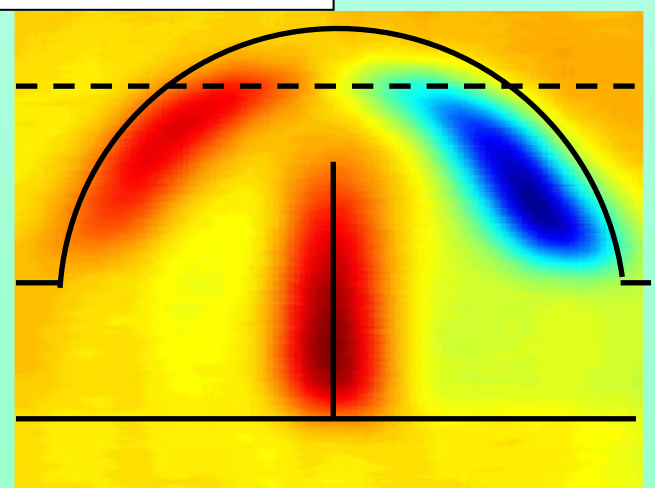




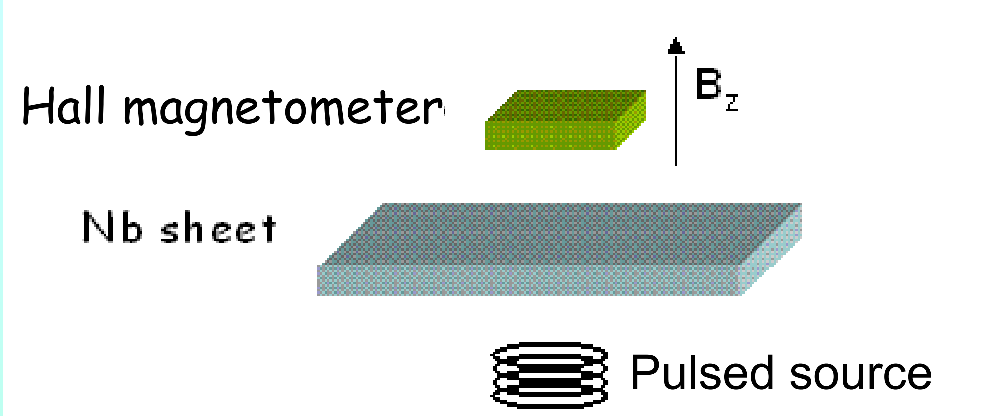


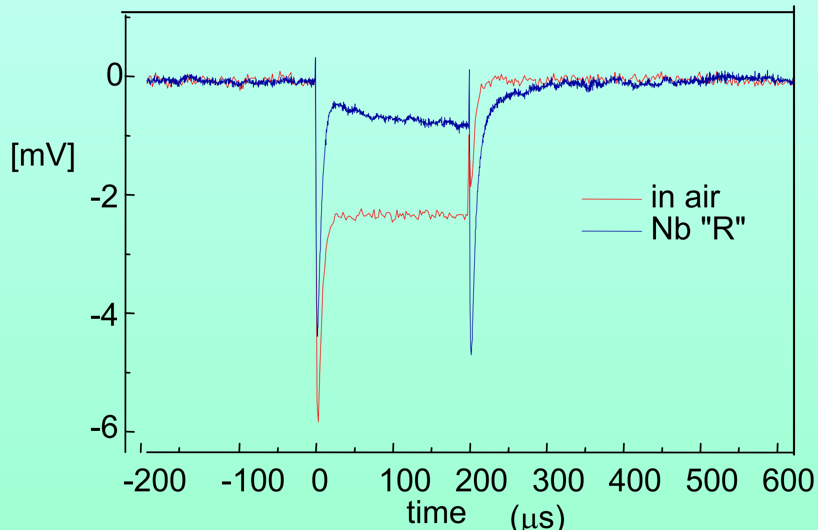


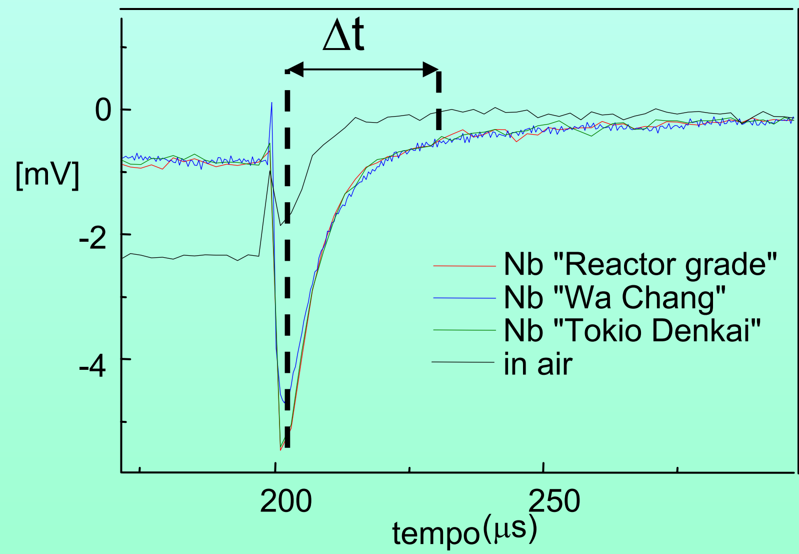
Line-scan



Evaluation of Niobium Resistivity
By Pulsed Eddy Current technique







Eigenvalue of D'alambert equation

$$z^2 = \frac{\Delta t}{\mu\sigma}$$

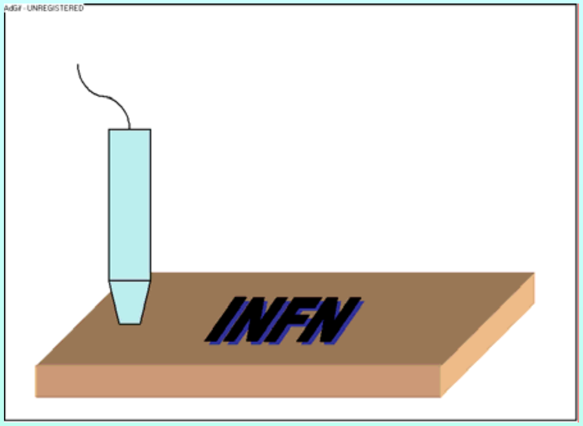
Niobium sample	RRR	Δt (μs)	Conductivity $(\Omega\ m)^{-1}$	Resistivity (Ω m)
Reactor Grade	50	251	$0.125\cdot10^{8}$	$8\cdot10^{-8}$
Wa Chang	230	267	$0.133\cdot10^{8}$	$7.5\cdot10^{-8}$
Tokio Denkai	250	271	$0.135\cdot10^{8}$	$7.4\cdot10^{-8}$

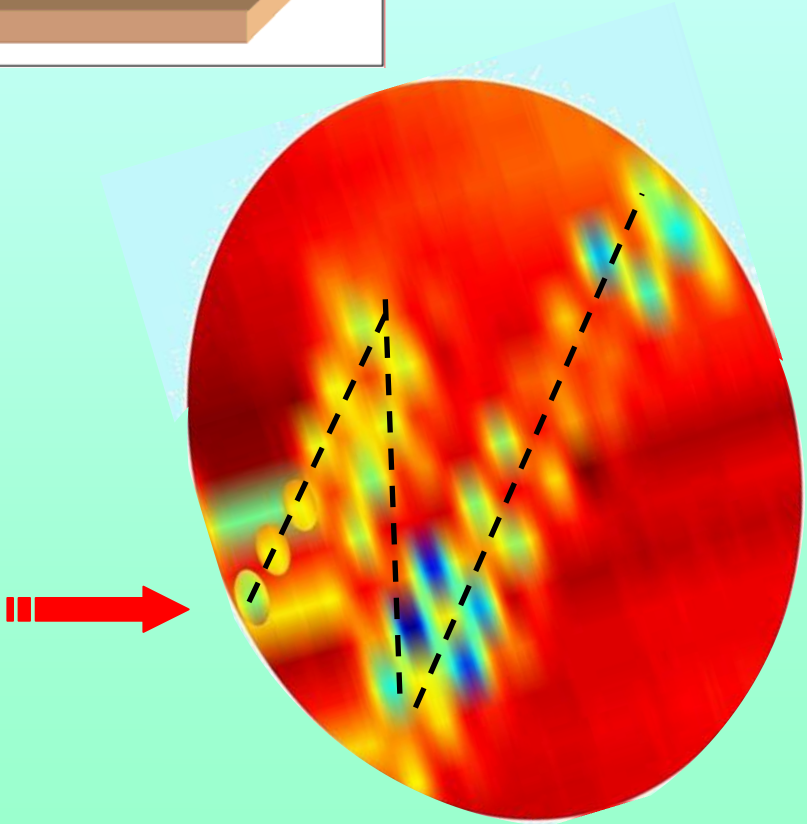
Work performed under the

Detection of defects on Niobium surface

Eddy current technique using ELOTEST B300

Working frequency= 1.4MHz





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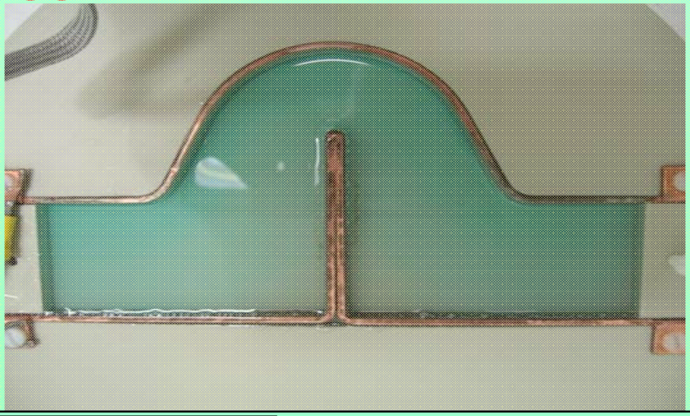
Conclusions

Electromagnetic technique using magnetic sensors as magnetometers or gradiometers allows:

- monitoring the ongoing corrosion during the electropolishing of metals surface
- evaluation of Nb room temperature resistivity with a sensitivity of about 1%
- Detection of surface sub-millimetric defects and scratches with depth less than 0.1 mm

Work in progress

Development of magnetic sensor array to measure the magnetic field during the electropolishing process on non- planar geometry.



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