IMAGIC Spin Valve Process

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Técnicas de Micro e Nanofabricação

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Content

1 Objective

2 Operation Base Concepts

3 Principles of detection - Spin Valves

4 Assembly

5 Fabrication
- Spin Valve Deposition
- Spin Valve Definition
- Contacts
- Passivation
- Sensor Transfer Curve
- Cutting and Wirebonding

6 Assemble and Testing

Objective:
Make a device that searches for microfissures in metallic samples, based on magnetic excitation and detection.

Content

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- A source of strong magnetic field is used to excite the metallic sample.
- In the metallic sample, a electric field is generated by simple Faraday induction:

$$\nabla \times E_i = -\frac{\partial B}{\partial t} \tag{1}$$

  (this just means that a time varying magnetic field is a source of circulation of a electric field).
- Being metallic, the medium has a finite conductivity σ_c that means that the induced electric field will create induced currents in the material:

$$J_i = \sigma_c E_i \tag{2}$$

- Now neglecting displacement currents, we can see by other Maxwell equation that the metal will respond with a generated magnetic field:

$$\nabla \times H_{gen} = J_i = \sigma_c E_i \tag{3}$$

- The principle of operation is therefore very simple, if we have any fissures in the sample, its conductivity will locally change and the generated magnetic field will also change. This means that detecting the generated magnetic field we can know, by its non-uniformities, where are their fissures or other defects.

Content

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- Basic thin film structure

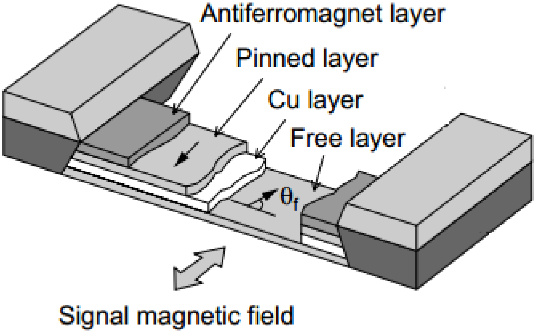

Figure: Basic spin-valve structure.

- The device consists in:
  - Two conducting magnetic materials (Pinned and Free Layer).
  - The two layers are made of two materials with different magnetic coercivities.
  - Due to the different coercivities the free layer changes polarity at small magnetic fields while the pinned layer changes polarity at a higher magnetic field.
  - The anti-ferromagnetic acts as a pinning layer.
  - A metallic non-magnetic inter-layer.

- It works based on the so called Giant Magnetoresistive Effect.
    - The unpaired carrier electrons in the free layer align their spins to the external magnetic field.
    - When a potential exists across a spin valve, the spin-polarized electrons keep their spin alignment as they move through the device.
    - If these electrons encounter a material with a magnetic field pointing in the opposite direction, they have to flip spins to find an empty energy state in the new material.
    - This flip requires extra energy which causes the device to have a higher resistance than when the magnetic materials are polarized in the same direction.

- Two different states:

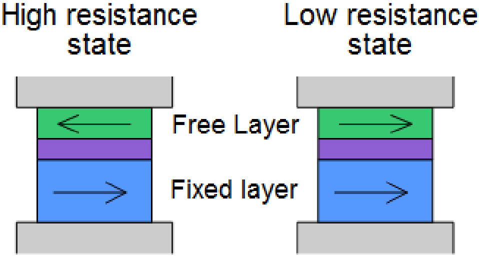

Figure: A schematic diagram of a spin valve. When the magnetic layers are anti parallel the resistance is higher than when they are aligned.

Content

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- Passivation
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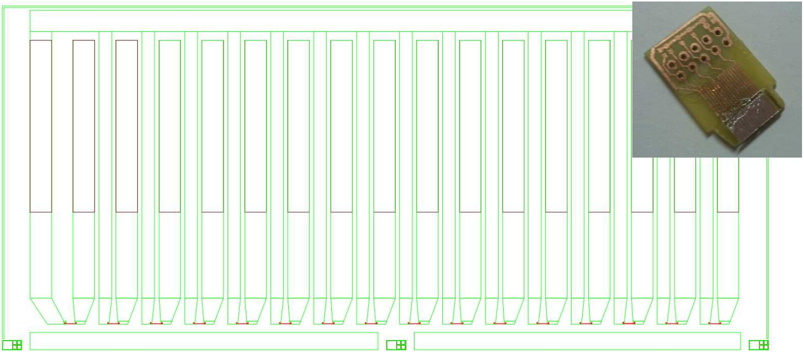

AutoCAD File

Figure: Mask and final assembly.

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4 Assembly

5 Fabrication
- Spin Valve Deposition
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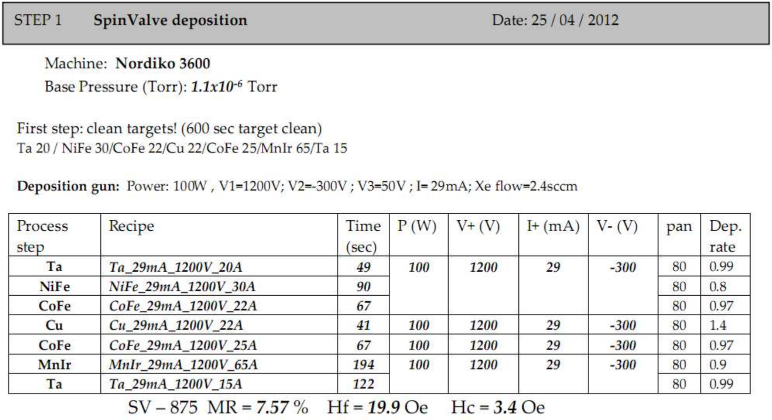
First of all we had to deposit the spin valves in a glass substrate.

SV deposition:



STEP 1 **SpinValve deposition** Date: 25 / 04 / 2012

Machine: **Nordiko 3600**
Base Pressure (Torr): ***$1.1x10^{-6}$*** Torr

First step: clean targets! (600 sec target clean)
Ta 20 / NiFe 30/CoFe 22/Cu 22/CoFe 25/MnIr 65/Ta 15

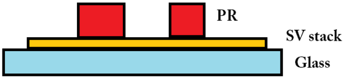
Deposition gun: Power: 100W , V1=1200V; V2=-300V ; V3=50V ; I= 29mA; Xe flow=2.4sccm

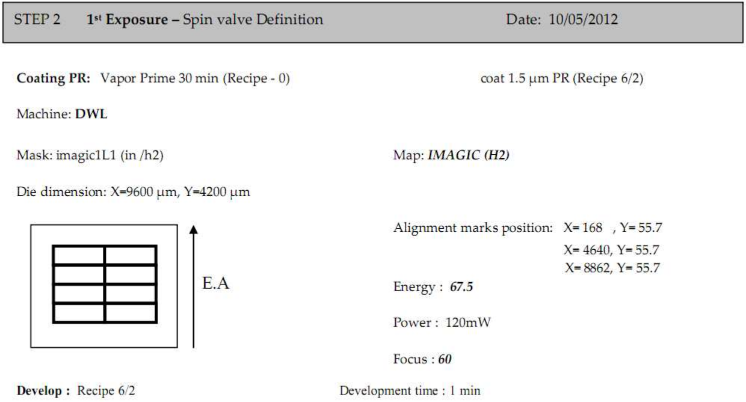
Process step	Recipe	Time (sec)	P (W)	V+ (V)	I+ (mA)	V- (V)	pan	Dep. rate
Ta	*Ta_29mA_1200V_20A*	*49*	*100*	*1200*	*29*	*-300*	80	0.99
NiFe	*NiFe_29mA_1200V_30A*	*90*					80	0.8
CoFe	*CoFe_29mA_1200V_22A*	*67*					80	0.97
Cu	*Cu_29mA_1200V_22A*	*41*	*100*	*1200*	*29*	*-300*	80	1.4
CoFe	*CoFe_29mA_1200V_25A*	*67*	*100*	*1200*	*29*	*-300*	80	0.97
MnIr	*MnIr_29mA_1200V_65A*	*194*	*100*	*1200*	*29*	*-300*	80	0.9
Ta	*Ta_29mA_1200V_15A*	*122*					80	0.99

SV – 875 MR = *7.57* % Hf = *19.9* Oe Hc = *3.4* Oe

This part has 3 steps: Lithography, Etching and Stripping.

Lithography:





STEP 2	**1st Exposure** – Spin valve Definition	Date: 10/05/2012

Coating PR: Vapor Prime 30 min (Recipe - 0)   coat 1.5 µm PR (Recipe 6/2)

Machine: **DWL**

Mask: imagic1L1 (in /h2)   Map: ***IMAGIC (H2)***

Die dimension: X=9600 µm, Y=4200 µm

Alignment marks position: X= 168 , Y= 55.7
X= 4640, Y= 55.7
X= 8862, Y= 55.7

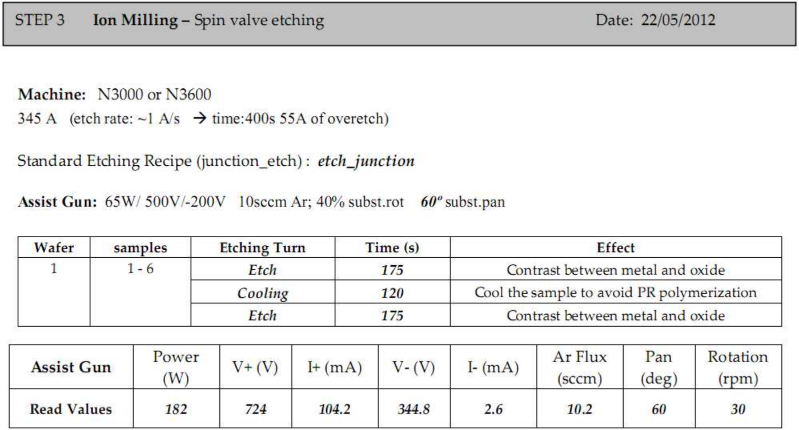
Energy : *67.5*

Power : 120mW

Focus : *60*

Develop : Recipe 6/2   Development time : 1 min

Etching:



STEP 3 **Ion Milling –** Spin valve etching Date: 22/05/2012

Machine: N3000 or N3600

345 A (etch rate: ~1 A/s → time:400s 55A of overetch)

Standard Etching Recipe (junction_etch) : ***etch_junction***

Assist Gun: 65W/ 500V/-200V 10sccm Ar; 40% subst.rot *60^o* subst.pan

Wafer	samples	Etching Turn	Time (s)	Effect
1	1 - 6	*Etch*	*175*	Contrast between metal and oxide
		Cooling	*120*	Cool the sample to avoid PR polymerization
		Etch	*175*	Contrast between metal and oxide

Assist Gun	Power (W)	V+ (V)	I+ (mA)	V- (V)	I- (mA)	Ar Flux (sccm)	Pan (deg)	Rotation (rpm)
Read Values	*182*	*724*	*104.2*	*344.8*	*2.6*	*10.2*	*60*	*30*

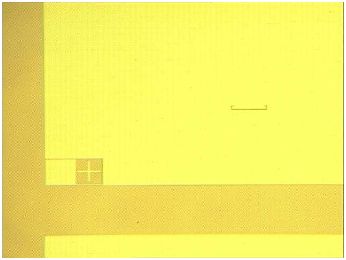
Stripping:

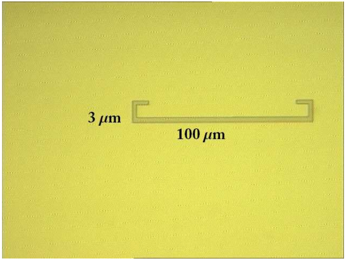
STEP 4	**Resist strip**	Date: 23/05/2012

Hot µ-strip + ultrasonic
Rinse with IPA + DI water + dry N_2

Started: *16:00* Stopped: *16:00*

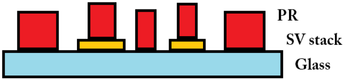
Total Time in hot µ-strip : *24h* Ultrasonic Time : ***No ultrasounds***

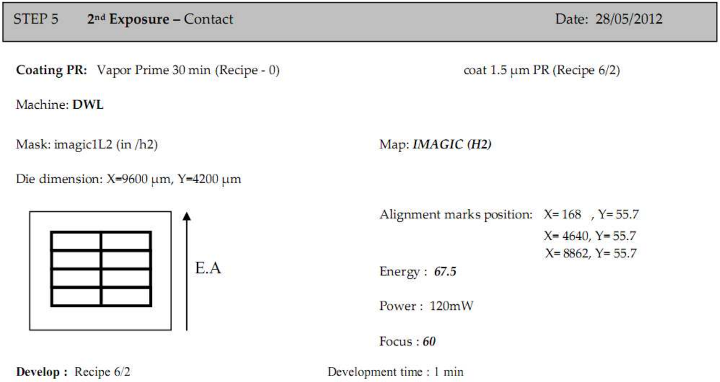




This part is done by lift-off and has 3 steps: Lithography, Deposition and Lift-off.

Lithography:





STEP 5 **2nd Exposure** – Contact Date: 28/05/2012

Coating PR: Vapor Prime 30 min (Recipe - 0) coat 1.5 µm PR (Recipe 6/2)

Machine: **DWL**

Mask: imagic1L2 (in /h2) Map: ***IMAGIC (H2)***

Die dimension: X=9600 µm, Y=4200 µm

Alignment marks position: X= 168 , Y= 55.7
X= 4640, Y= 55.7
X= 8862, Y= 55.7

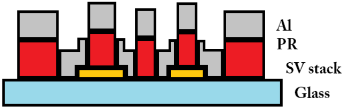
Energy : *67.5*

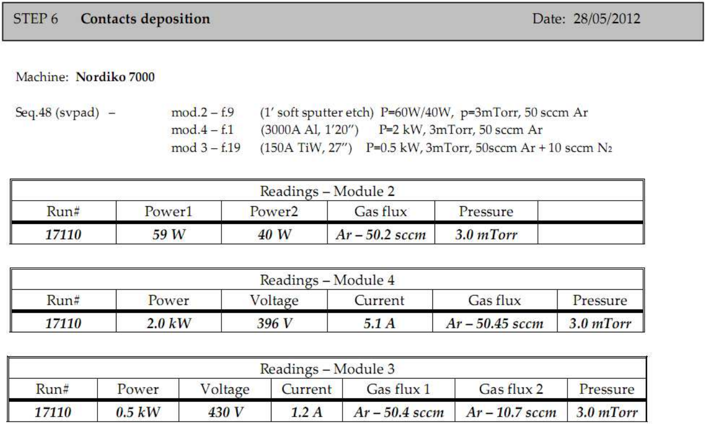
Power : 120mW

Focus : ***60***

Develop : Recipe 6/2 Development time : 1 min

Deposition:





STEP 6 **Contacts deposition** Date: 28/05/2012

Machine: **Nordiko 7000**

Seq.48 (svpad) – mod.2 – f.9 (1′ soft sputter etch) P=60W/40W, p=3mTorr, 50 sccm Ar
mod.4 – f.1 (3000A Al, 1′20″) P=2 kW, 3mTorr, 50 sccm Ar
mod 3 – f.19 (150A TiW, 27″) P=0.5 kW, 3mTorr, 50sccm Ar + 10 sccm N_2

Readings – Module 2

Run#	Power1	Power2	Gas flux	Pressure	
17110	*59 W*	*40 W*	*Ar – 50.2 sccm*	*3.0 mTorr*	

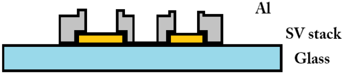
Readings – Module 4

Run#	Power	Voltage	Current	Gas flux	Pressure
17110	*2.0 kW*	*396 V*	*5.1 A*	*Ar – 50.45 sccm*	*3.0 mTorr*

Readings – Module 3

Run#	Power	Voltage	Current	Gas flux 1	Gas flux 2	Pressure
17110	*0.5 kW*	*430 V*	*1.2 A*	*Ar – 50.4 sccm*	*Ar – 10.7 sccm*	*3.0 mTorr*

Lift-off:



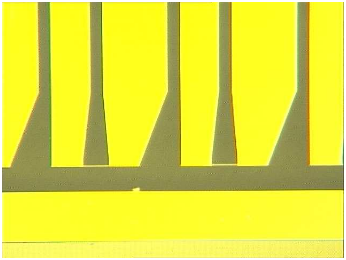
STEP 7	**Aluminum Lift-Off**	Date: 28/05/2012

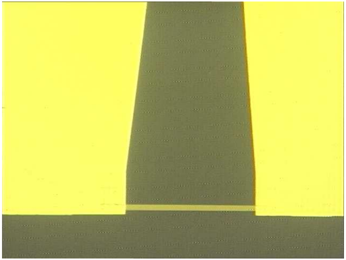
Hot µ-strip + ultrasonic
Rinse with IPA + DI water + dry N_2

Started: 28/05 Stopped: 31/05

Total Time in hot µ-strip : 3 dias

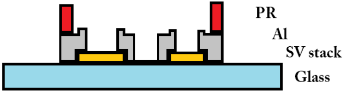
Ultrasonic Time : 1 noite

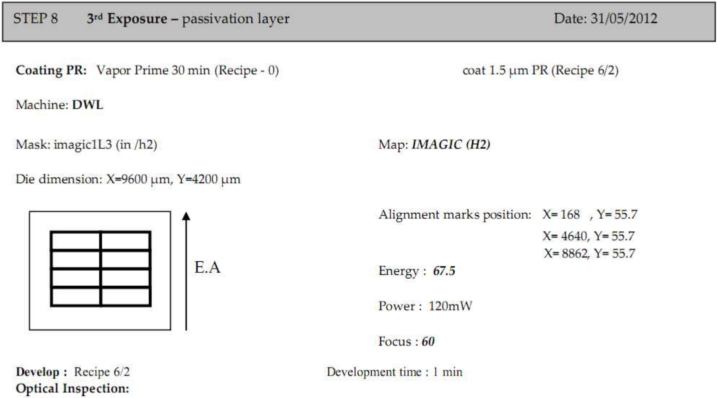




This part is also done by lift-off and has 3 steps: Lithography, Deposition and Lift-off.

Lithography:





STEP 8 **3rd Exposure** – passivation layer Date: 31/05/2012

Coating PR: Vapor Prime 30 min (Recipe - 0) coat 1.5 µm PR (Recipe 6/2)

Machine: **DWL**

Mask: imagic1L3 (in /h2) Map: ***IMAGIC (H2)***

Die dimension: X=9600 µm, Y=4200 µm

Alignment marks position:
X= 168 , Y= 55.7
X= 4640, Y= 55.7
X= 8862, Y= 55.7

Energy : *67.5*

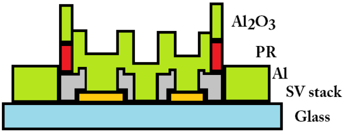
Power : 120mW

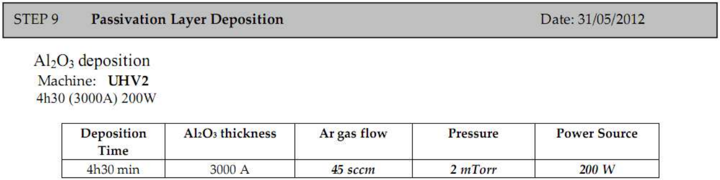
Focus : *60*

Develop : Recipe 6/2 Development time : 1 min

Optical Inspection:

Deposition:



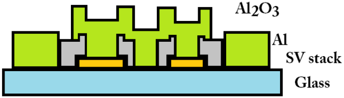


STEP 9 **Passivation Layer Deposition** Date: 31/05/2012

Al_2O_3 deposition
Machine: **UHV2**
4h30 (3000A) 200W

Deposition Time	**Al_2O_3 thickness**	**Ar gas flow**	**Pressure**	**Power Source**
4h30 min	3000 A	*45 sccm*	*2 mTorr*	*200 W*

Lift-off:

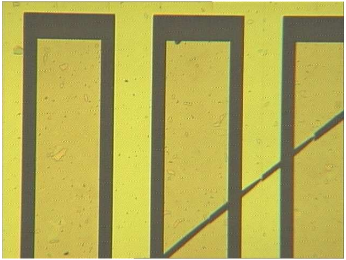


STEP 10	**Oxide Lift-Off**	Date: 1/06/2012

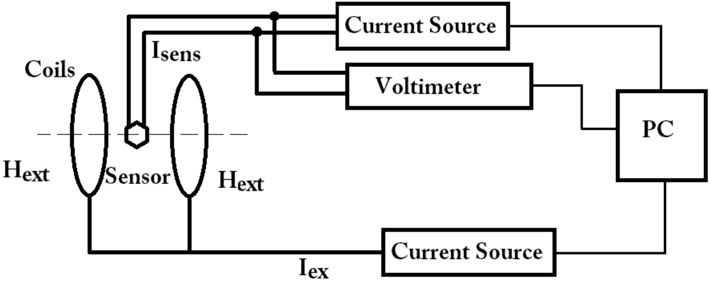
Hot μ-strip + ultrasonic
Rinse with IPA + DI water + dry N_2

Started: *1/06* Stoped: *6/06*

Total Time in hot μ-strip : *5 dias* Ultrasonic Time : *1 hora*

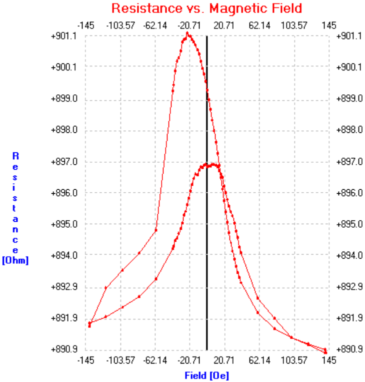


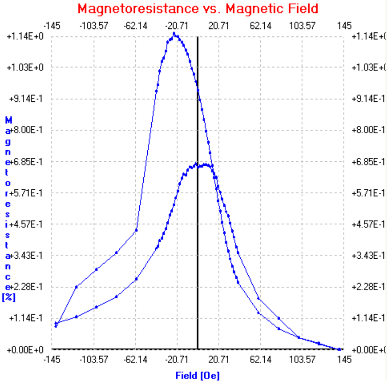
Fabrication over, now the task is to **measure the transference curve of the sensors**.



- Coils produce a computer controlled excitation magnetic field.
- A constant current is imposed to the sensors.
- Voltage at its terminals is measured and then the resistance of the sensor is extrapolated.

Results.





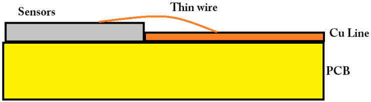
⇒ Not the expected. After a certain value of the field, the **pinned layer magnetization stops being fixed** and starts rotating with the free layer magnetization, reducing the resistance.

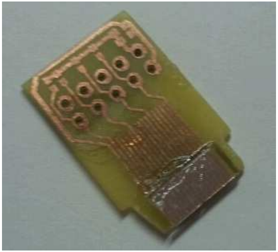
Although the sensors are useless, the process proceeds to the **cutting**.

1. Sample coating with PR to avoid dust deposition.
2. Align sample in the diamond saw.
3. Definition of the cutting directions and dimensions.
4. Cutting.
5. Stripping.

Result:

Final phase before testing is to pick one sensor array and the PCB and do the **wirebonding**.





- Connect the contacts of the sensors to the copper lines on the PCB.
- The machine exerts a force and ultrasounds on the sample, and this is enough to melt the aluminium and connect the wire.
- Lastly, silicon is applied where the wirebonding was done to protect the links.

Fabrication over.

Content

1. Objective
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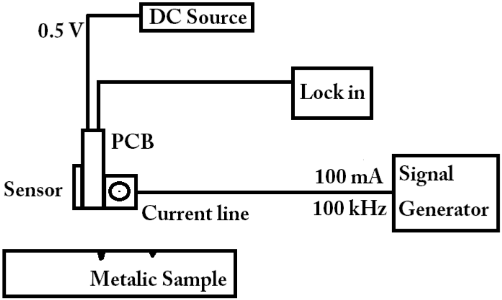
6. Assemble and Testing

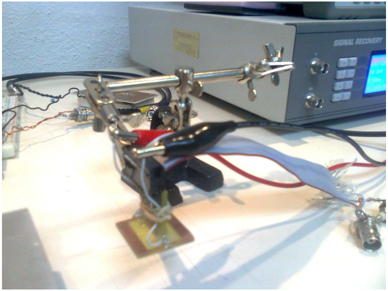
After the fabrication and assemble of the chip we have to **test the device (actually other device (MR 5.8 %)) using some metallic samples**.

Experimental set-up:



- Current line is used to induce current loops in the metal.
- Lock in reads the output of the sensor at the frequency of 100 kHz.

Experimental set-up

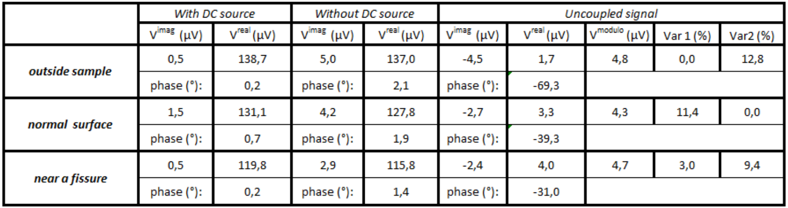


Method:

1. First measurement is done away from the sample with and without the DC power source, this measurement gives the influence of the current line on the output of the sensor - direct coupling.
2. Then the measurement over the metallic sample is done, again with and without the DC power source, to subtract the direct coupling.

- When the probe is over a metallic sample, the induced currents on the metal will generate a magnetic field that reduces the total field.
- For each measurement the lock in gives both the real and imaginary values of the sensor voltage, as it may have a certain phase.

Results:



	With DC source		Without DC source		Uncoupled signal				
	V^{imag} (μV)	V^{real} (μV)	V^{imag} (μV)	V^{real} (μV)	V^{imag} (μV)	V^{real} (μV)	V^{modulo} (μV)	Var 1 (%)	Var2 (%)
outside sample	0,5	138,7	5,0	137,0	-4,5	1,7	4,8	0,0	12,8
	phase (°):	0,2	phase (°):	2,1	phase (°):	-69,3			
normal surface	1,5	131,1	4,2	127,8	-2,7	3,3	4,3	11,4	0,0
	phase (°):	0,7	phase (°):	1,9	phase (°):	-39,3			
near a fissure	0,5	119,8	2,9	115,8	-2,4	4,0	4,7	3,0	9,4
	phase (°):	0,2	phase (°):	1,4	phase (°):	-31,0			

$$V_{real}^{uncoupled} = V_{real}^{withDC} - V_{real}^{withoutDC}$$

$$V_{imag}^{uncoupled} = V_{imag}^{withDC} - V_{imag}^{withoutDC}$$

$$V_{modulo}^{2} = V_{real}^{2} + V_{imag}^{2}$$

$$\mathrm{phase} = \arctan \frac{V_{imag}}{V_{real}}$$

$$\mathrm{Var1} = 100 \times \frac{|V_{modulo}^{outside} - V_{modulo}|}{V_{modulo}^{outside}}$$

$$\mathrm{Var2} = 100 \times \frac{|V_{modulo}^{normal} - V_{modulo}|}{V_{modulo}^{normal}}$$

Discussion:

- As predicted, the signal over the sample is lower than away from the sample.
- Fissures prevent induced currents to flow, then the response field would be smaller and the measured field would be higher. That kind of behaviour was observed: $(V_{modulo}^{normal} < V_{modulo}^{fissure} < V_{modulo}^{outside})$.
- The variation of the signal when go from normal surface to a fissure (Var2 (%)) would be higher for deeper fissures and smaller for superficial ones.
- The measured variation come from the magnetic field variation and not directly from magnetoresistance effects.