

Accessoires connexes sur un FIB Dual Beam - Applications

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PFNC... en quelques chiffres

Créée en **2006**...

... au sein du **Campus Minatec**,

Regroupement des ressources en caractérisation de 3 Instituts du CEA Grenoble

- **leti** (DRT/Laboratoire d'Electronique & Technologies de l'Information)
- **liten** (DRT/Laboratoire d'Innovations pour les Technologies des Energies Nouvelles & nanomatériaux)
- **INOC** (DSM/Institut Nanosciences & Cryogénie)

INOC
INSTITUT NANOSCIENCES
ET CRYOGÉNE



~70 chercheurs & techniciens,
40 équipements lourds de caractérisation,
2500m² de laboratoires,
3,5M€ d'investissements / an,
1 accord bilatéral avec le CMTC
1 partenariat avec la société




7 Centres de Compétences




Analyse par
Rayons X



Microscopie
électronique



Analyse par
Faisceaux d'ions



Analyse
de surface



Préparation
d'échantillons



Résonance
magnétique



Champ proche



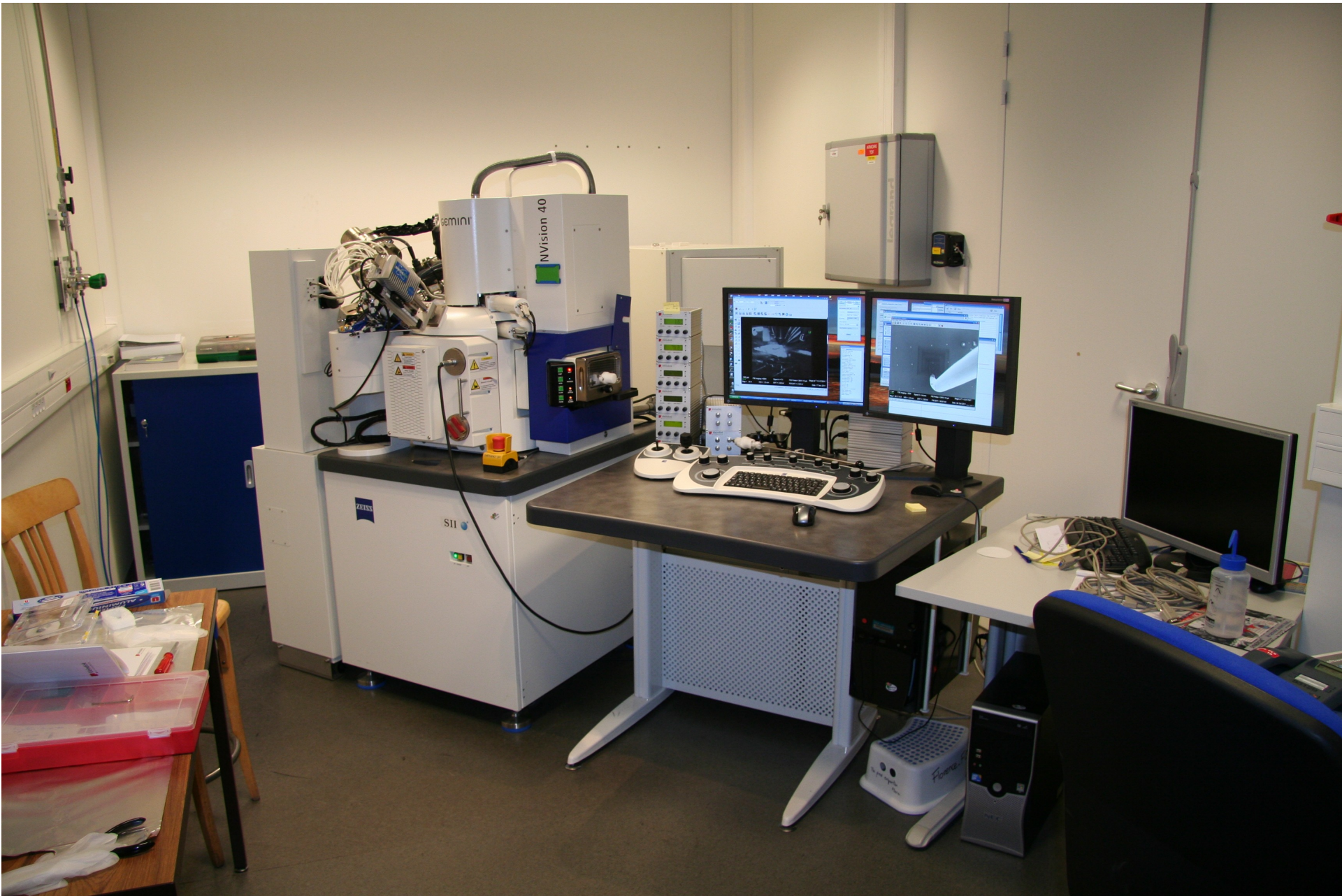
3 Dual Beam

L'équipement inter-plateforme (RTRA) & ses équipements connexes

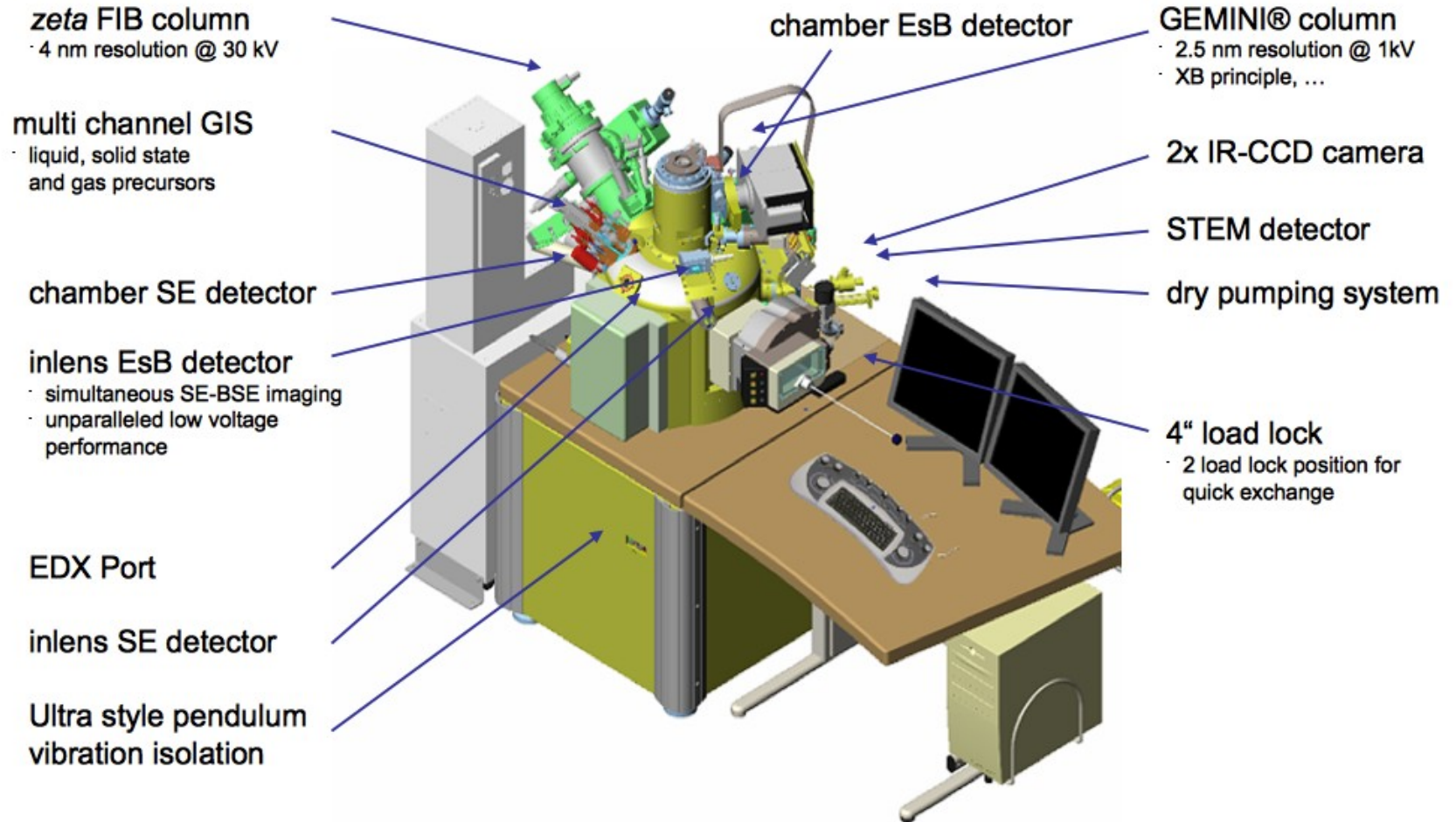
- Le neutraliseur de charge Flood Gun**
- Manipulation de nanofils GaAs pour cross section TEM**
- Découpe et déplacement de microtores**
- Tests électriques sur pads 45 nm**
- Rot-Tip préparation TEM face arrière, affutage des pointes**
- Micro-pince et Rot-Tip**
- RT-STEM**

Conclusion & Perspectives

L'équipement inter-plateforme (RTRA) & ses équipements connexes



System Overview NVision40 Projet RTRA

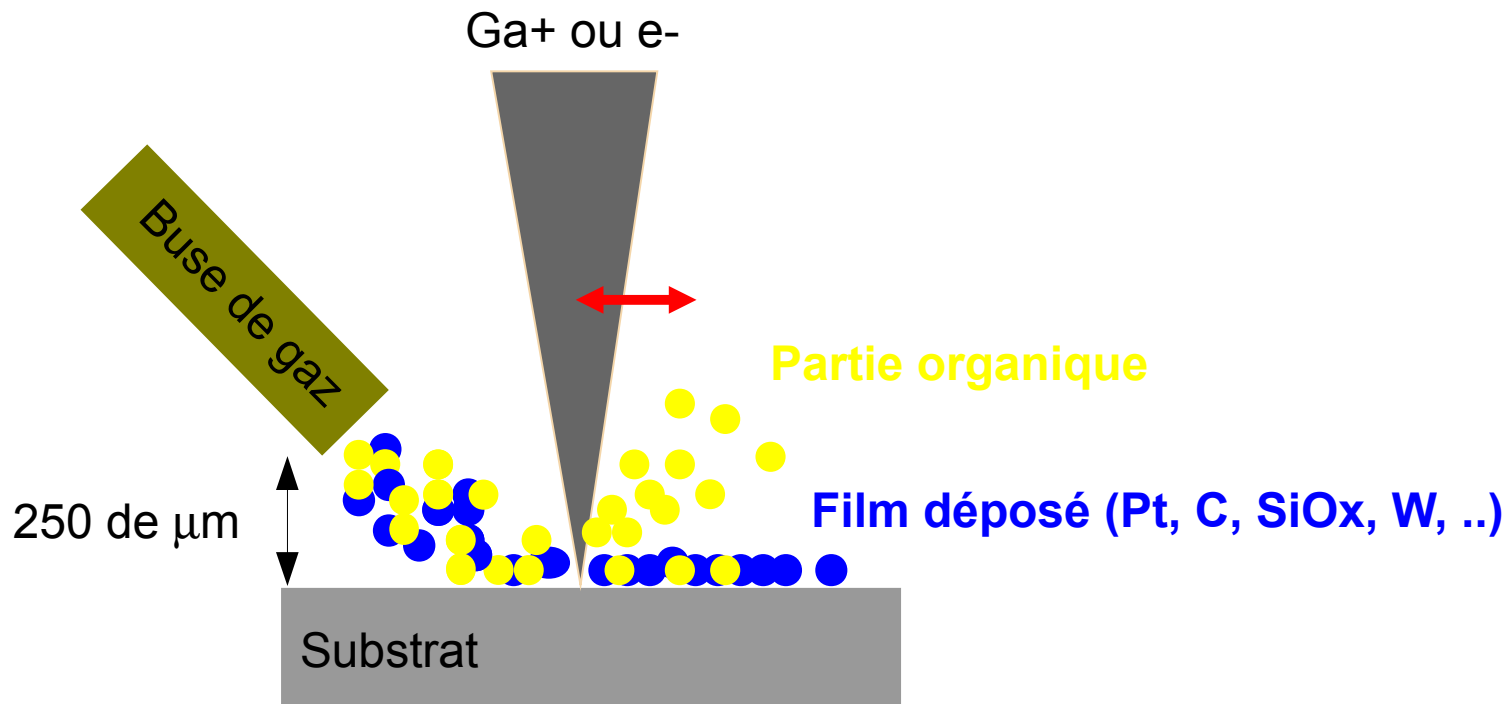


La 'soudure' ou le 'collage' par faisceau ionique ou e- Injecteur de gaz

(organométalique → molécules adsorbées à la surface

- ions (e-) → dissociation des molécules avec les ligands organiques quittent la surface évacués dans la chambre et des **atomes déposés à la surface**

→ **dépôt** CVD assisté par faisceau d'ions ou d'e-





Support grille TEM

2 μm



FIB Imaging = SEM

Signal A = SESI

FIB Probe = 30KV:80 pA

Stage at T = 55.204106 °

Mag = 11.89 K X

WD = 5.0 mm

EHT = 5.00 kV

FIB EHT = 30.01 kV

Date :8 Apr 2010

Canon à e- basse tension

Ga⁺



+++++

Echantillon

gamme d'énergie : 5 - 500 eV
courant : 5 - 100 μ A

distance de travail : 46 mm

Applications :

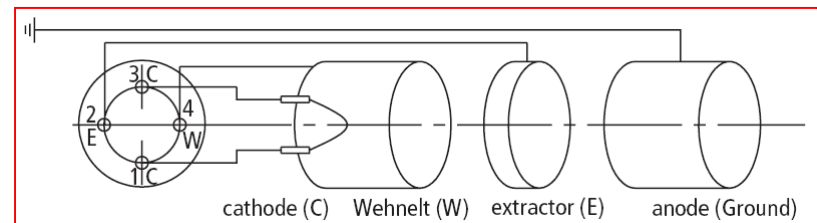
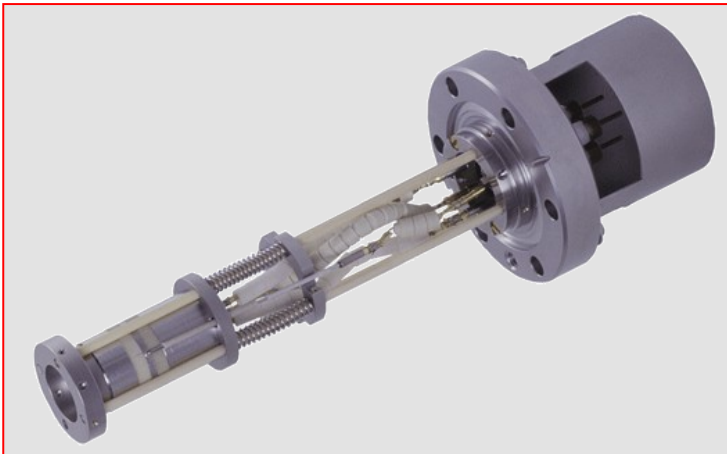
isolants, SC

Neutraliseur de charges + au cours de l'abrasion ionique

Flux d'e- diffus autour du champ de l'image

$$E_{e^-} \sim 50 \text{ eV}$$

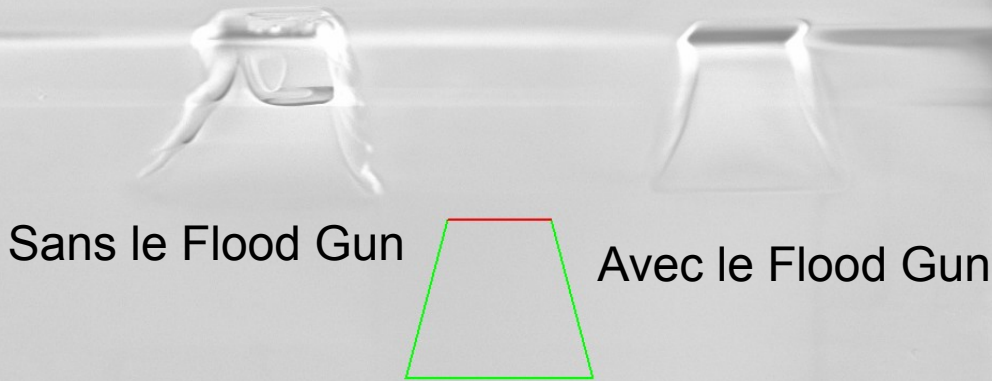
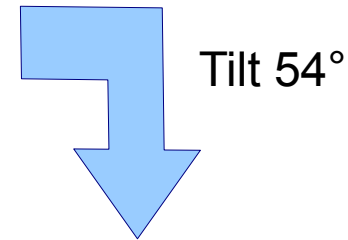
$$I_{e^-} \sim 50 \times I_{\text{ion}}$$



Pilotage depuis l'interface SmartSEM du NVision 40
Réalisation JC Menard – Zeiss France

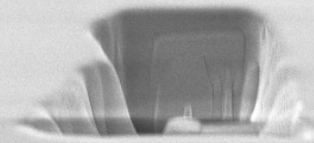
Trous en trapèzes sur lame de verre

$$I_{Ga} = 1,5 \text{ nA}$$

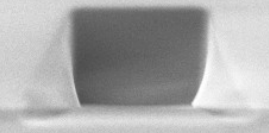


3 μm EHT = 2.00 kV Signal A = InLens FIB Milling Probe = 30KV:6.5 nA CMTC
Mag = 1.96 K X Date : 29 Nov 2011
WD = 4.8 mm FIB Imaging = SEM Time : 15:12:26

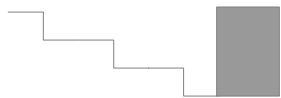
Sans le Flood Gun



Avec le Flood Gun

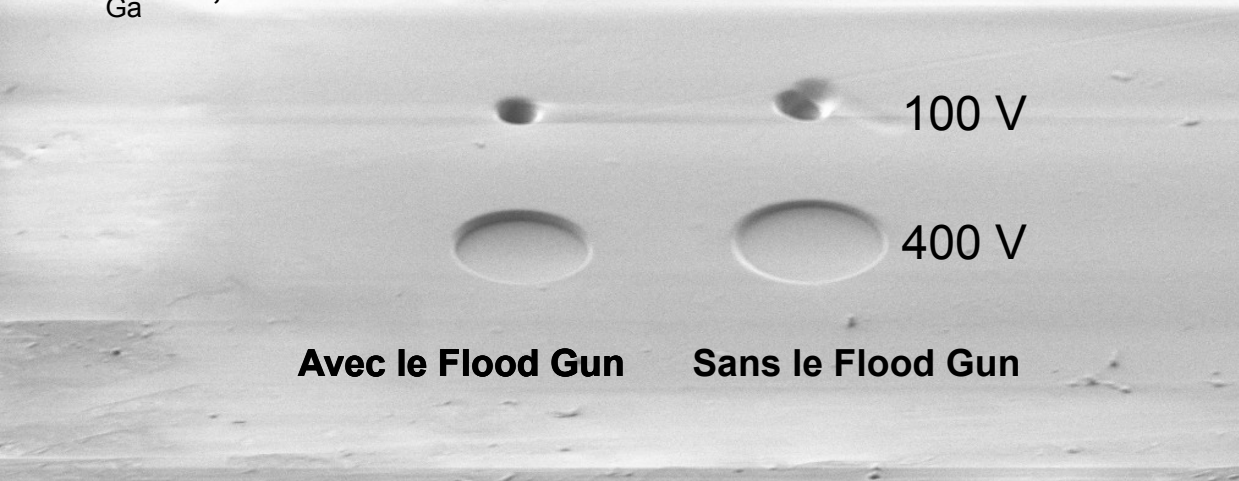


Profil souhaité




2 μm EHT = 2.00 kV Signal A = SESI FIB Milling Probe = 30KV:6.5 nA CMTC
Mag = 2.08 K X Date : 29 Nov 2011
WD = 4.9 mm FIB Imaging = SEM Time : 15:14:49

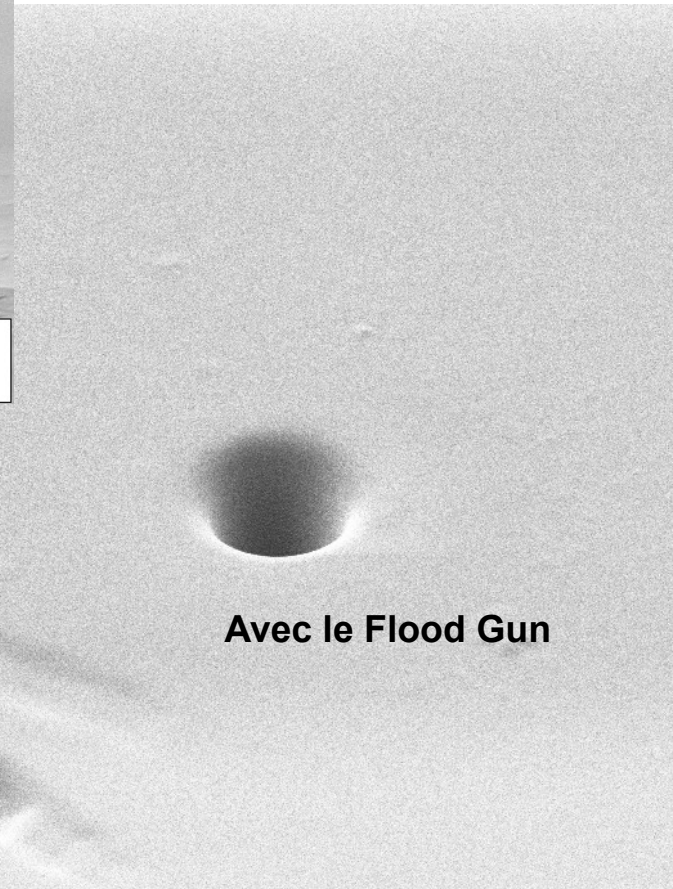
sonde statique en FIB
Defocus_{object} de 100 V et 400 V
 $I_{Ga} = 6,5 \text{ nA}$



Avec le Flood Gun

Sans le Flood Gun

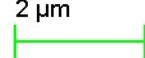
 2 μm	EHT = 2.00 kV Mag = 2.08 K X WD = 4.9 mm	Signal A = SESI FIB Imaging = SEM	FIB Milling Probe = 30KV:6.5 nA	CMTC Date :29 Nov 2011 Time : 15:23:14
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Sans le Flood Gun

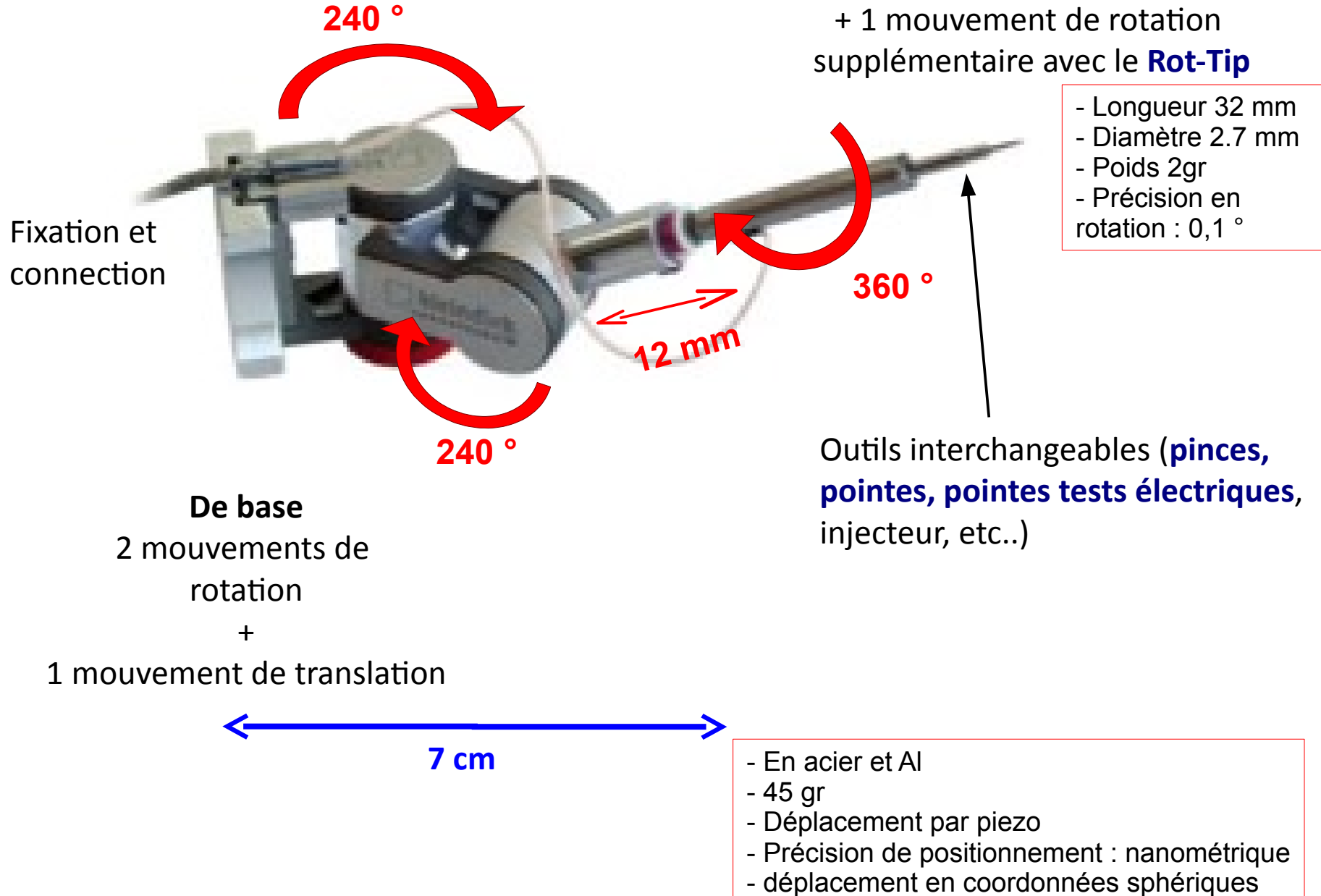
Avec le Flood Gun

Trous circulaires avec sonde statique en FIB
Defocus_{object} 0
 $I_{Ga} = 6,5 \text{ nA}$

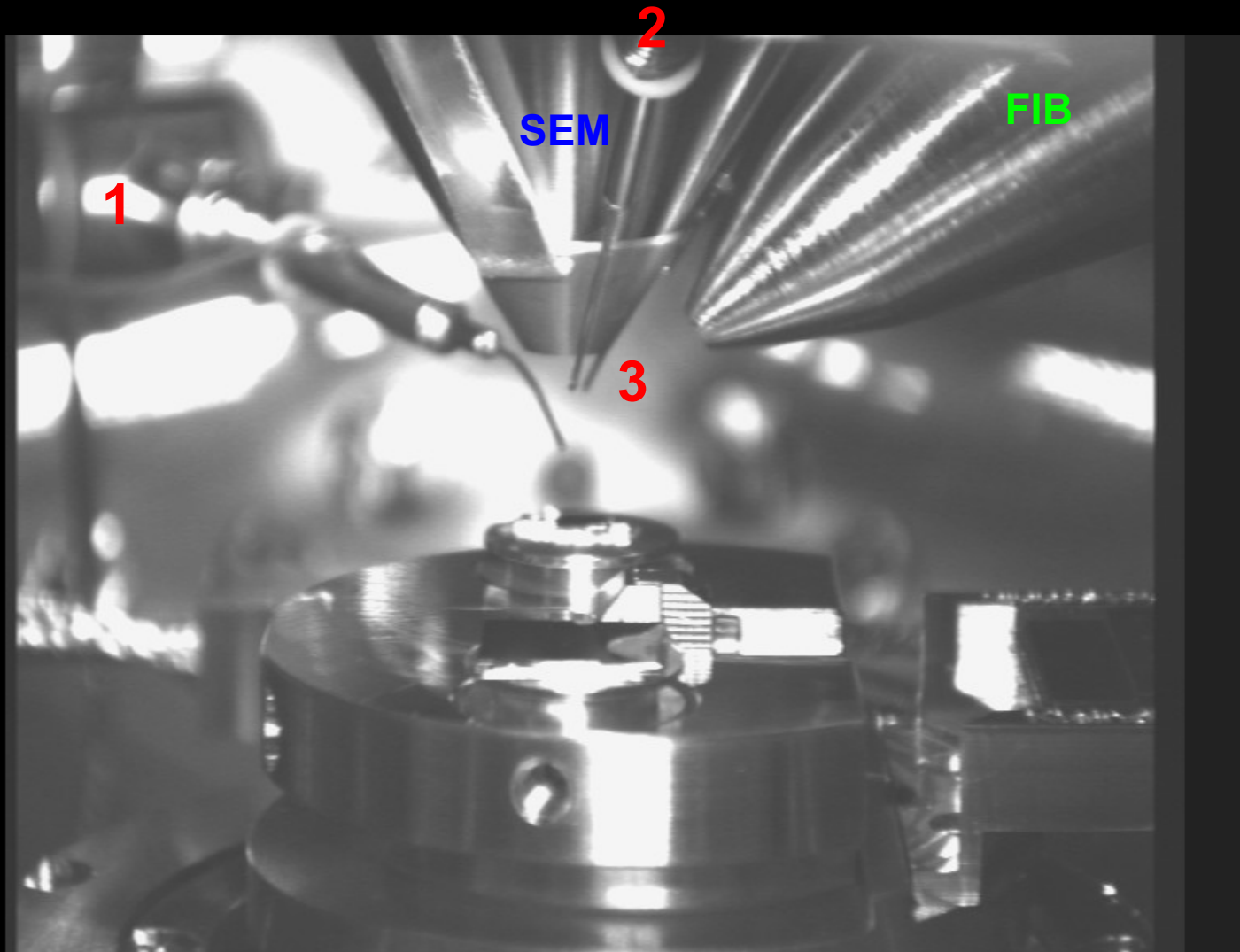
 2 μm	EHT = 2.00 kV Mag = 5.65 K X WD = 4.9 mm	Signal A = SESI FIB Imaging = SEM	FIB Milling Probe = 30KV:150 pA	CMTC Date :29 Nov 2011 Time :16:05:25
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L'équipement inter-plateforme (RTRA) & ses équipements connexes

L'ensemble micromanipulateur (Kleindiek)



Situation avec 3 micromanipulateurs dans la chambre



20 μm

FIB Imaging = SEM

Signal A = TV

FIB Probe = 30KV:3 nA

Stage at T = 0.000858 °

Mag = 596 X WD = 5.6 mm

EHT = 5.00 kV

FIB EHT = 30.01 kV

Date :23 Oct 2009

Micromanipulateur

Buse de gaz



10/9/2008
15:51:36

HV
10.00 kV

WD
5.0 mm

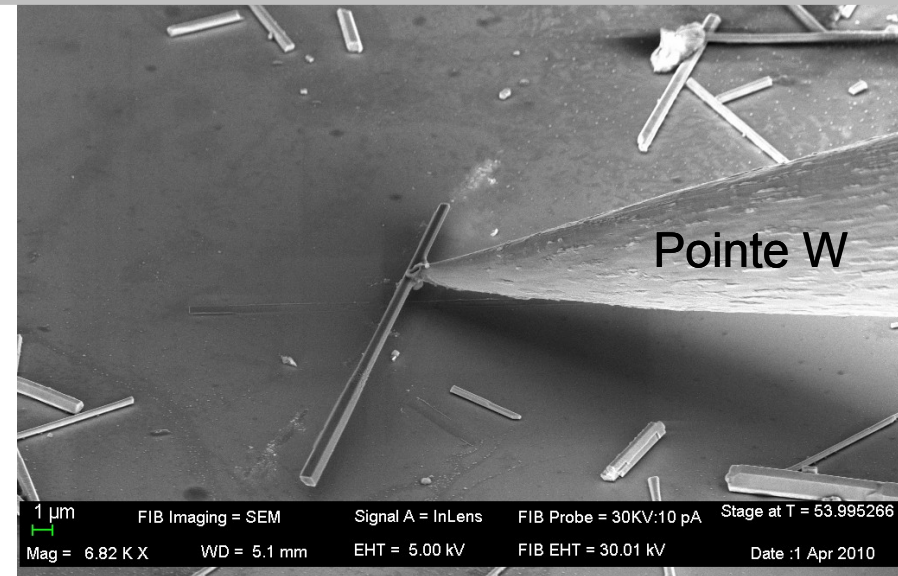
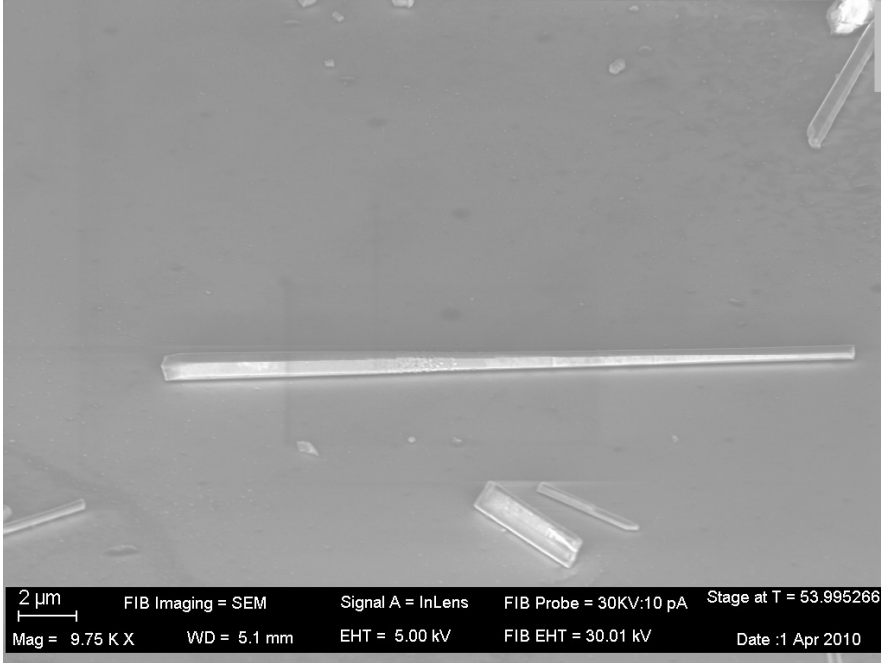
mag
80 x

det
TLD

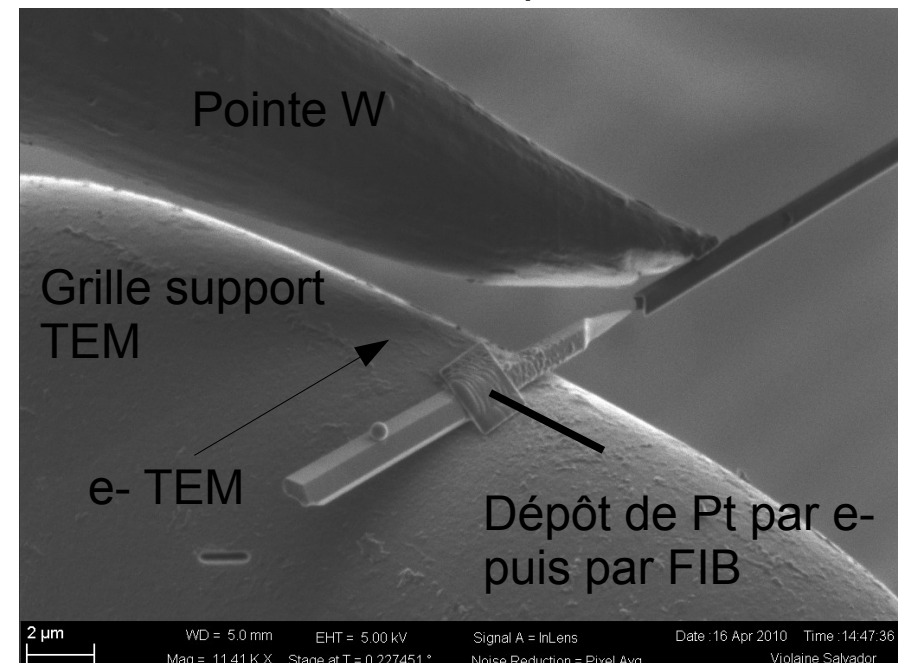
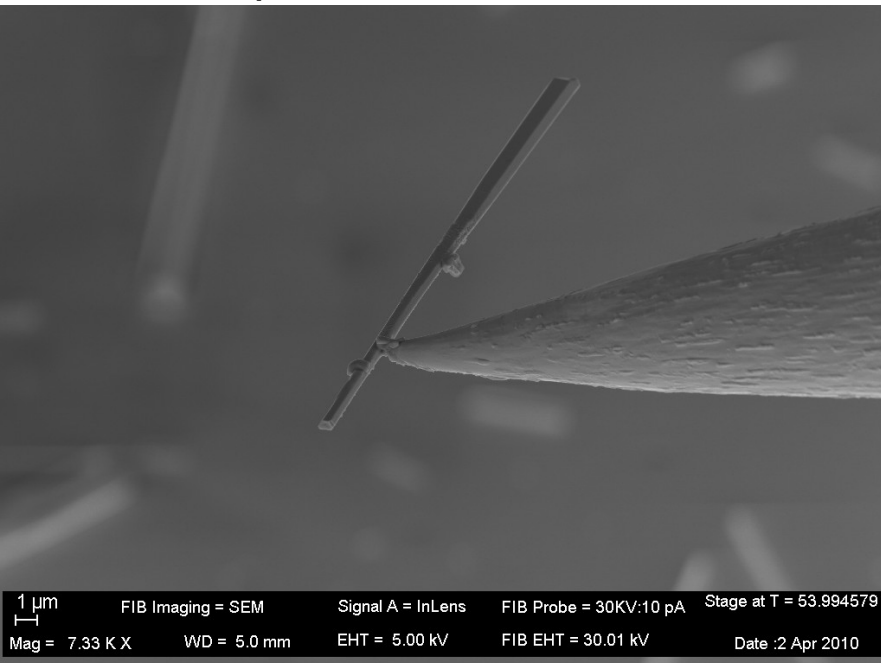
tilt
52 °

1 mm
xt790

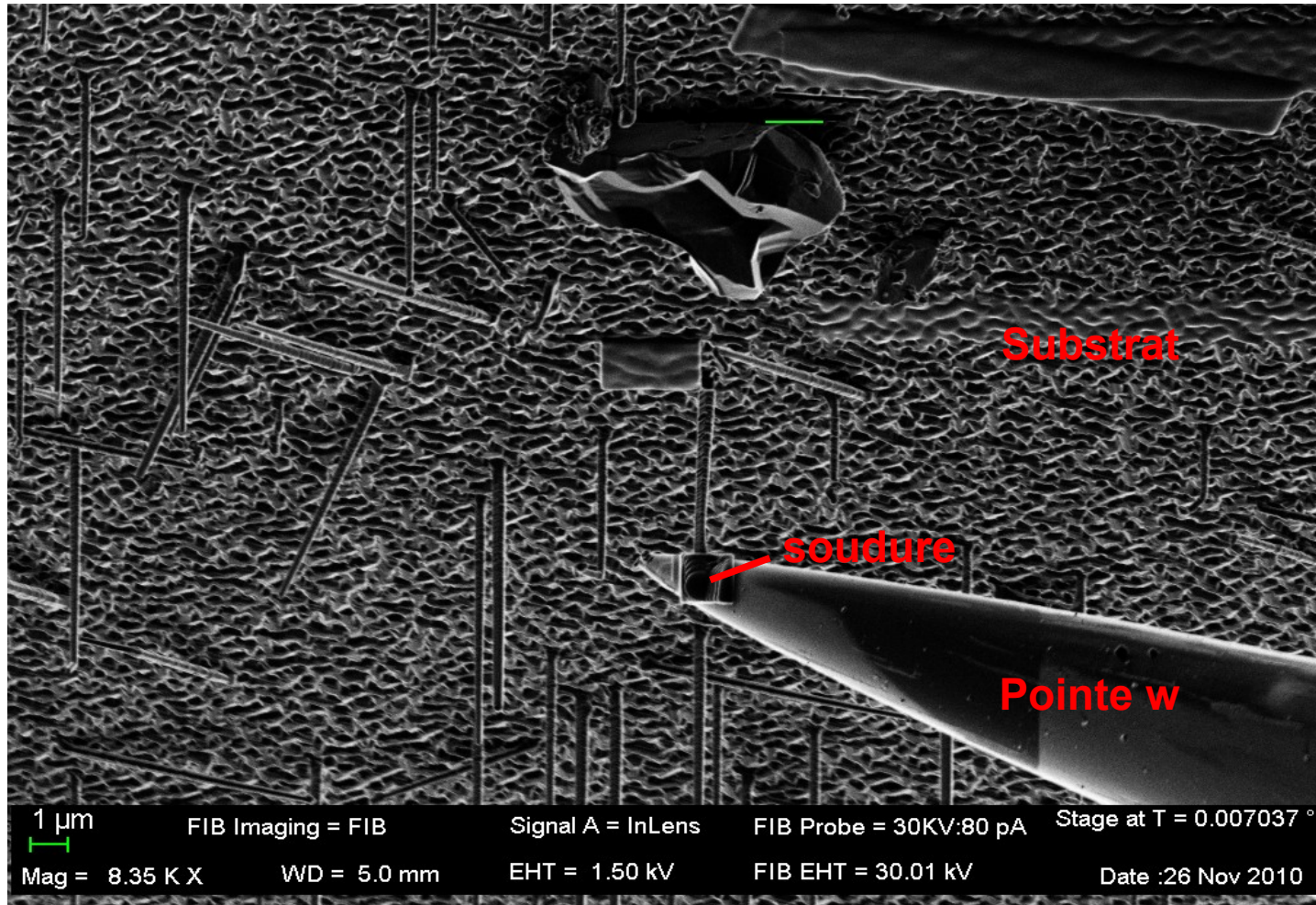
Manipulation de nanofils ZnO pour cross section TEM



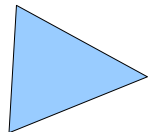
Cas simple : fils sur une surface . But préparation en cross-section pour le TEM



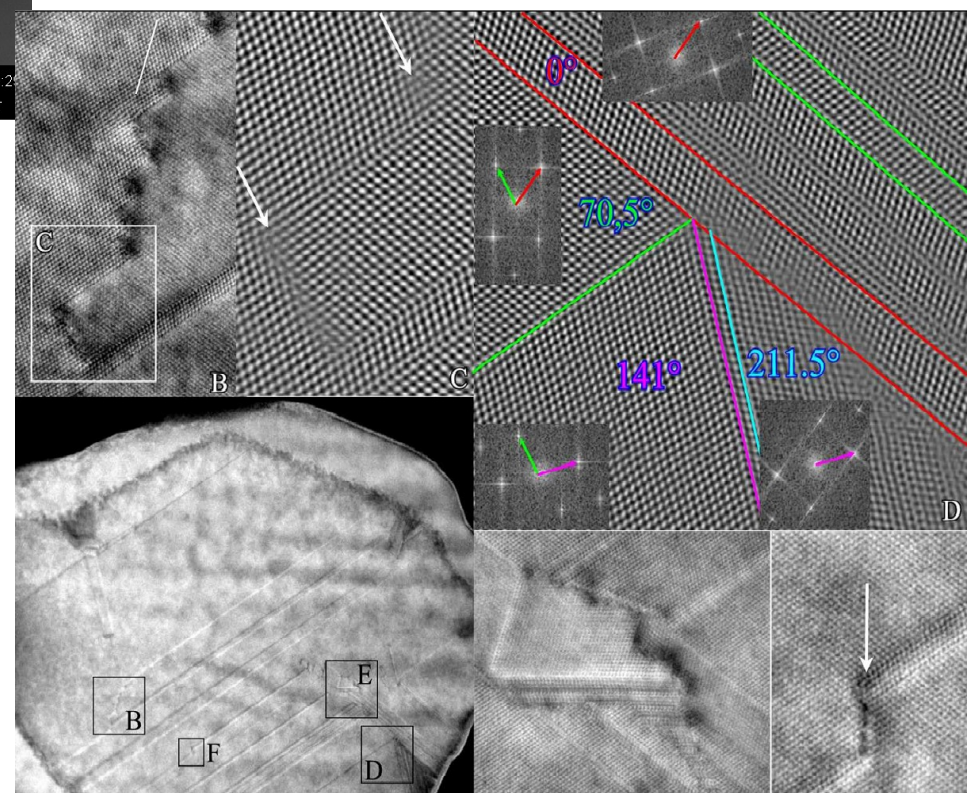
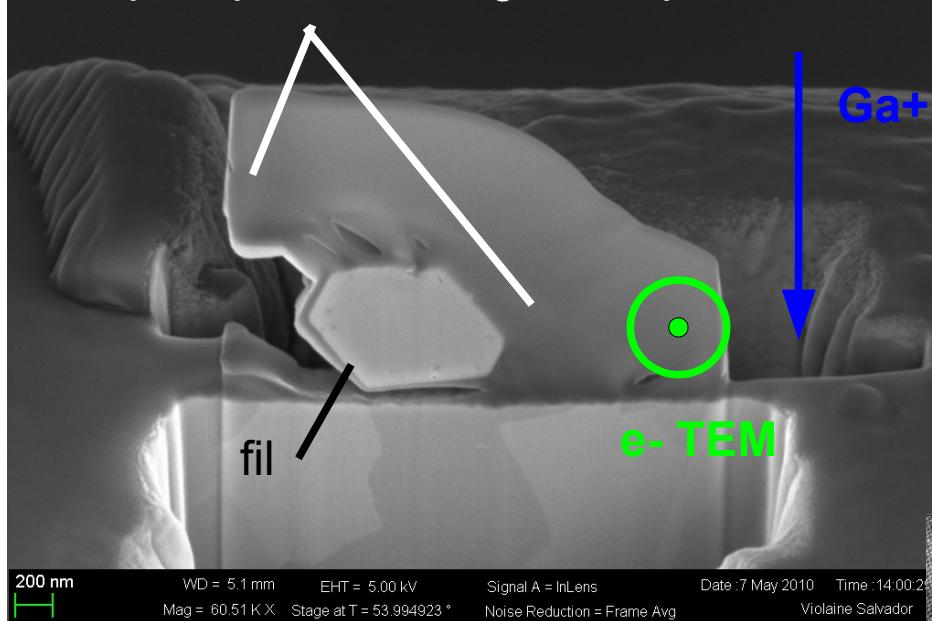
La pointe est trop grosse par rapport à l'objet déplacé ... facile on soude un premier fil qui servira pour la manipulation.



Vue FIB



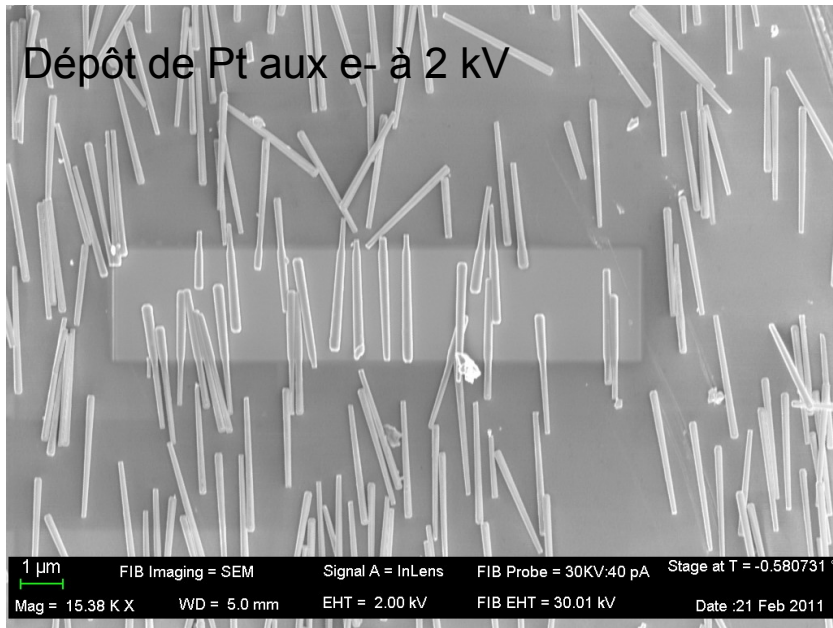
Dépôts pour le collage et la protection



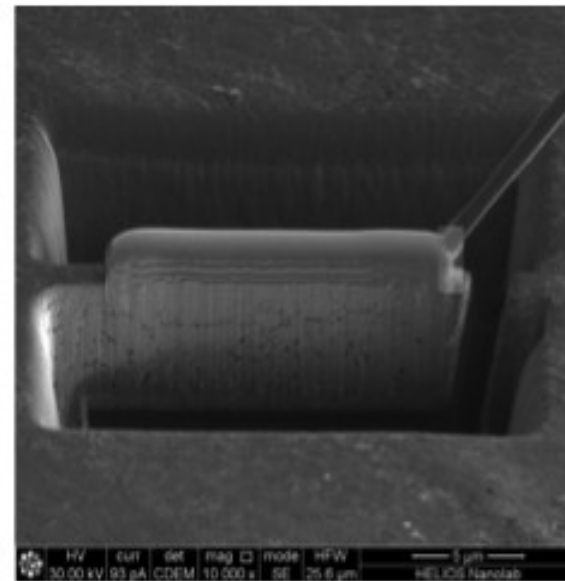
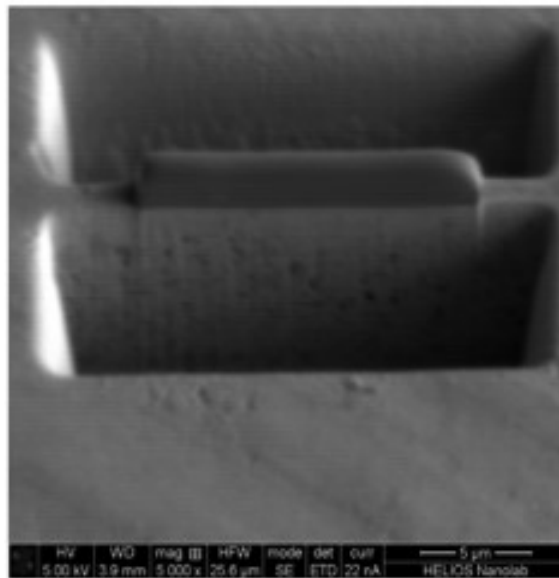
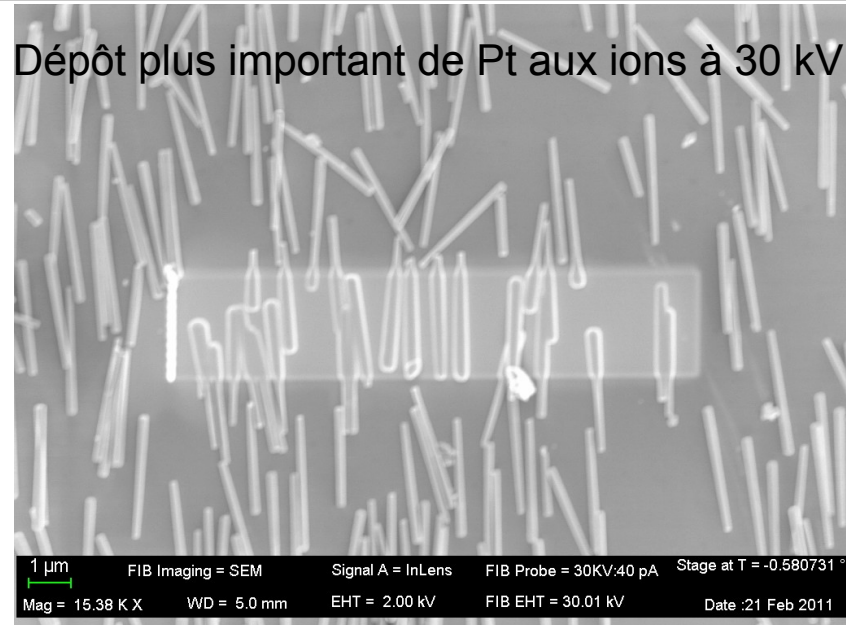
Observation en HRTEM

Manipulation de nanofils ZnO pour cross section TEM

Dépôt de Pt aux e- à 2 kV

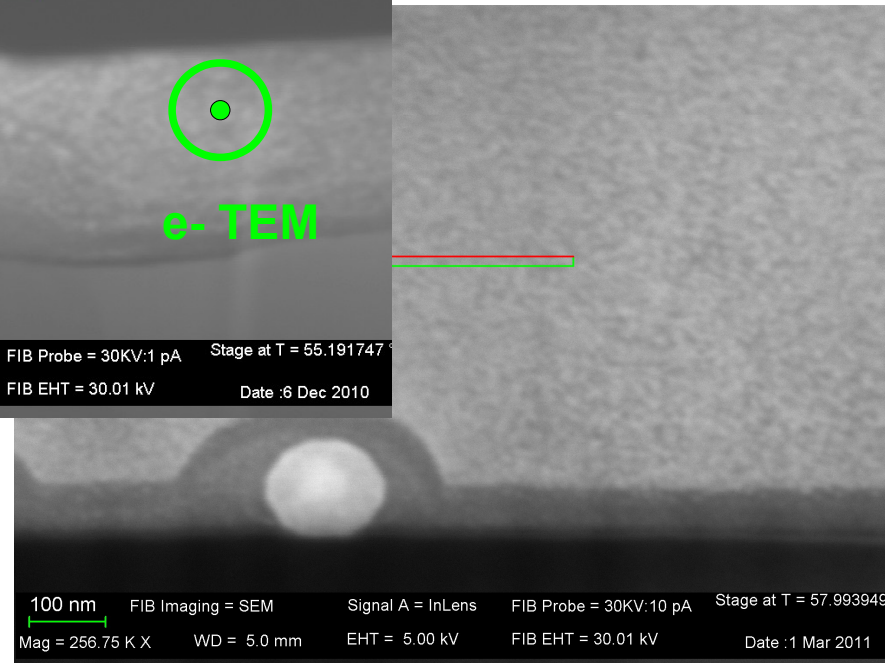
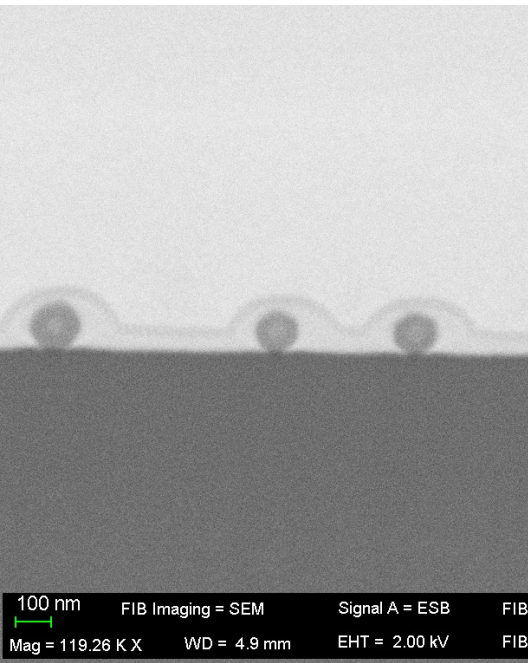
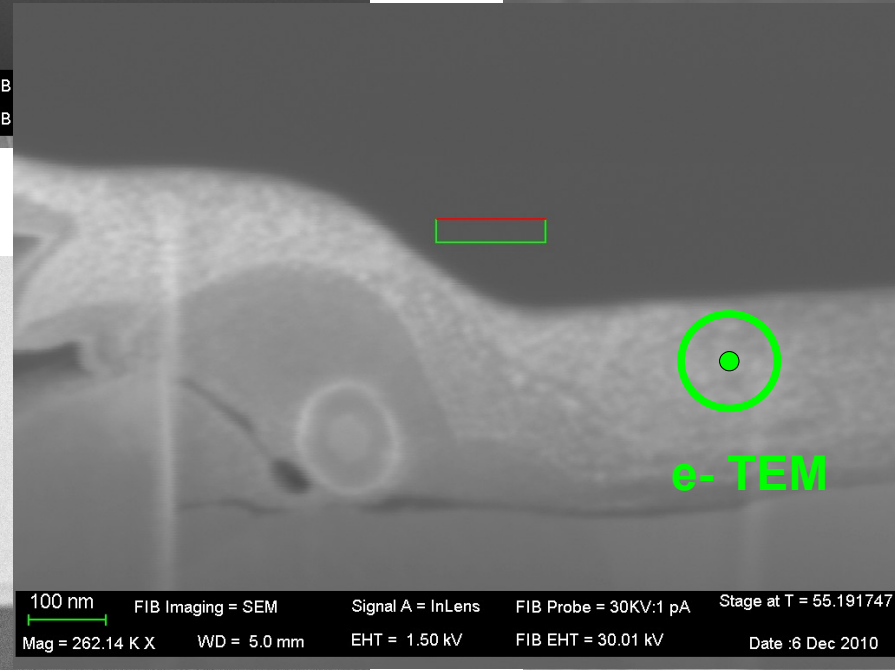
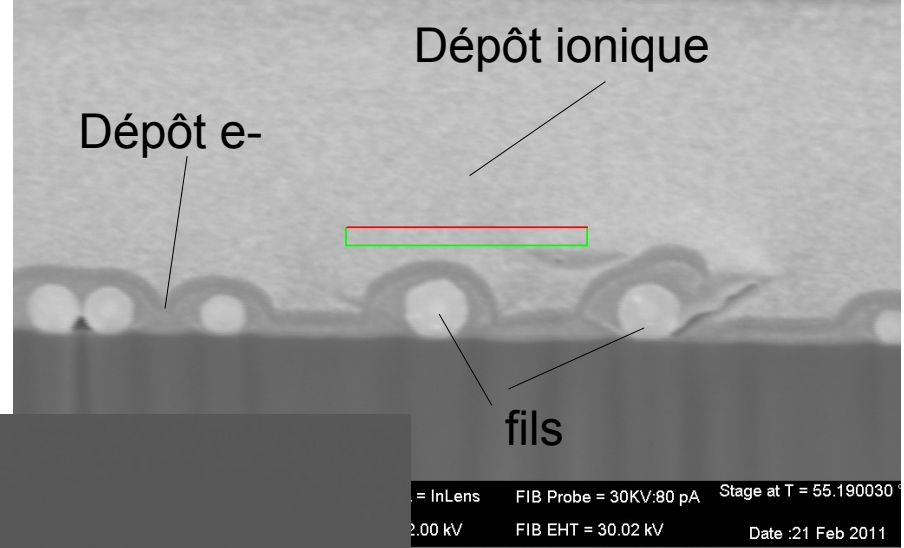
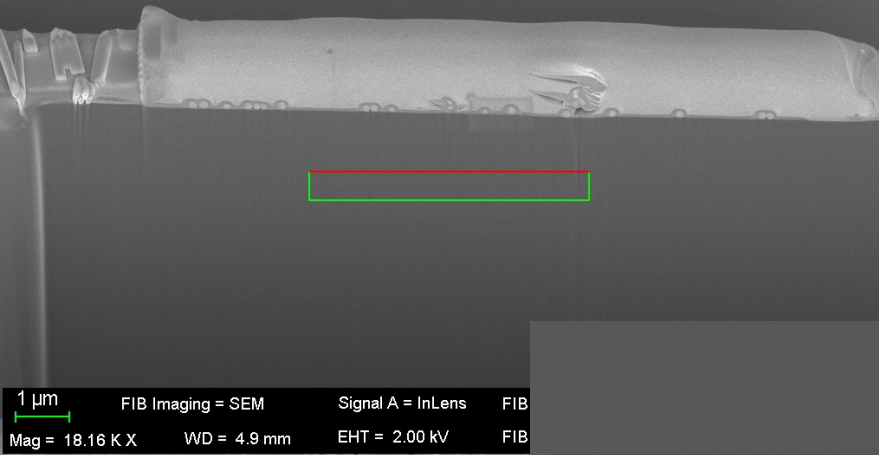


Dépôt plus important de Pt aux ions à 30 kV

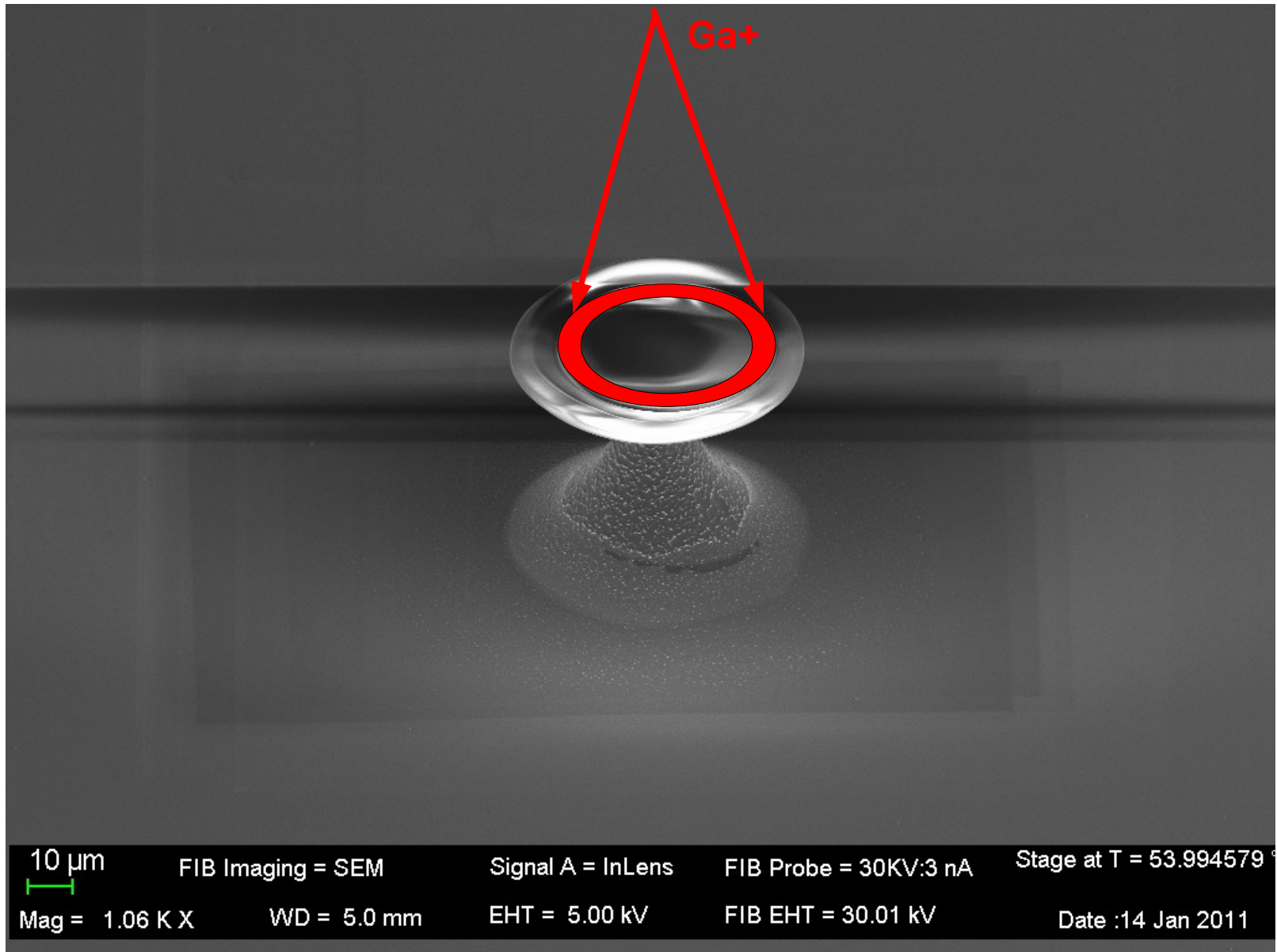


Gravure latérale, découpe des flans, soudure sur la miromanipulateur et extraction

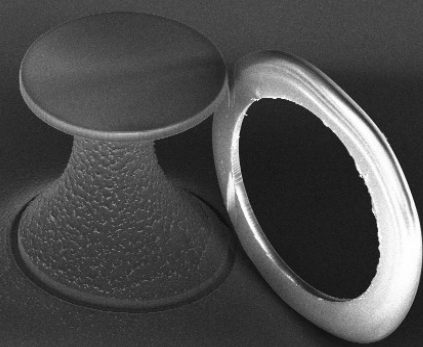
Manipulation de nanofils ZnO pour cross section TEM



Manipulation d'un tore en silice, découpe et déplacement

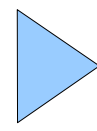


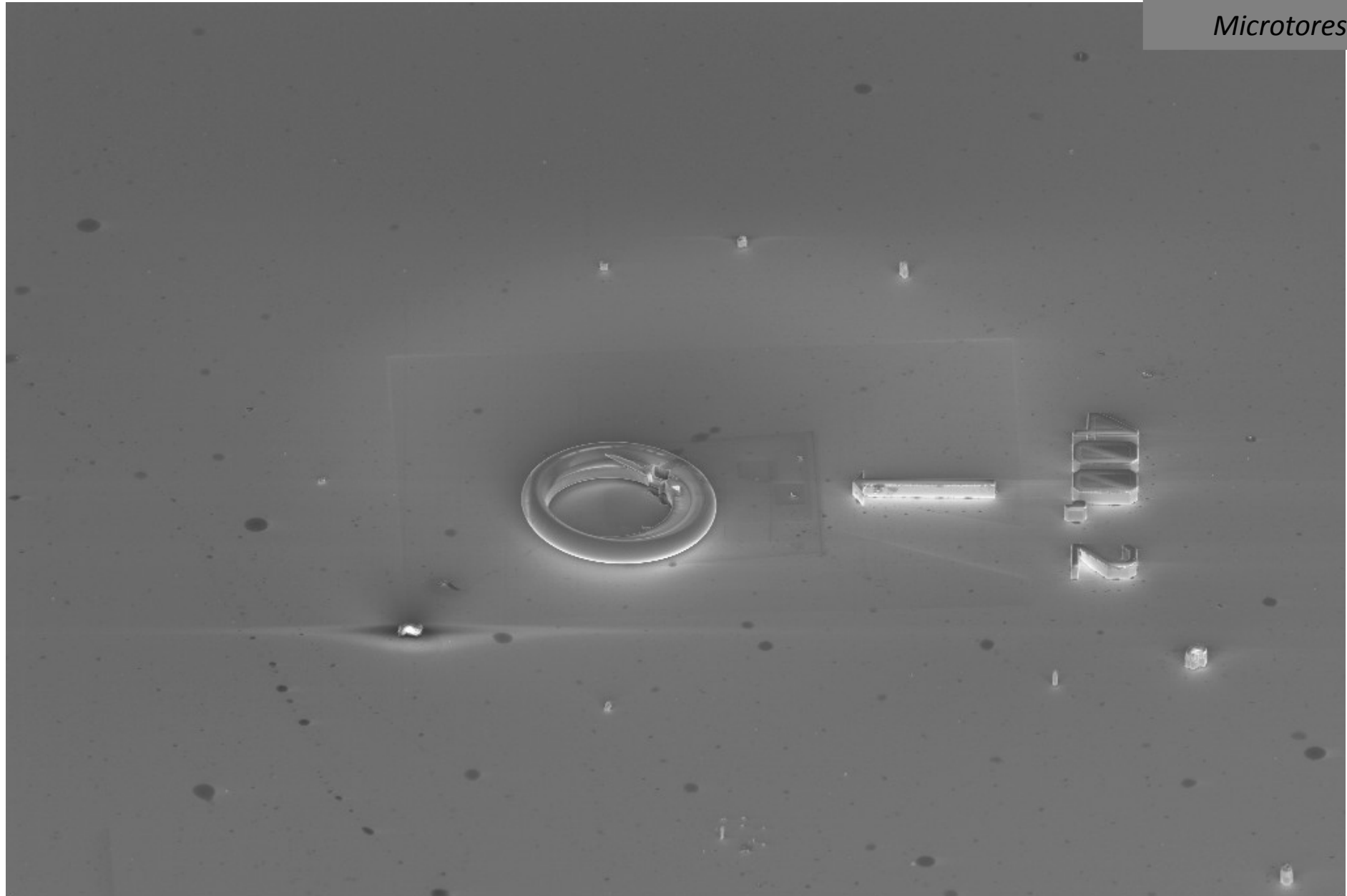
Si découpe seule
C'est perdu !!!



Signal A = InLens FIB Probe = 30KV:3 nA Stage at T = 53.994579
EHT = 5.00 kV FIB EHT = 30.01 kV Date :14 Jan 2011

10 μ m FIB Imaging = SEM Signal A = InLens FIB Probe = 30KV:3 nA Stage at T = 53.994579
Mag = 1.33 K X WD = 5.0 mm EHT = 5.00 kV FIB EHT = 30.01 kV Date :14 Jan 2011





10 μ m



EHT = 5.00 kV

WD = 5.0 mm

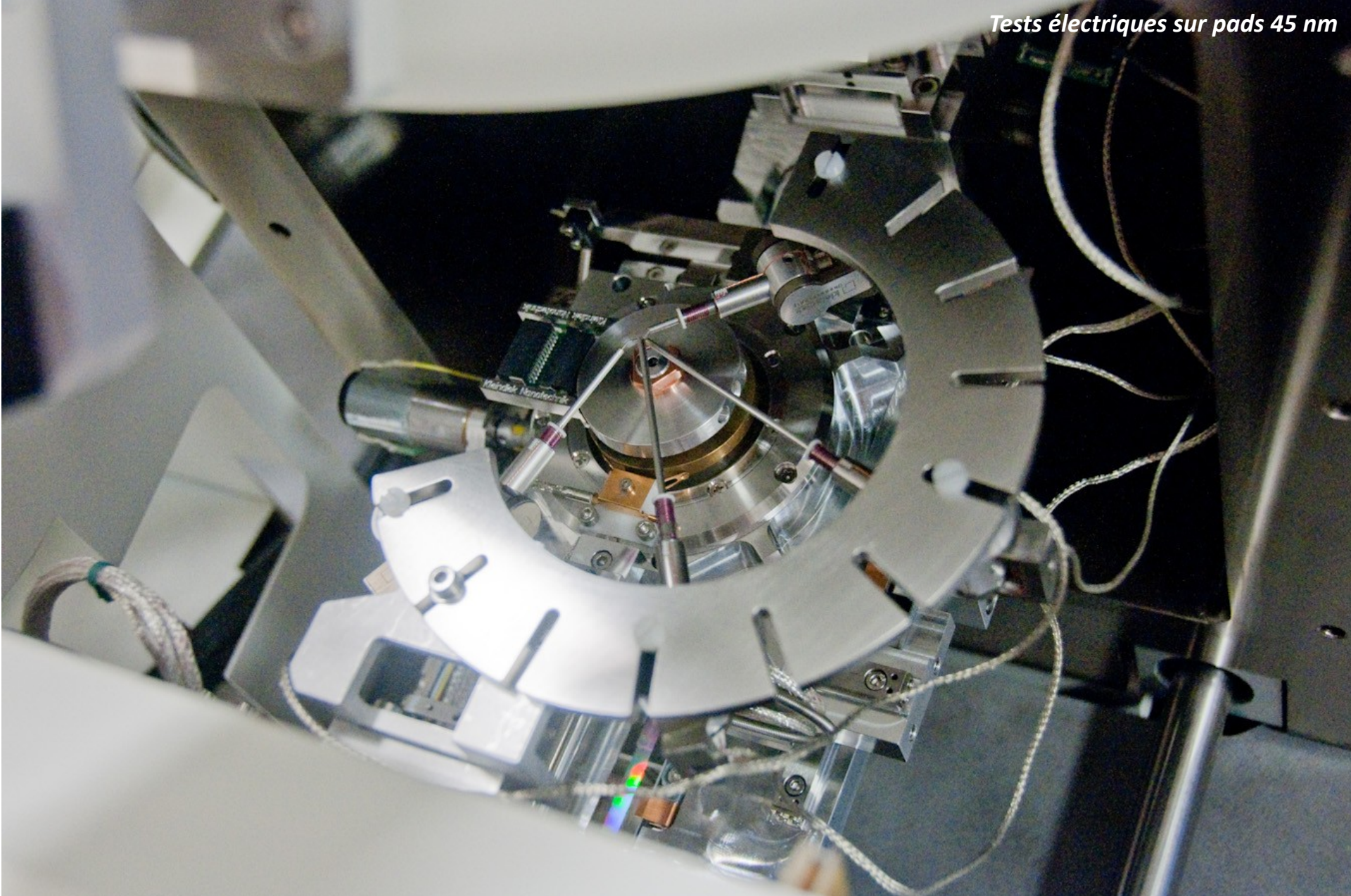
Signal A = InLens

Tilt Angle = 0.0 °

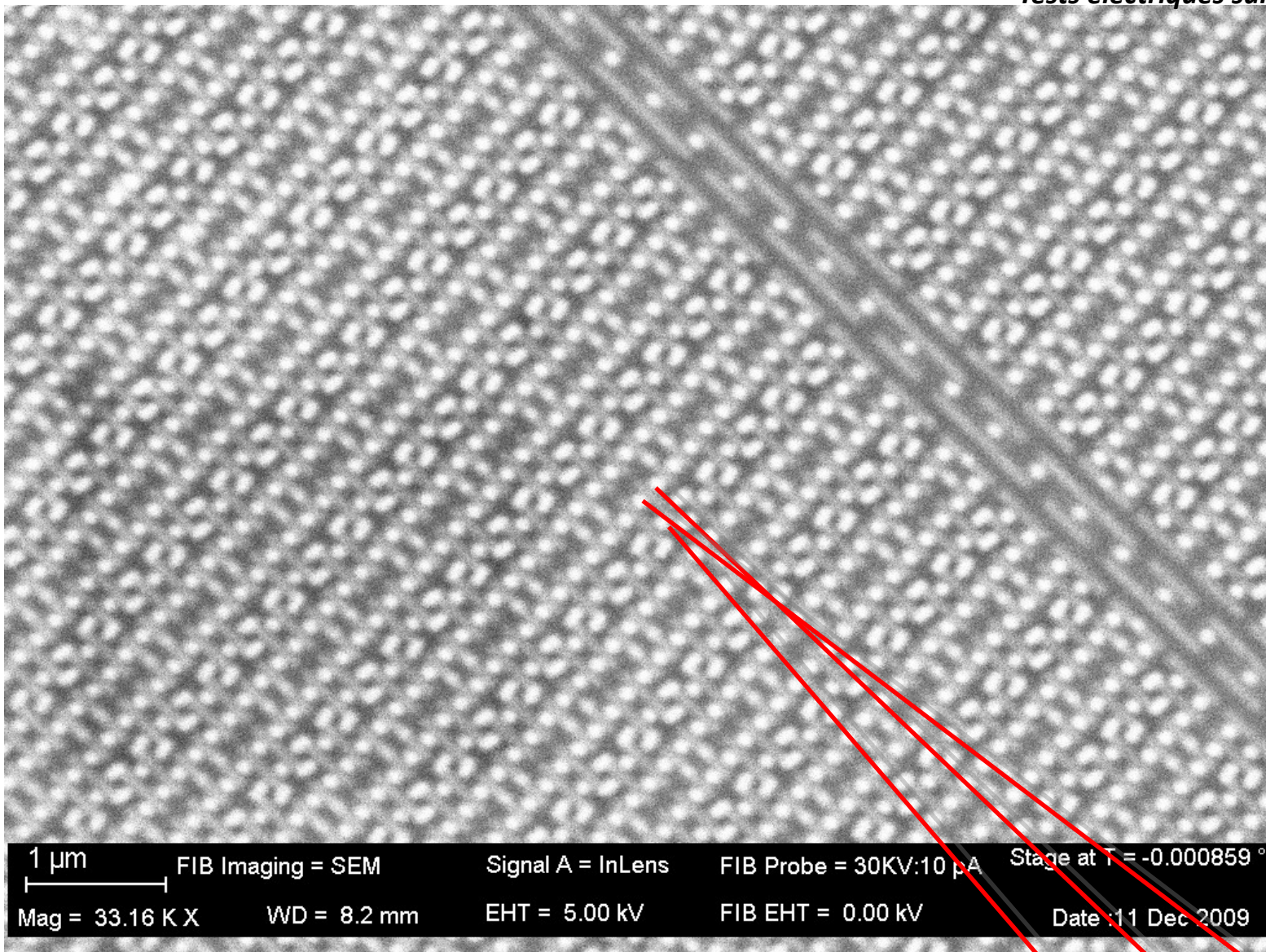
FIB EHT = 30.01 kV

Date :11 May 2011

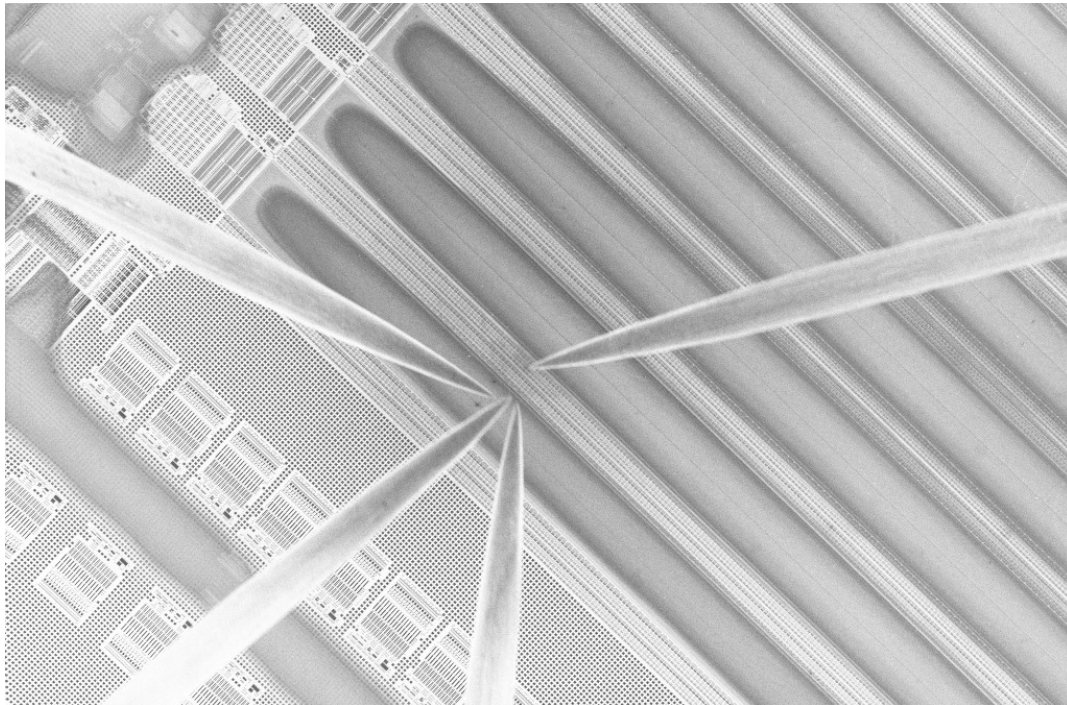
PTA



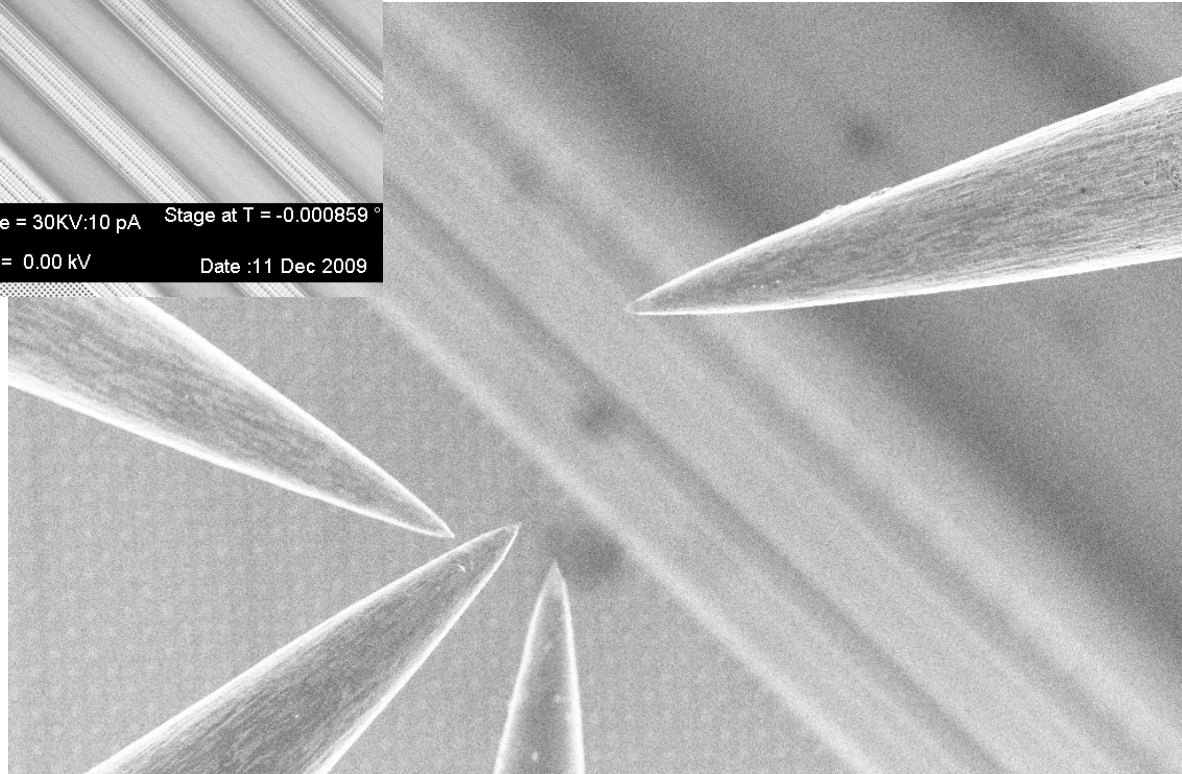
4 micromanipulateurs en montage sur la porte



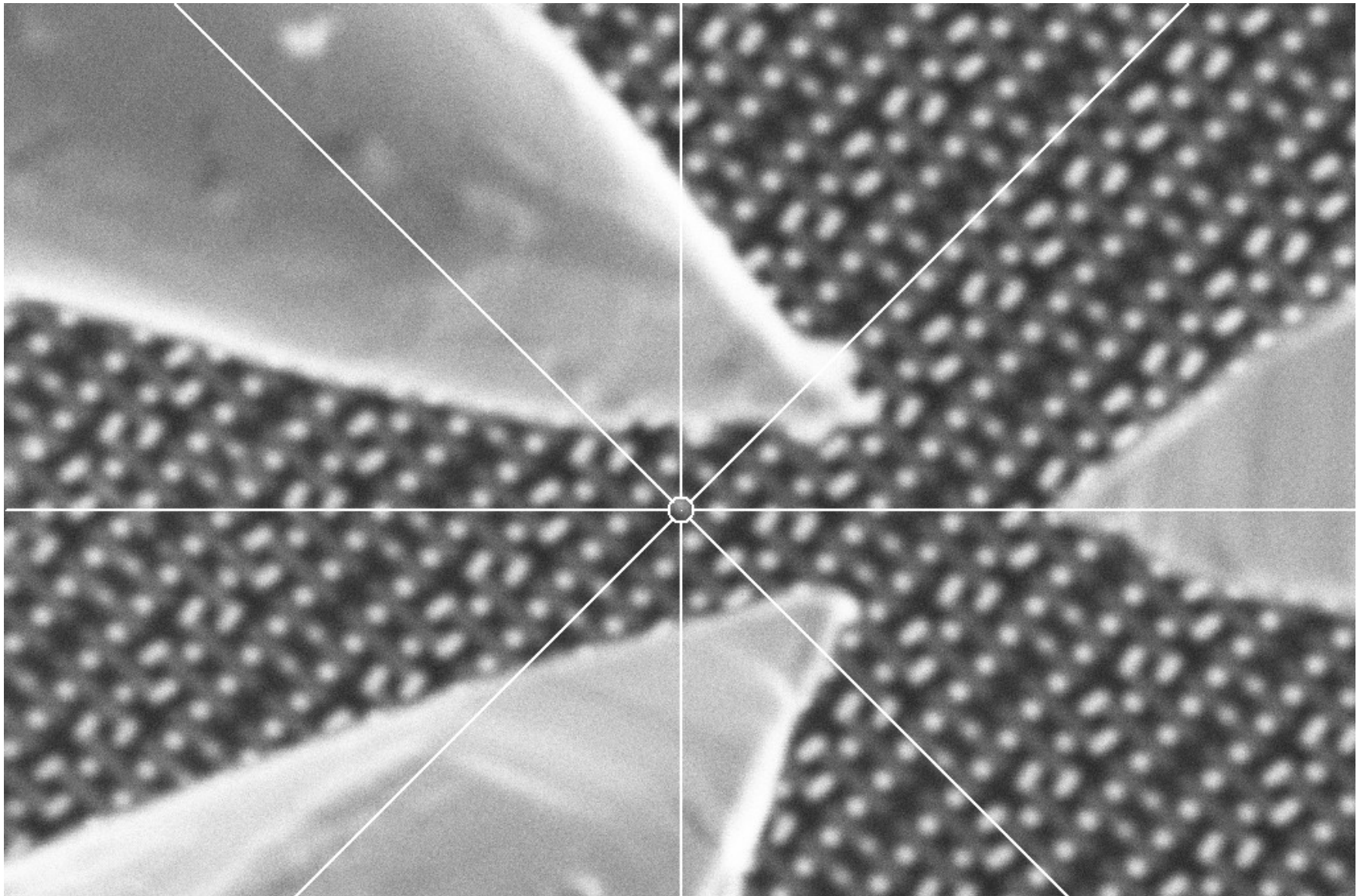
But: caractériser un transistor pour cela il faut mettre une pointe ici puis ici et là !!!!!
Surface d'atterrissage des pointes **45 nm²**



20 µm FIB Imaging = SEM Signal A = InLens FIB Probe = 30KV:10 pA Stage at T = -0.000859 °
Mag = 379 X WD = 8.6 mm EHT = 5.00 kV FIB EHT = 0.00 kV Date :11 Dec 2009



10 µm FIB Imaging = SEM Signal A = InLens FIB Probe = 30KV:10 pA Stage at T = -0.000859 °
Mag = 2.32 K X WD = 7.6 mm EHT = 5.00 kV FIB EHT = 0.00 kV Date :11 Dec 2009



200 nm



FIB Imaging = SEM

Signal A = InLens

FIB Probe = 30KV:10 pA

Stage at T = -0.000859 °

Mag = 48.22 K X

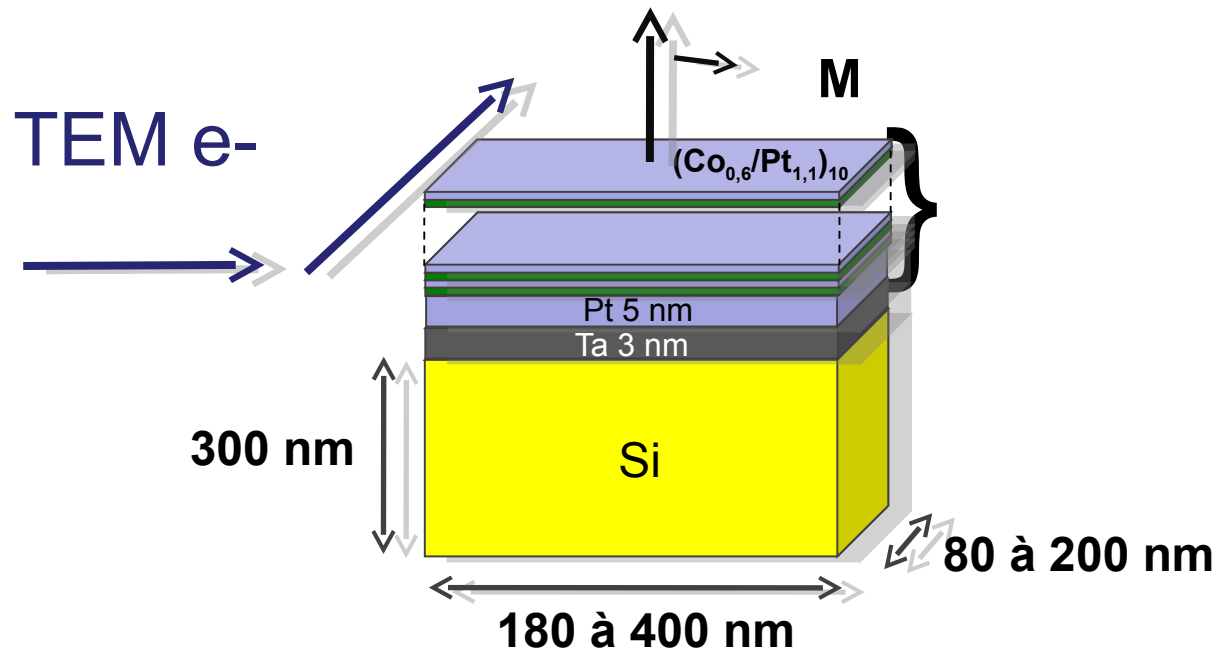
WD = 7.7 mm

EHT = 5.00 kV

FIB EHT = 0.00 kV

Date :11 Dec 2009

Système: Films minces (Co/Pt) aimantation perpendiculaire sur des plots pré-gravés de Si pour enregistrement ultra haute densité 1Tbit/in² sur média discret

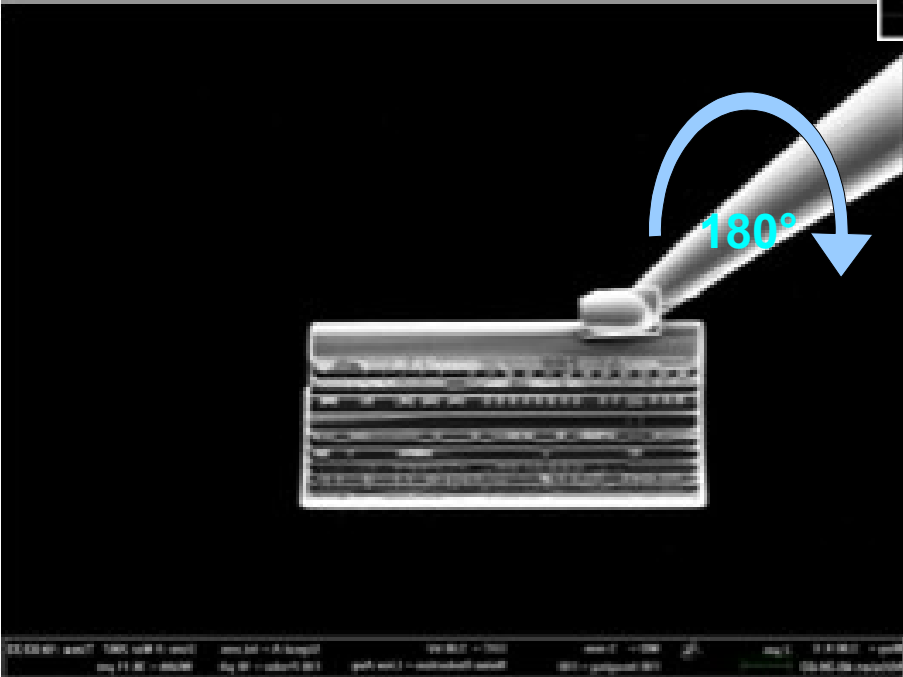
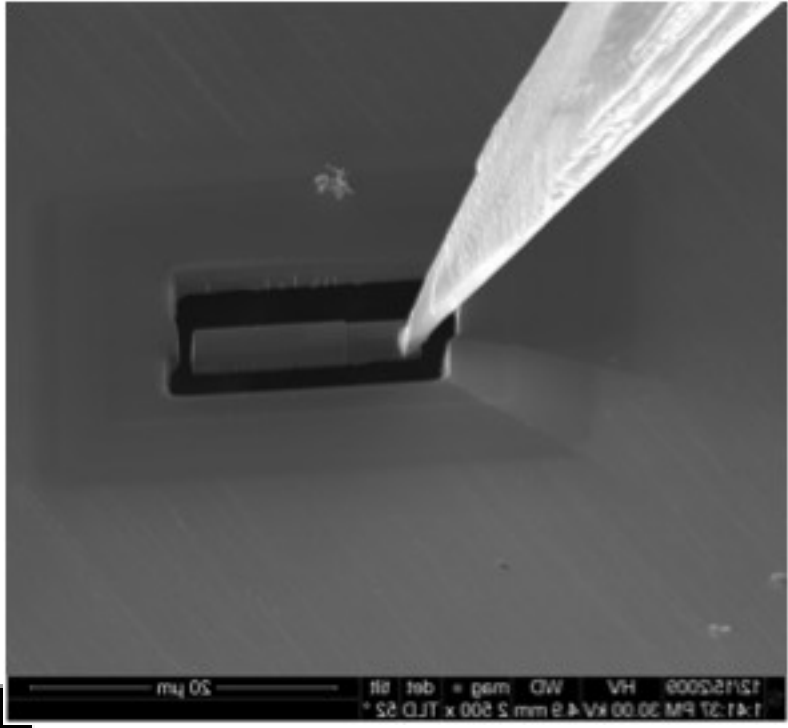
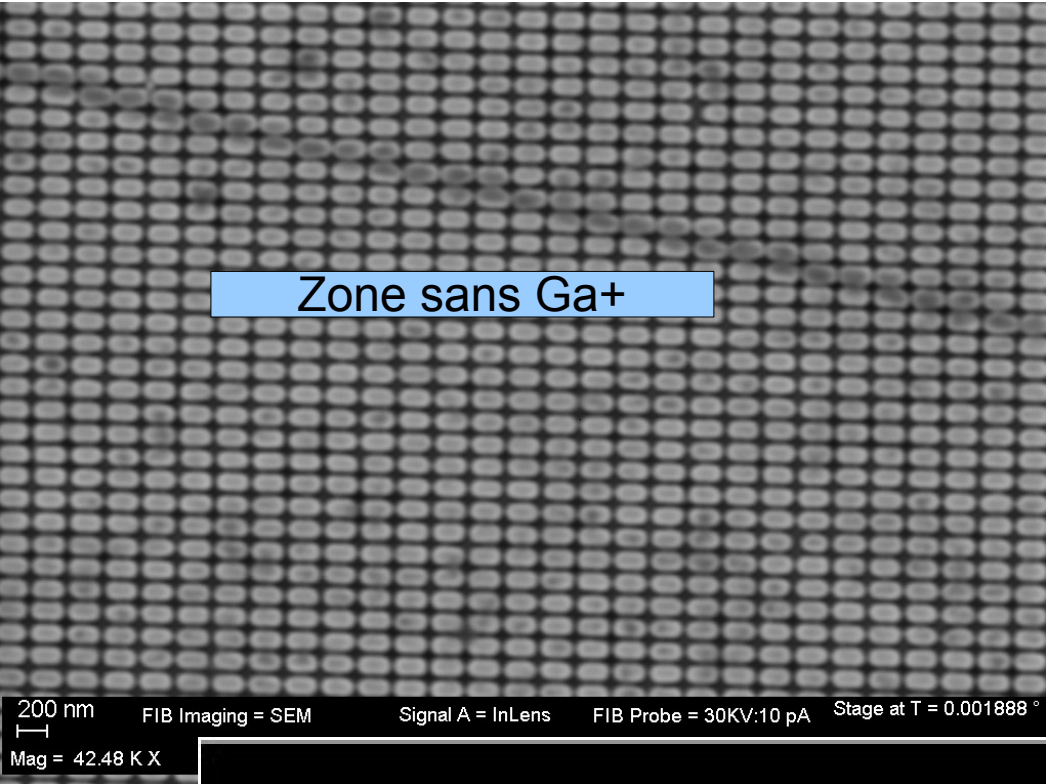


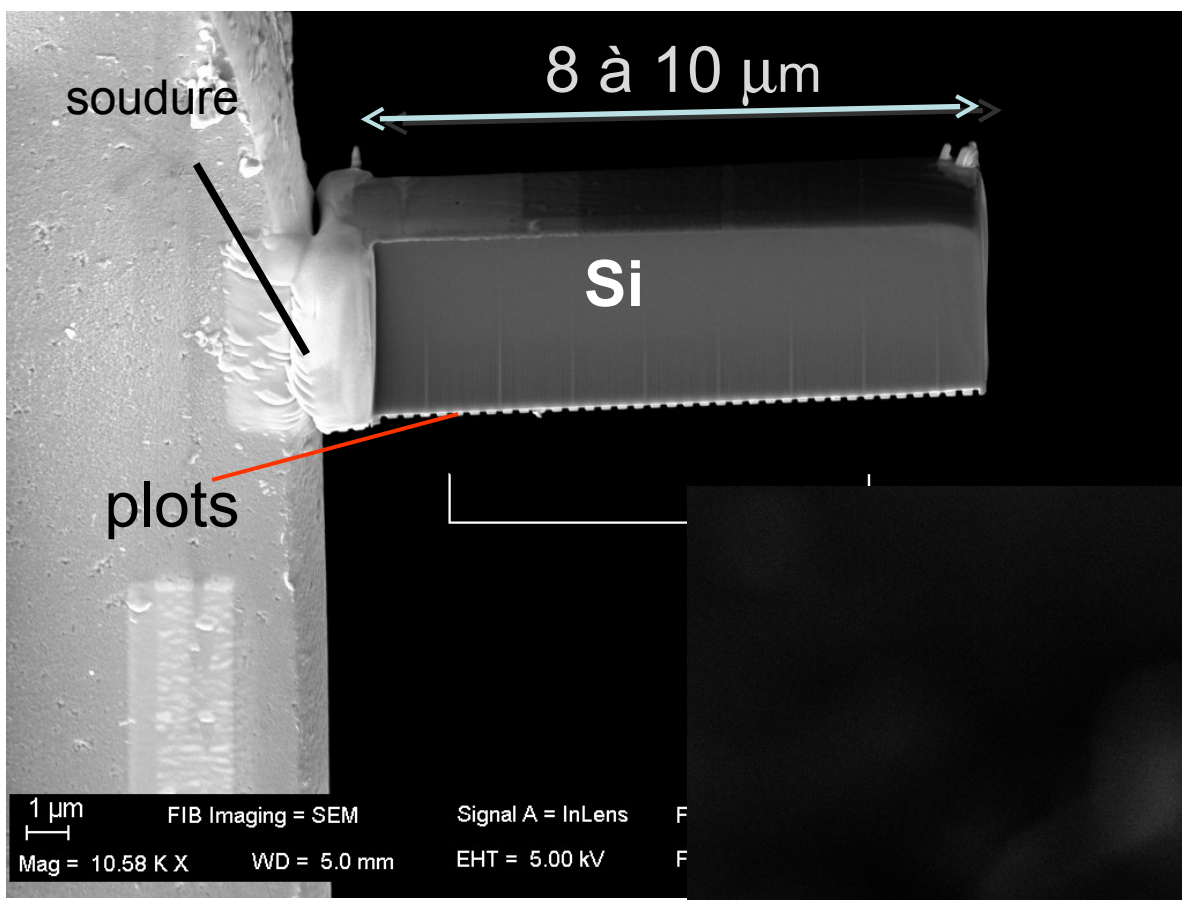
▪ **Idée:** les dimensions naturelles de l'objet sont adaptées pour certaines observations TEM et notamment l'holographie électronique

But : Préparer puis observer en TEM un objet unique 'as deposited' pour quantifier le champs rayonné dans le vide, dans le matériau...

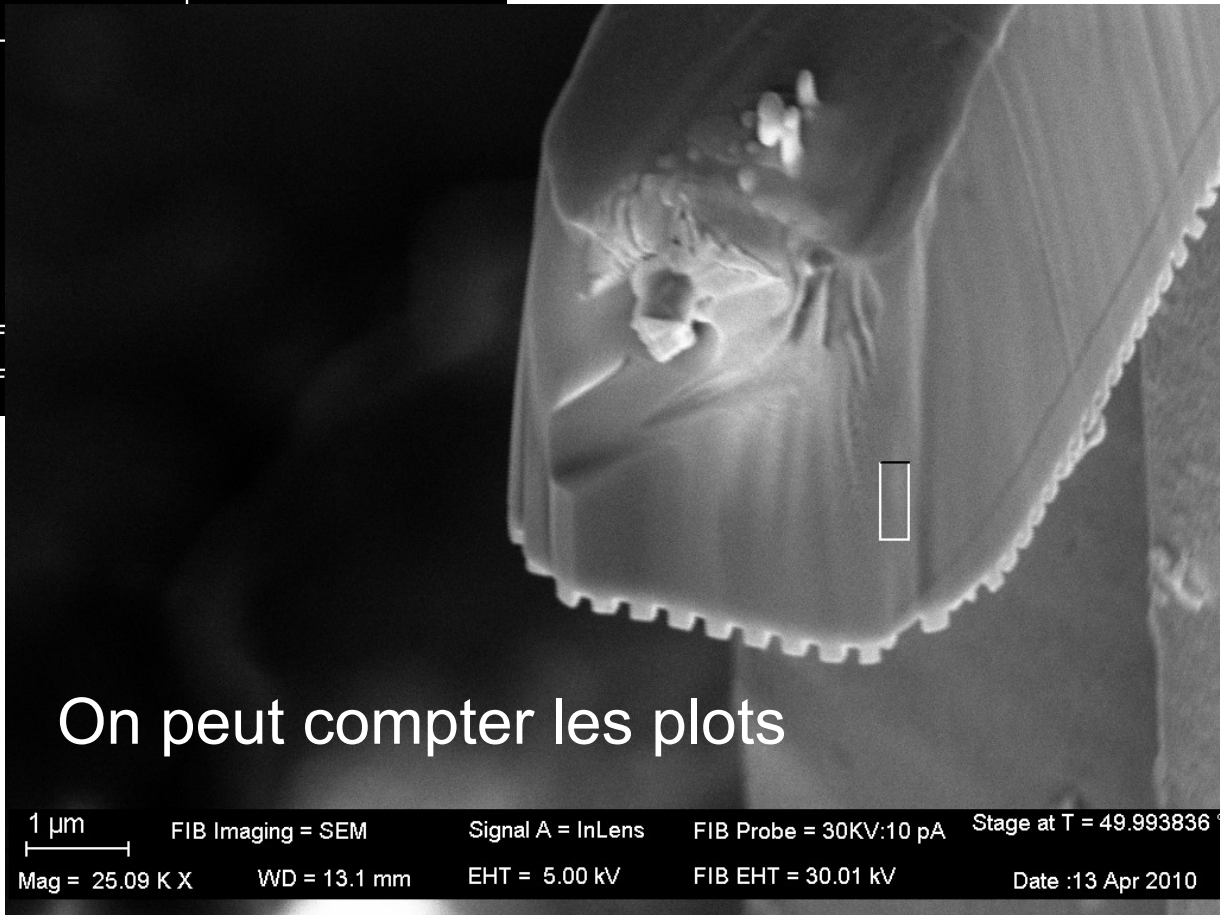
Problème : Multicouche très sensible à l'implantation de Ga⁺, impossible de faire une image FIB sans détruire les propriétés magnétiques

attaquer l'échantillon par la face arrière

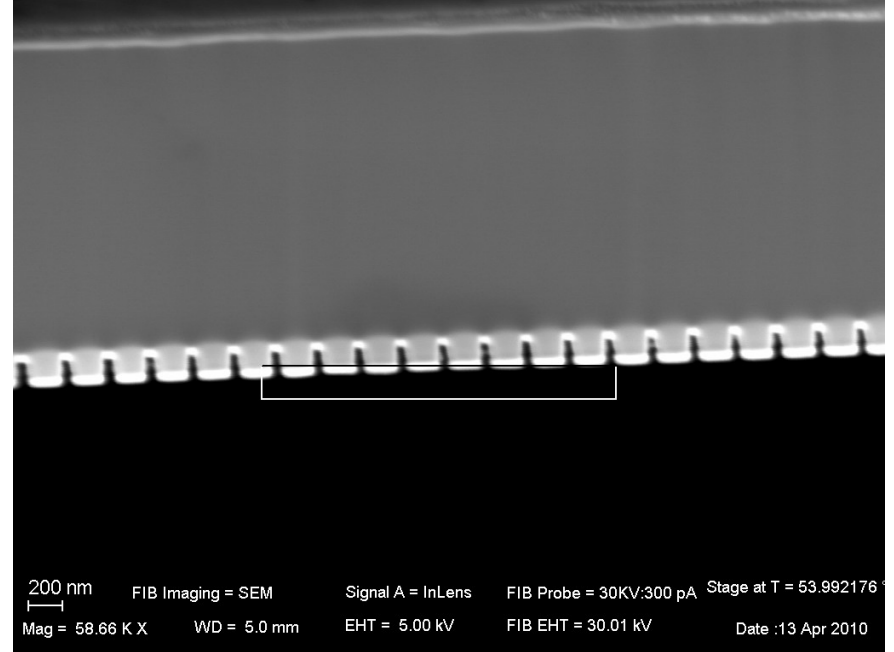
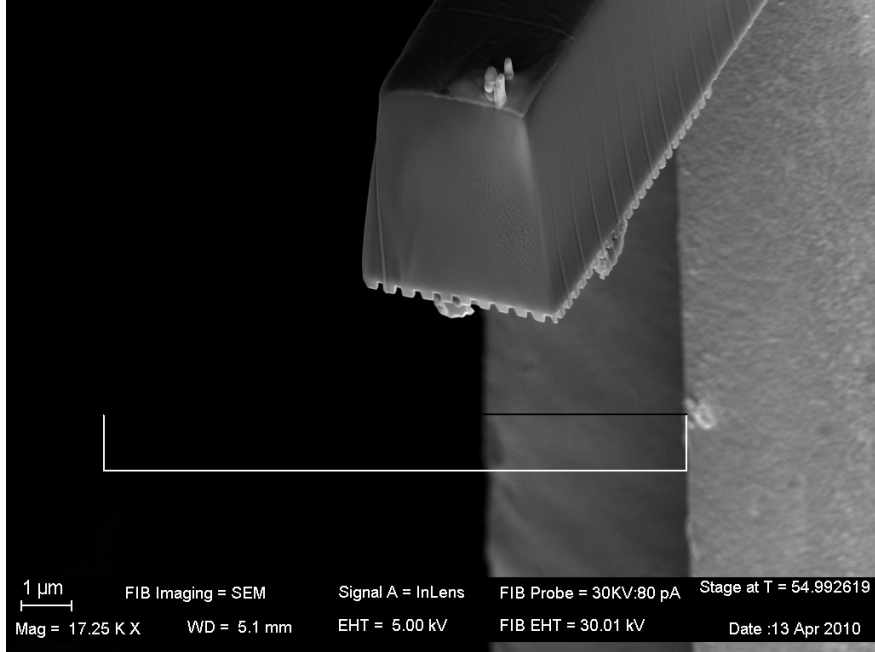




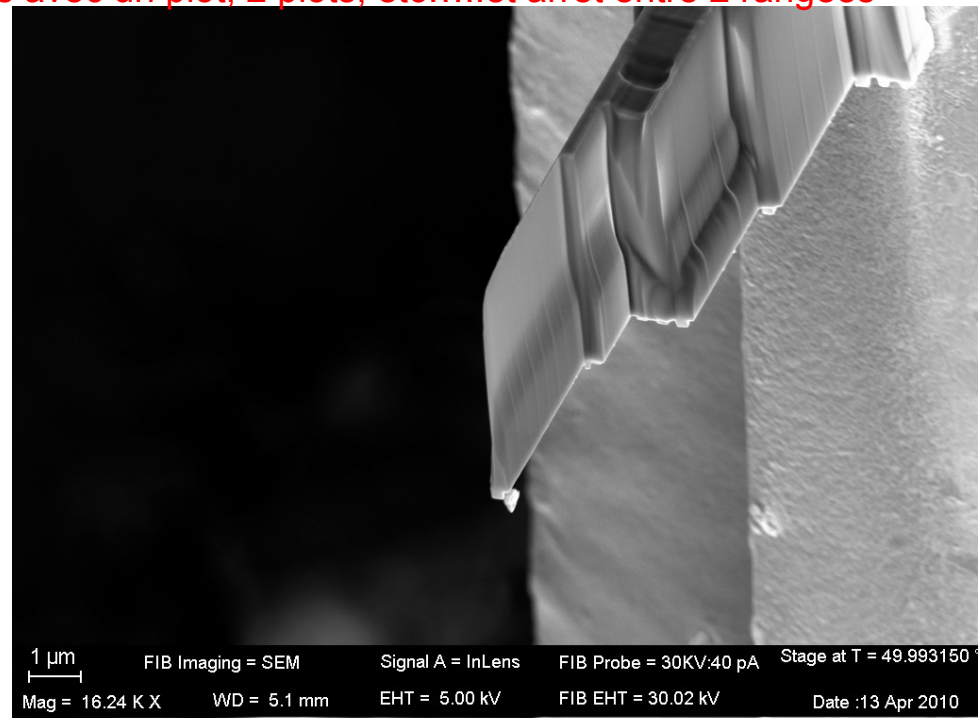
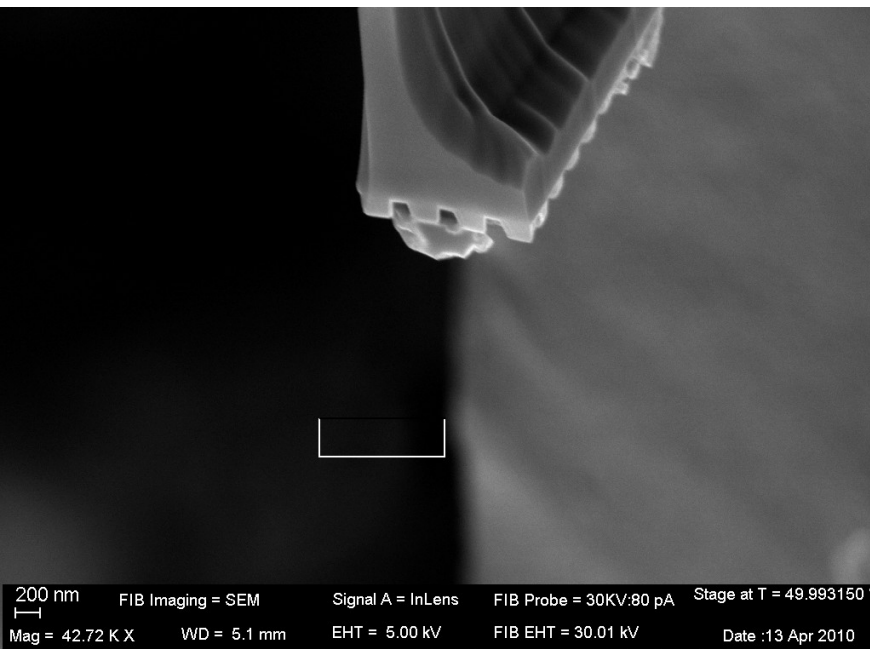
soudure par dépôt de Pt ou C sur la grille en Cu pour le TEM



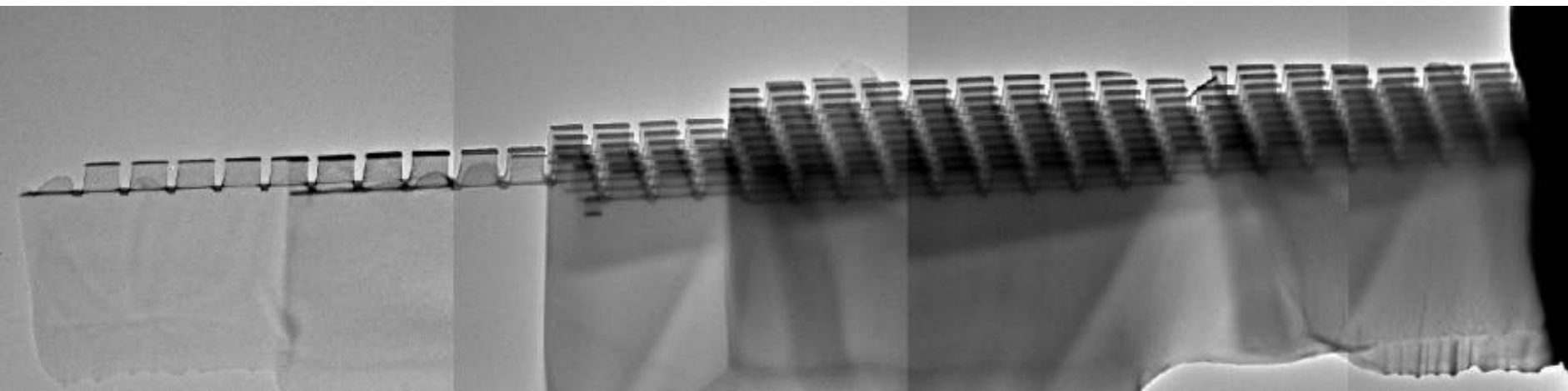
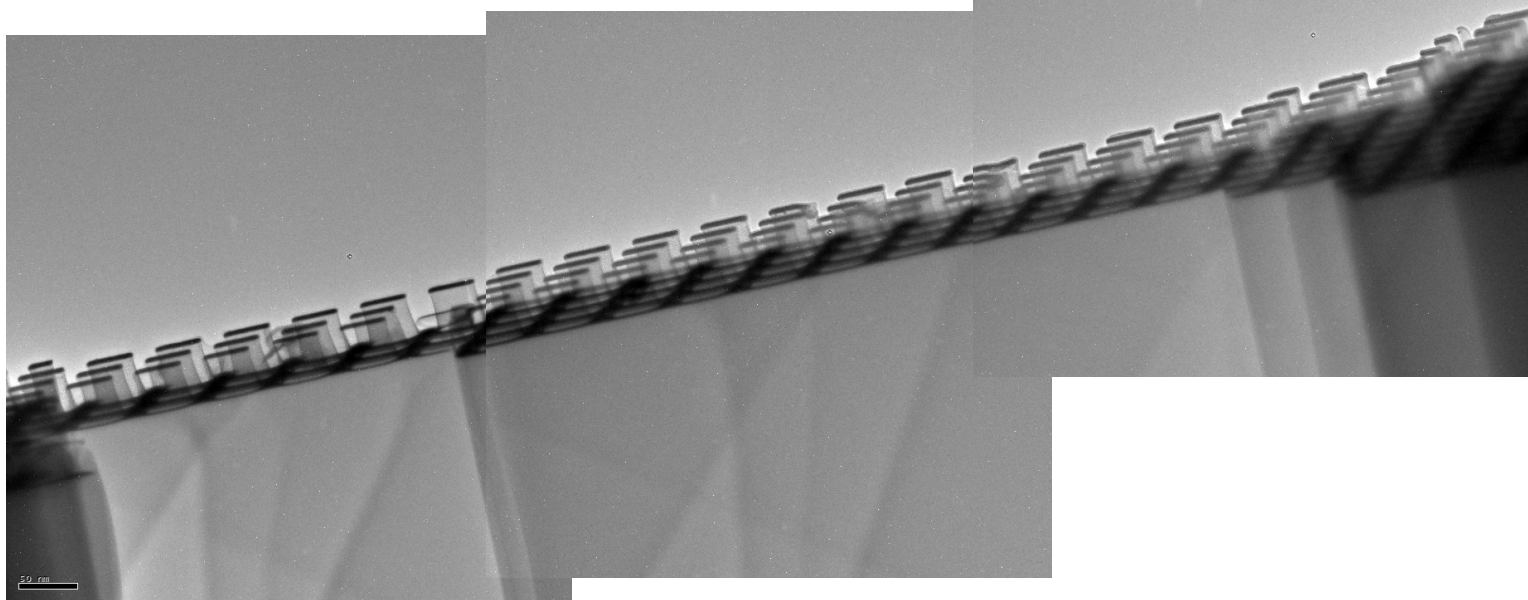
On peut compter les plots

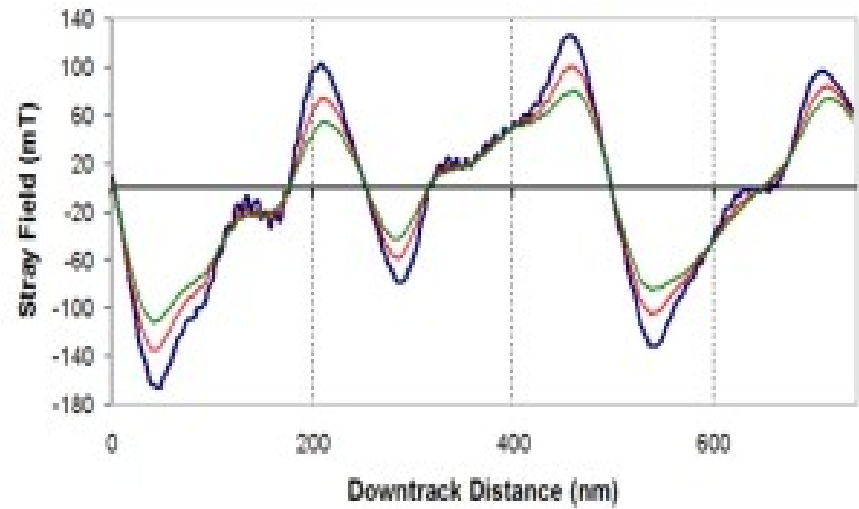
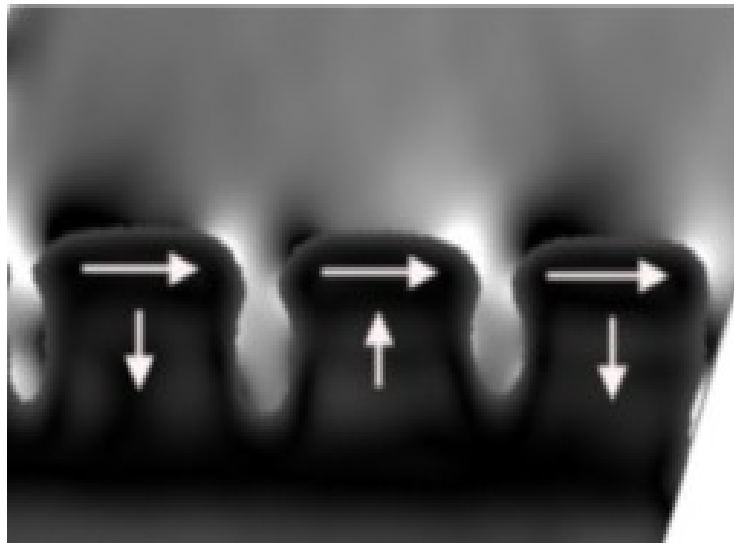
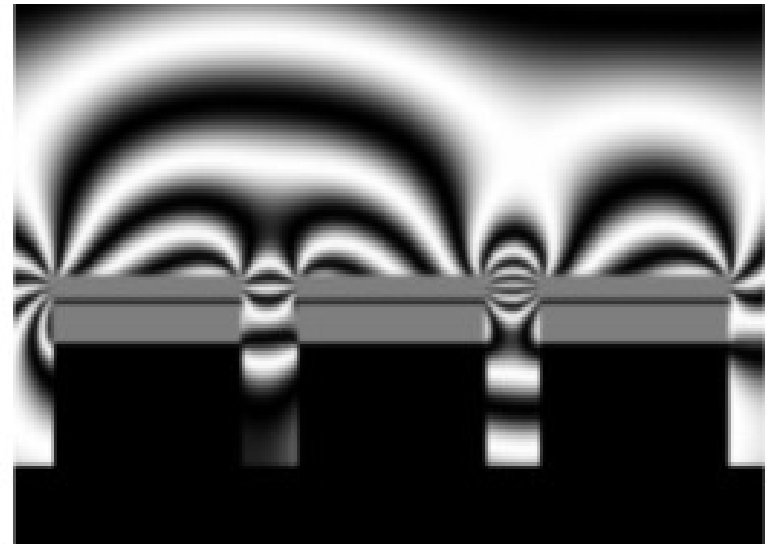
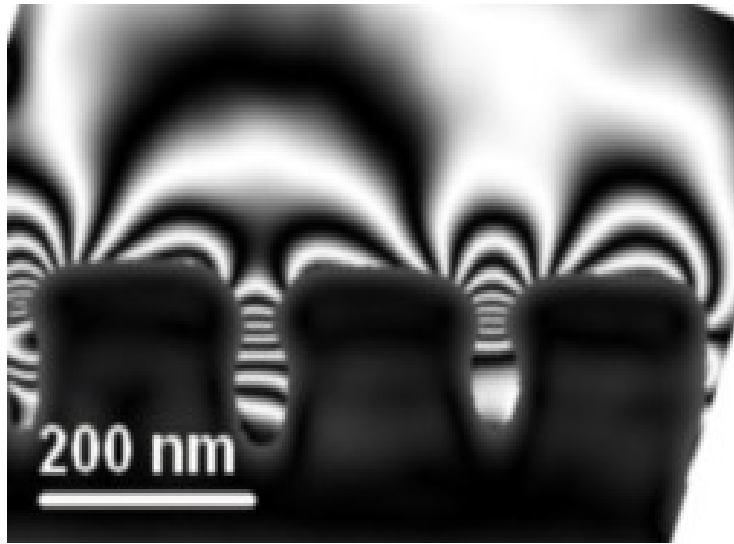


5: Contrôle parfait de l'amincissement par **SEM** → zones avec un plot, 2 plots, etc....et arrêt entre 2 rangées

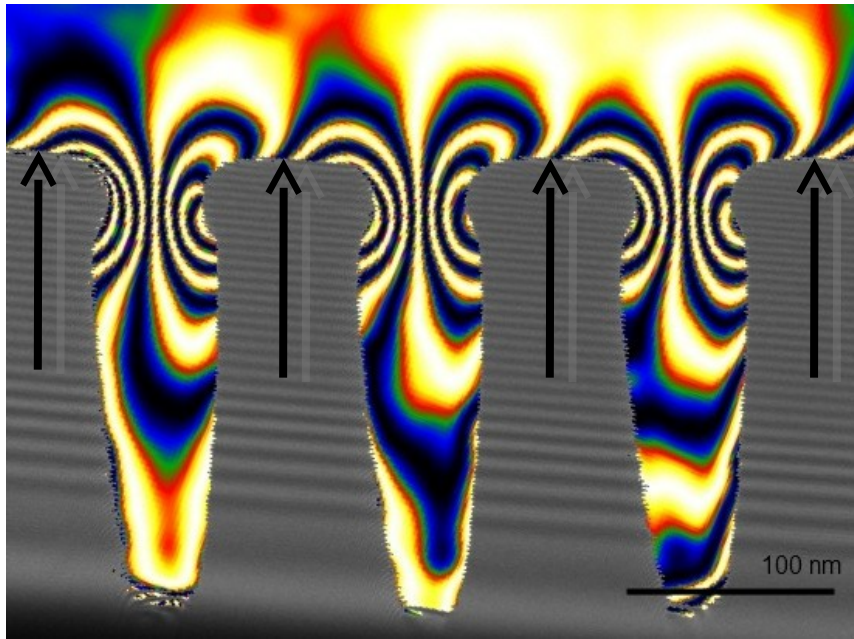


Vue '3D' au 400 kV



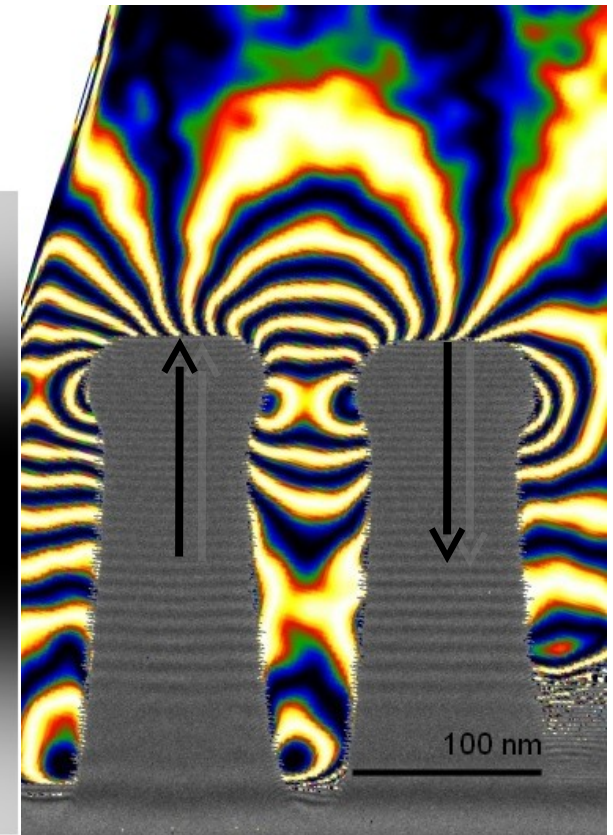


Saturé

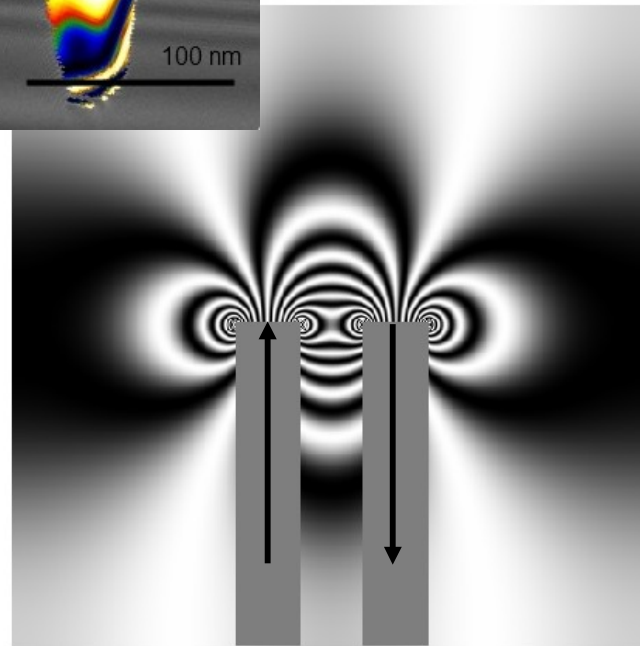


Couplage anti //

Désaimanté



Couplage //



Simulation

Expérience

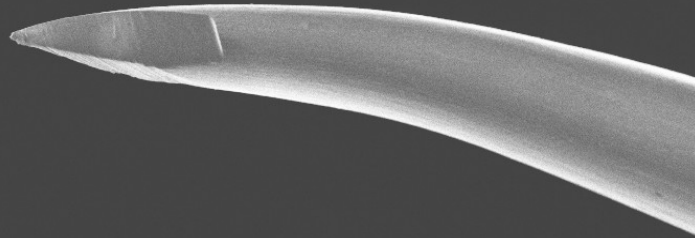
Pas d'influence du Ga+, pas détecté par EDX



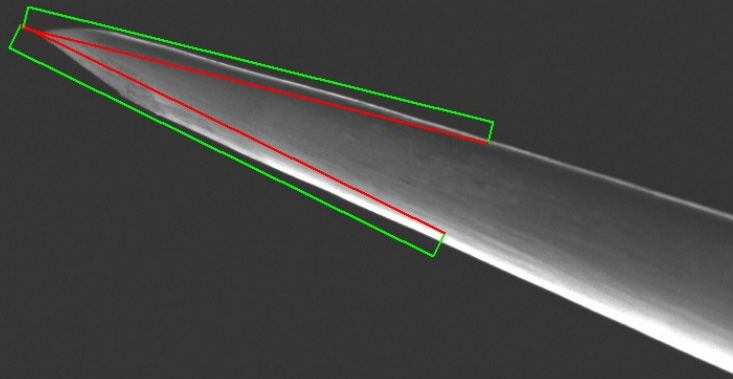
Micromanipulateur + Rot TIP



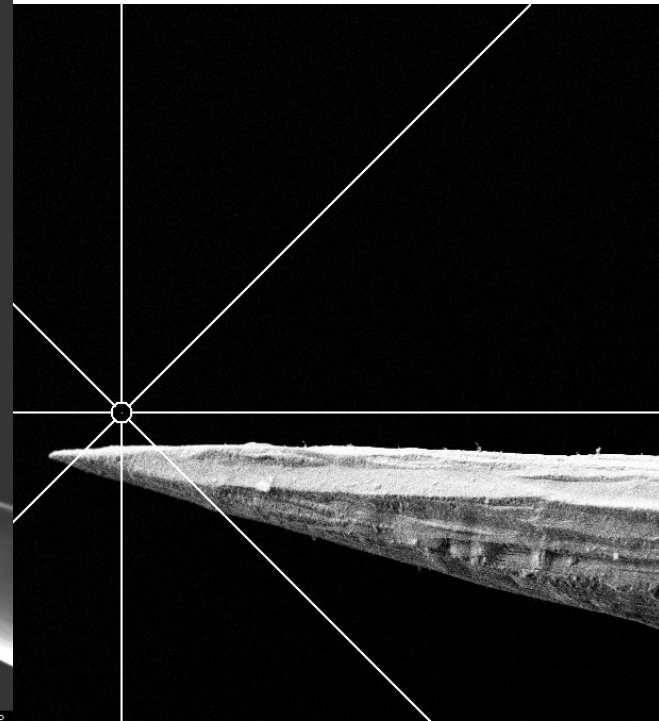
Affutage de la pointe W in-situ par FIB



20 μm FIB Imaging = FIB Signal A = InLens FIB Probe = 30KV:10 pA Stage at T = 0.000858 $^\circ$
Mag = 1.46 K X WD = 5.1 mm EHT = 2.00 kV FIB EHT = 30.01 kV Date :9 Feb 2011



10 μm FIB Imaging = FIB Signal A = InLens FIB Probe = 30KV:6.5 nA Stage at T = 0.000514 $^\circ$
Mag = 1.03 K X WD = 4.9 mm EHT = 2.00 kV FIB EHT = 30.01 kV Date :9 Feb 2011

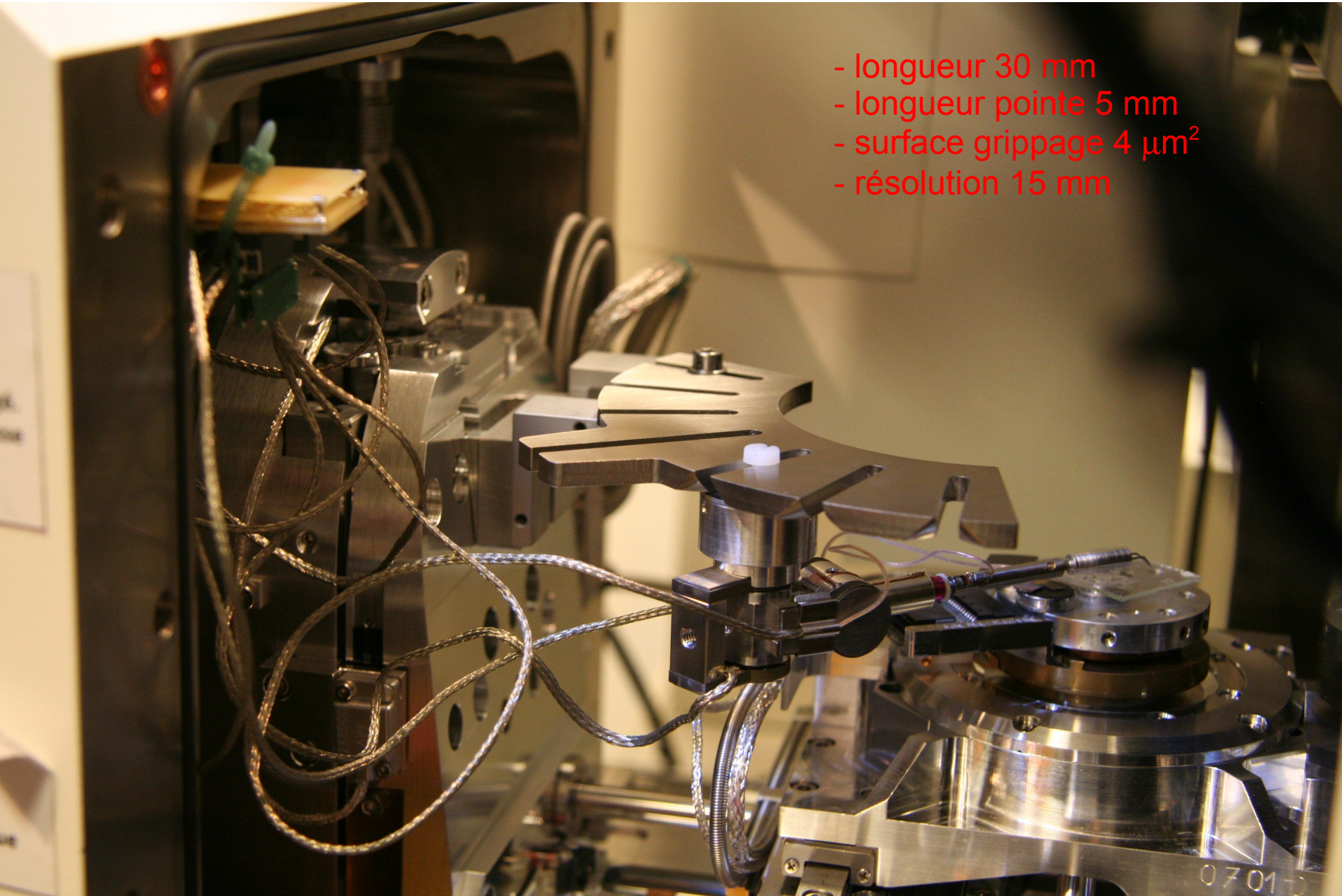


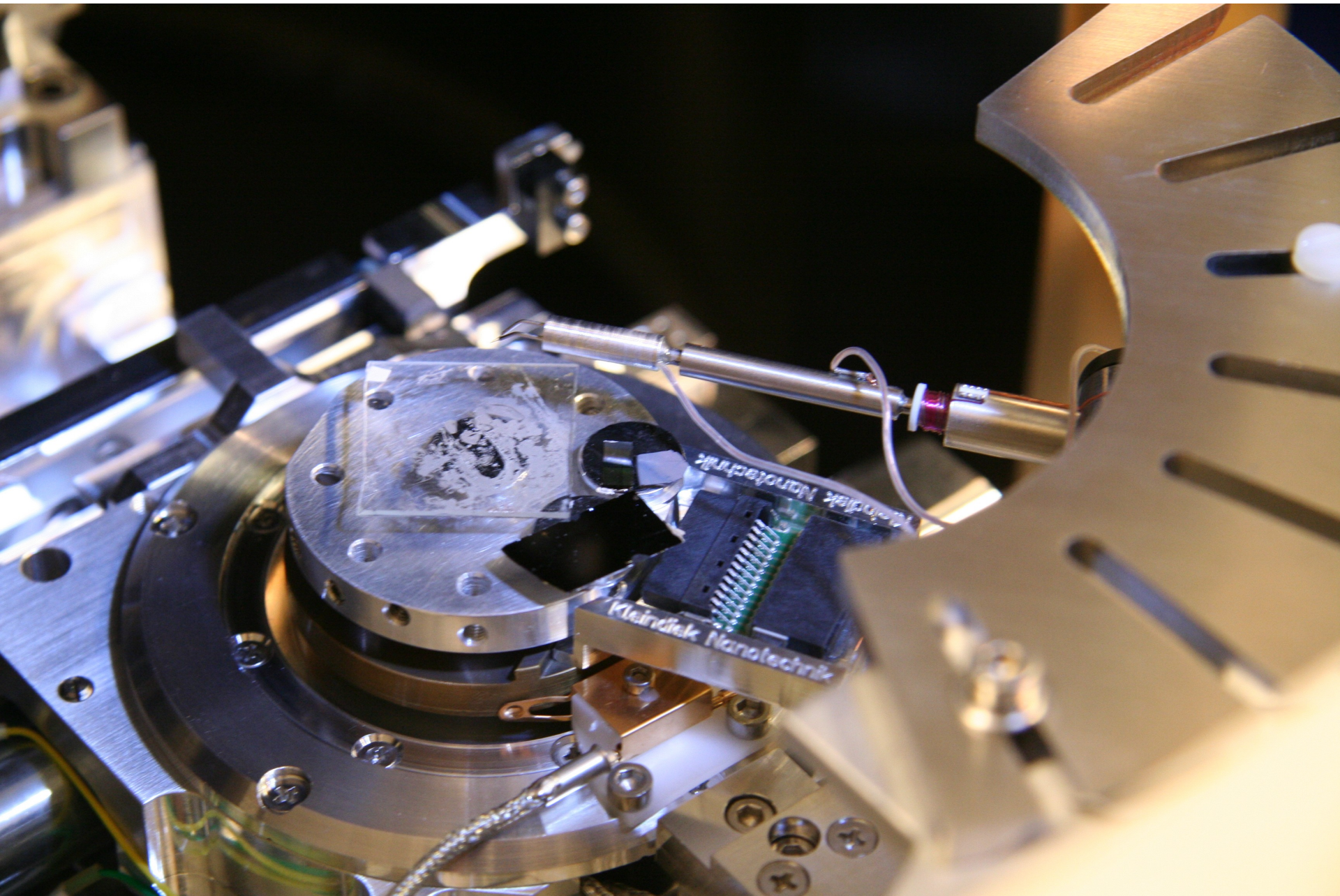
Signal A = SEI Date :7 Oct 2009
Photo No. = 280 Time :15:12:51



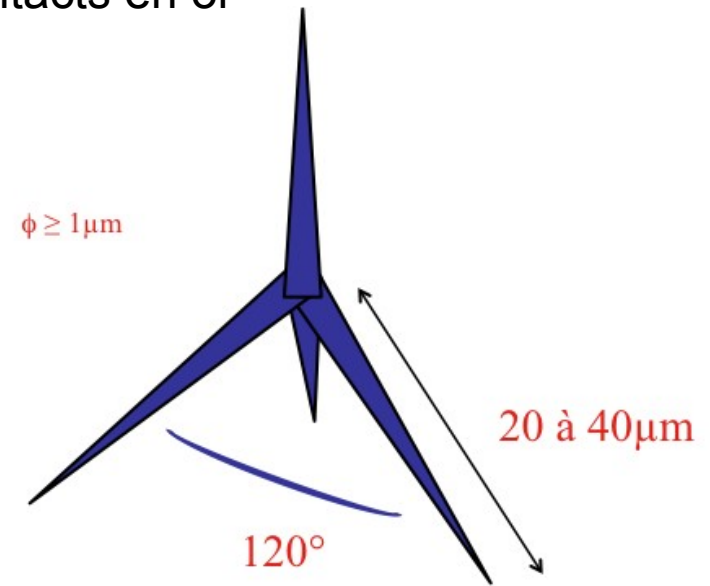
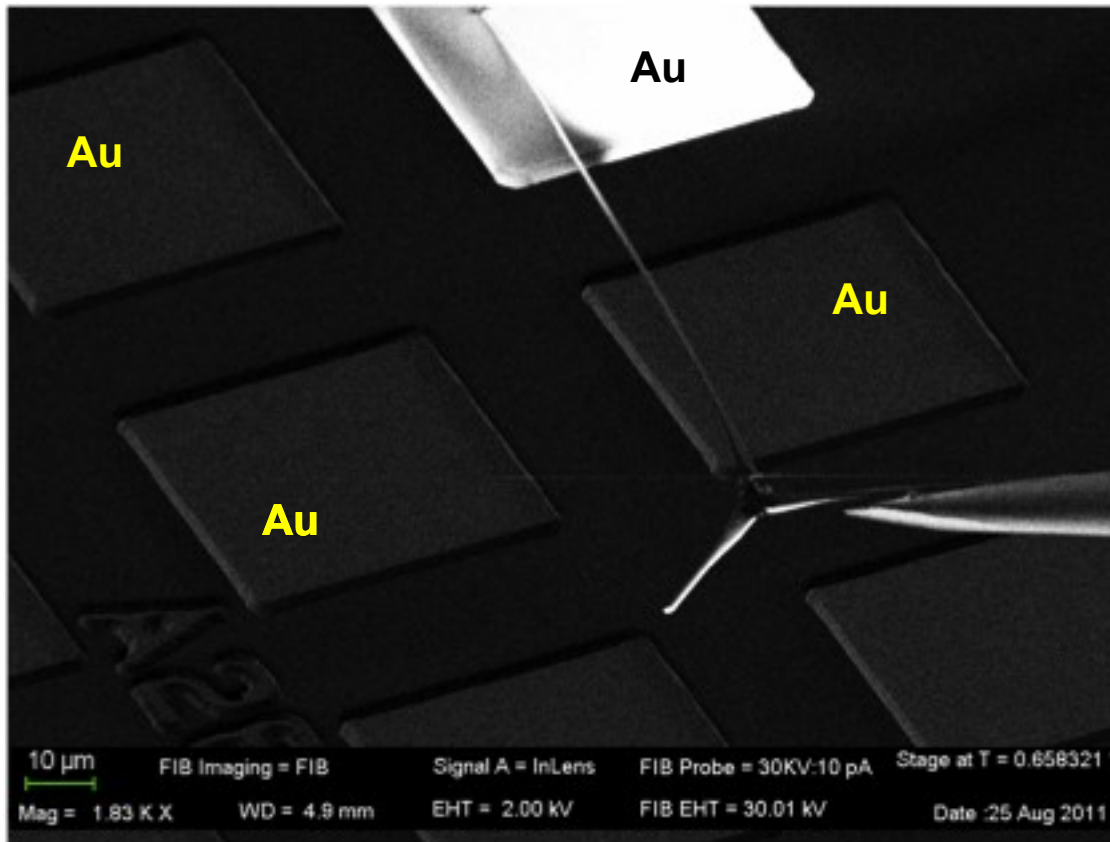
La micro-pince associé au le rot-tip

- longueur 30 mm
- longueur pointe 5 mm
- surface grippage $4 \mu\text{m}^2$
- résolution 15 mm



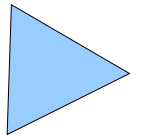


But : prendre un tétrapode et le déplacer vers les contacts en or

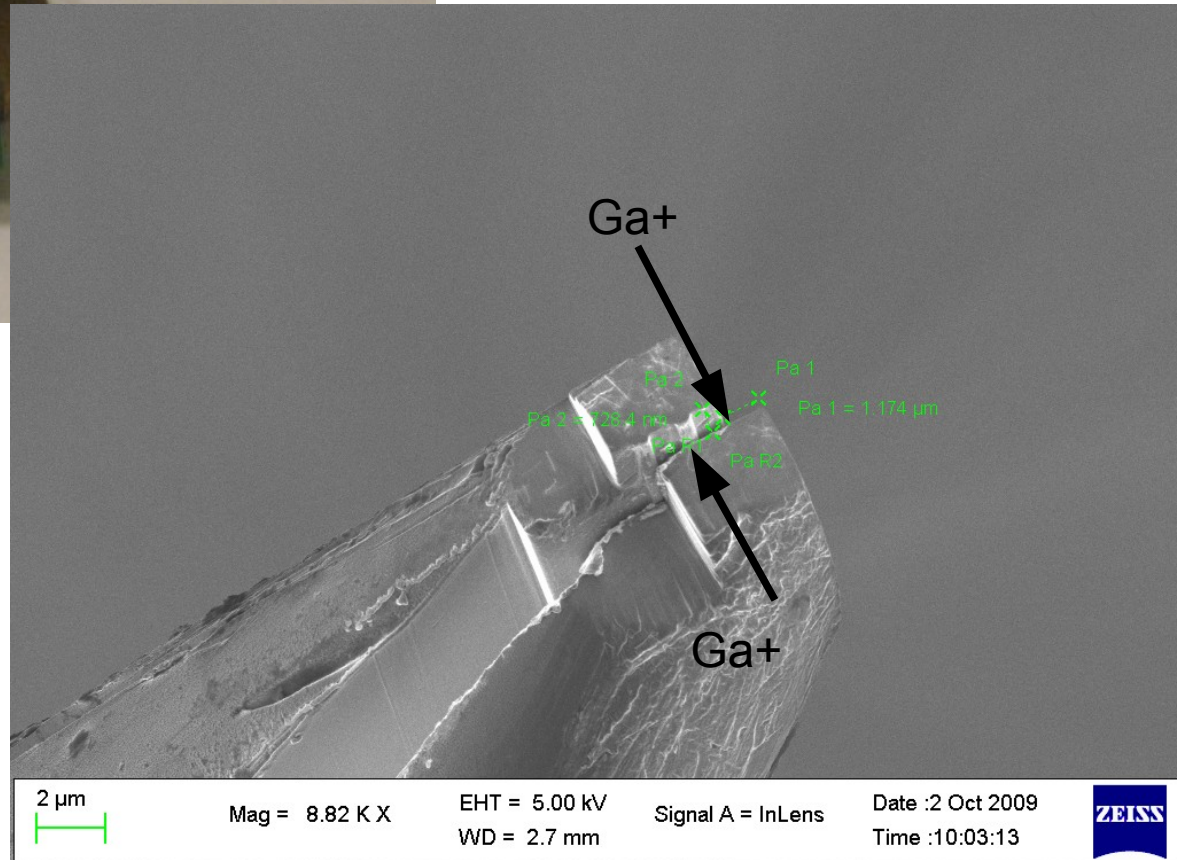
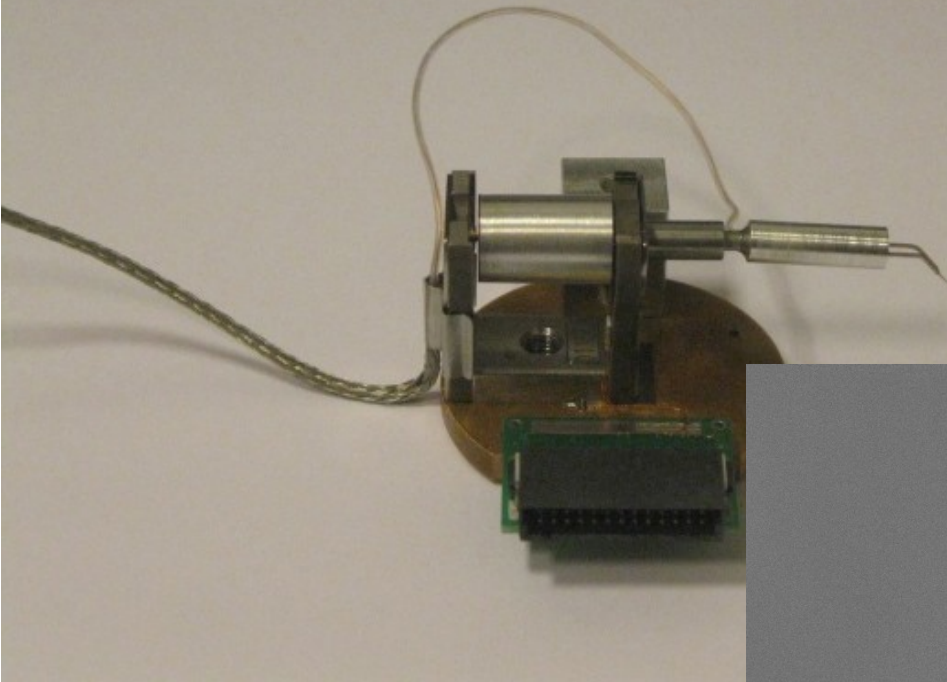


Avec la technique classique 1 pointe et soudure FIB

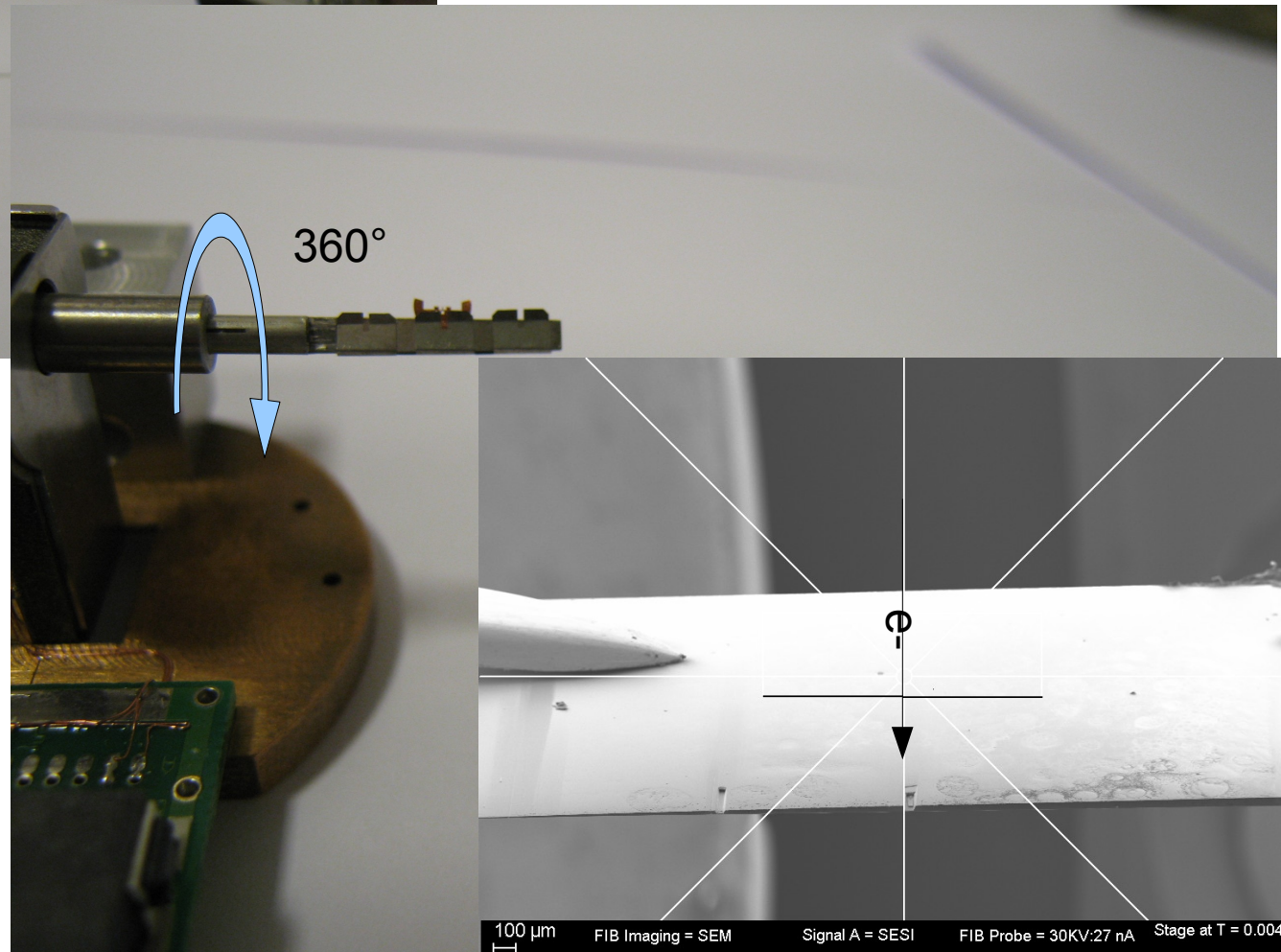
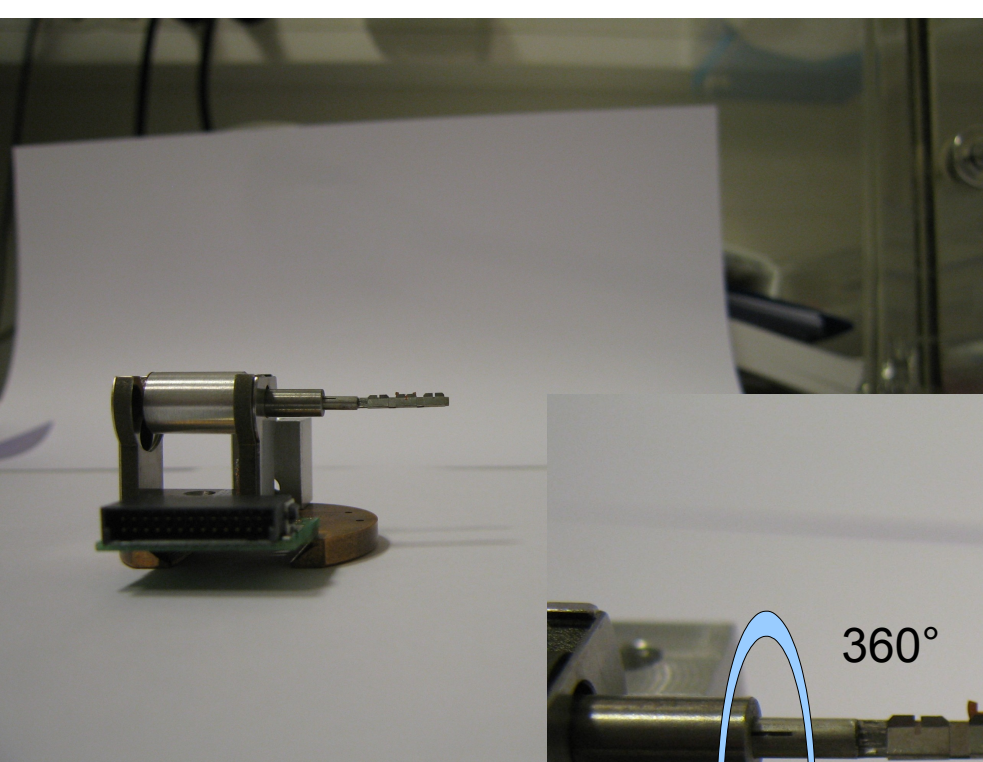
- problème d'implantation en Ga^+
- Problème d'ombrage
- Problème de tilt
- Problème de charge électrique sur un substrat isolant



Le RT-STEM Usinage de la pince



Le RT-STEM pour du STEM in-situ



100 μ m FIB Imaging = SEM Signal A = SEI FIB Probe = 30KV:27 nA Stage at T = 0.004978 °
Mag = 81 X WD = 4.6 mm EHT = 5.00 kV FIB EHT = 30.01 kV Date :10 Dec 2009

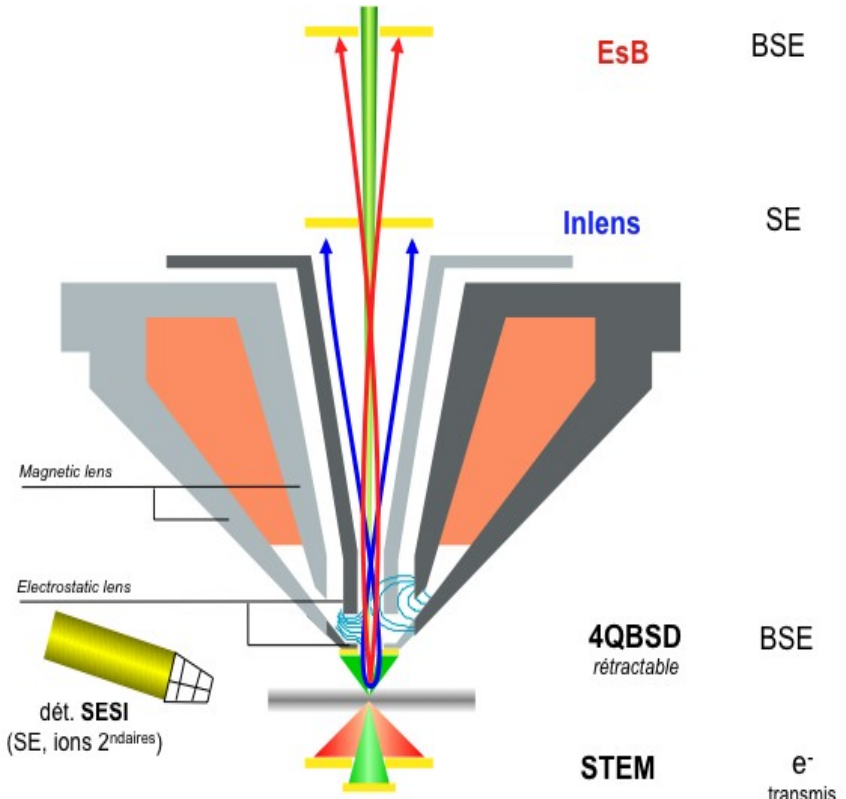
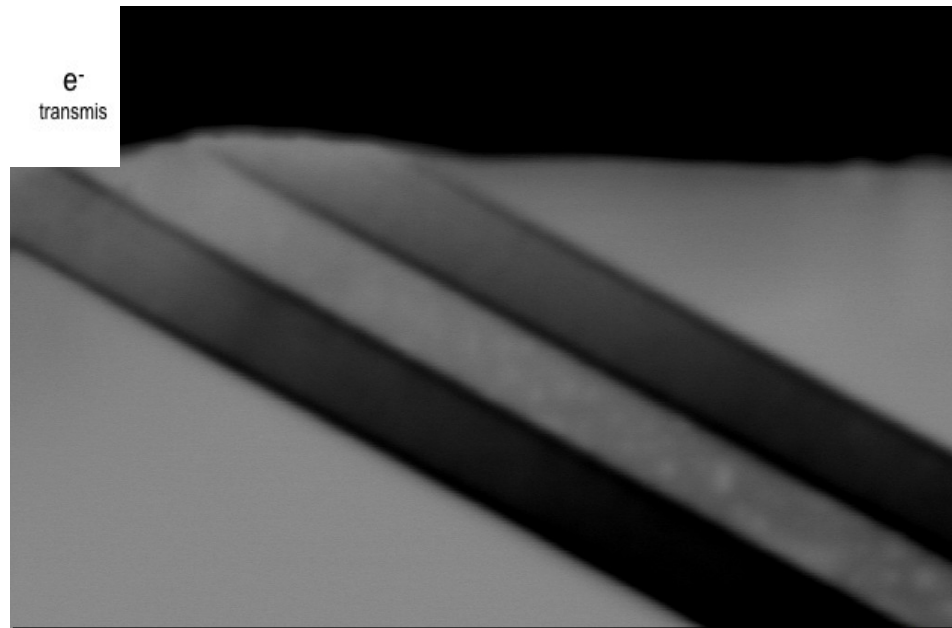


Fig. P. Gnauck  CARL ZEISS SMT

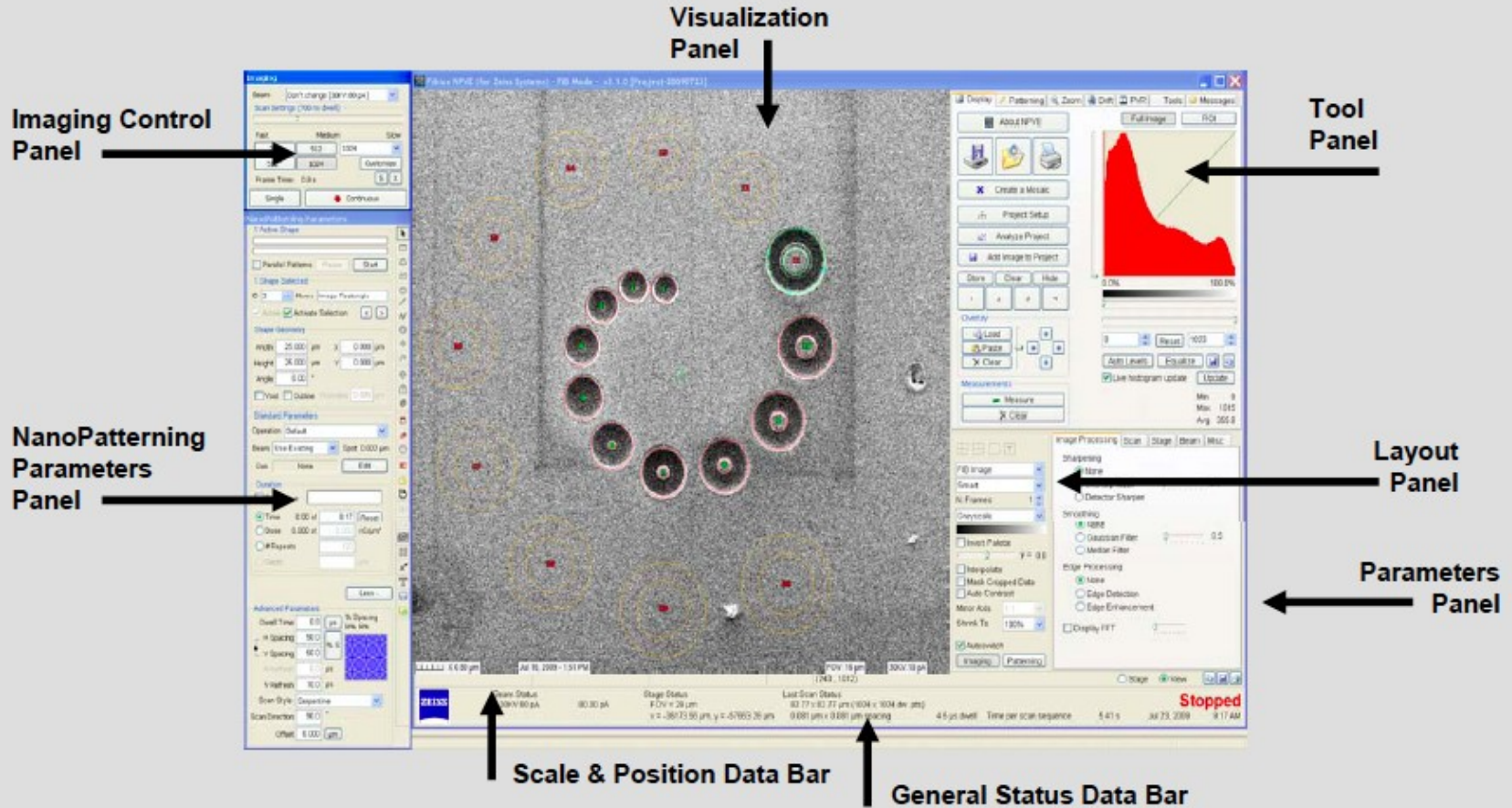


Conclusion

- Le FIB Dual Beam est un 'microlaboratoire' avec soudure/découpe/usinage
déplacement d'objet micro --> nano
- C'est facile
- Quelques précautions avec les dégâts d'implantation avec les ions Ga
- Beaucoup d'instruments dans la chambre → attention

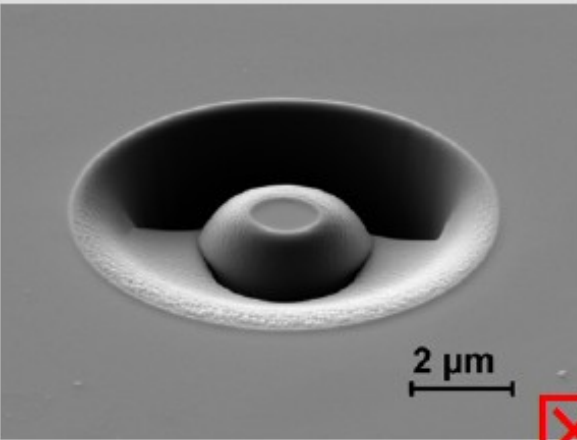
Perspectives

- Pilotage par API avec Dwell Time minimum de l'ordre de la ms → dépôt impossible et trop lent pour certaines gravures

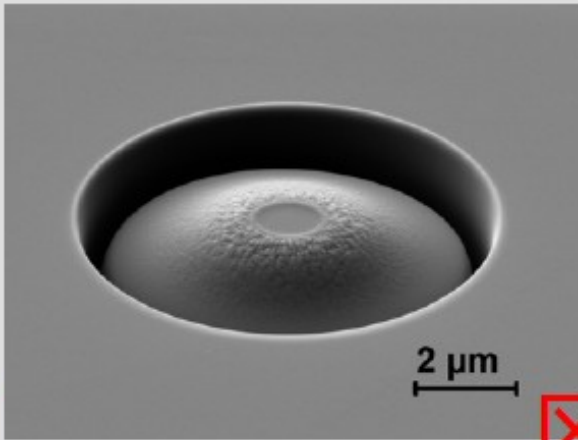


Module de Pilotage total des faisceaux ions et e-
Dwell time de 25 ns, image de $2^{32} \times 2^{32}$

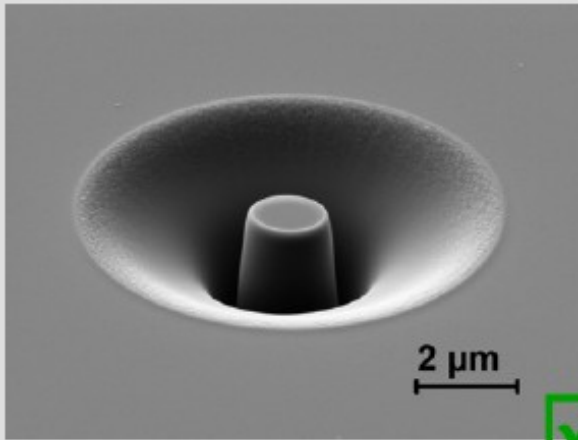
pillar structure created using the same dose and beam current settings but different milling strategies



line wise milling from bottom to top



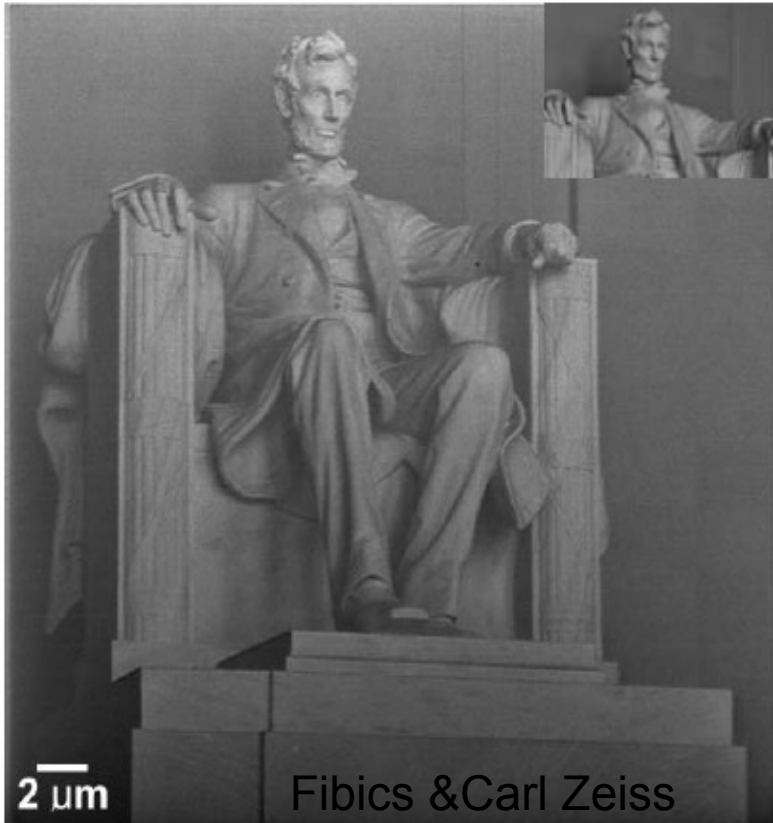
circular milling from in to out



circular milling from out to in

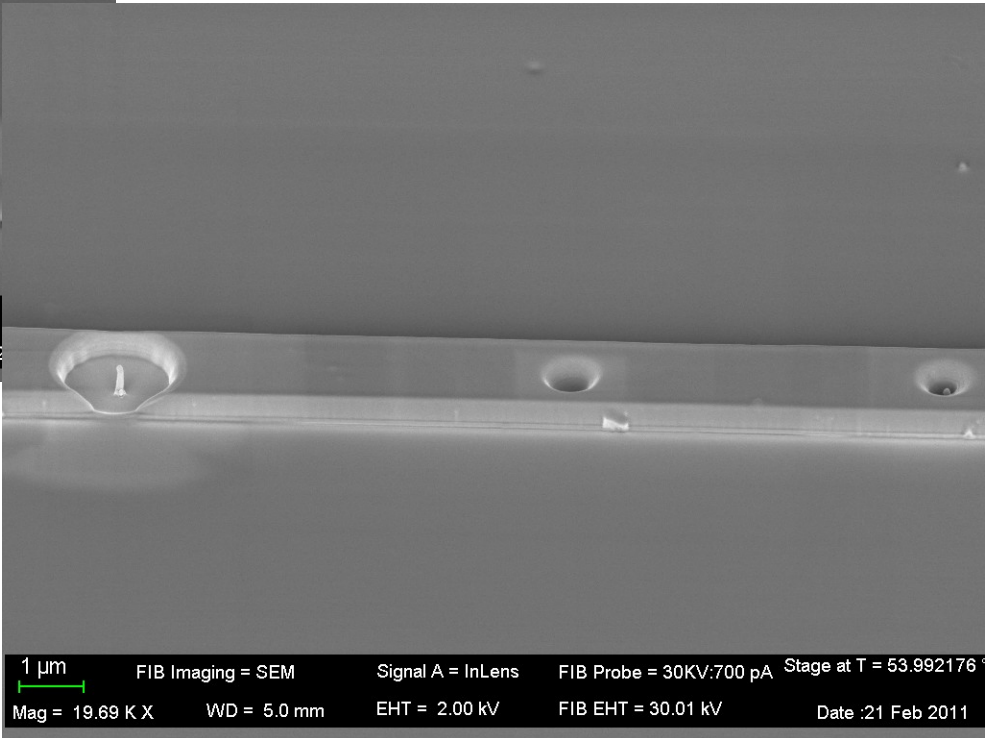
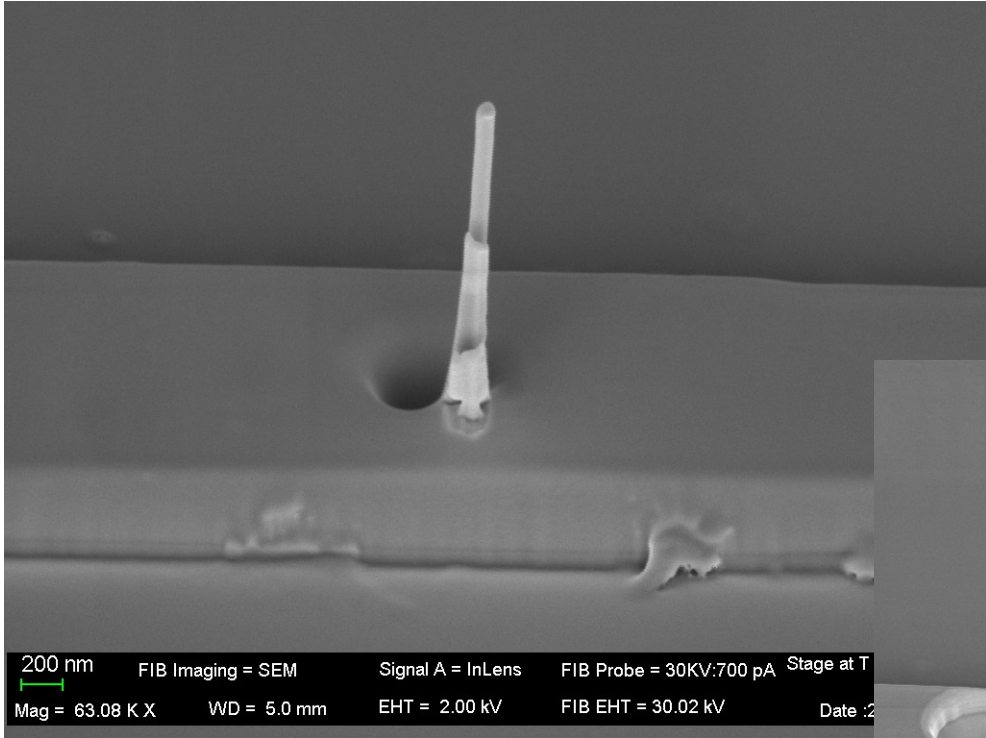
Définition de stratégies de gravure pour limiter le re-dépôt

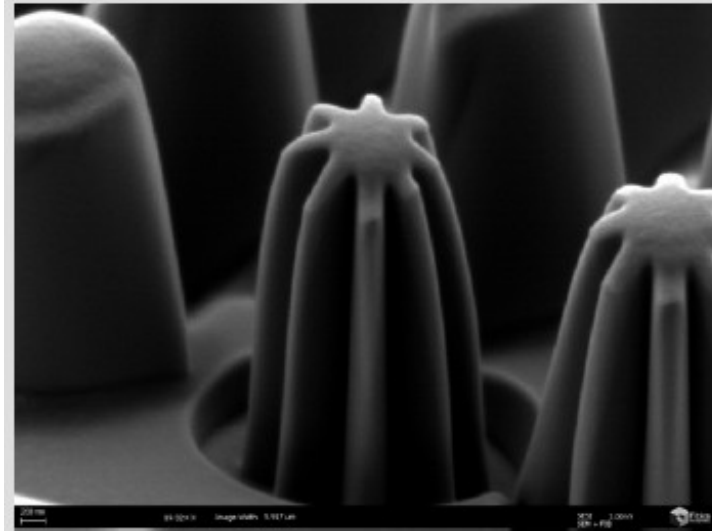
- 3D nanopatterning based on greyscale bitmap image. Example shows a "NanoLincoln" (large image) and the original photography of the Lincoln Memorial (inset)



Nano usinage comme une fraise 3D

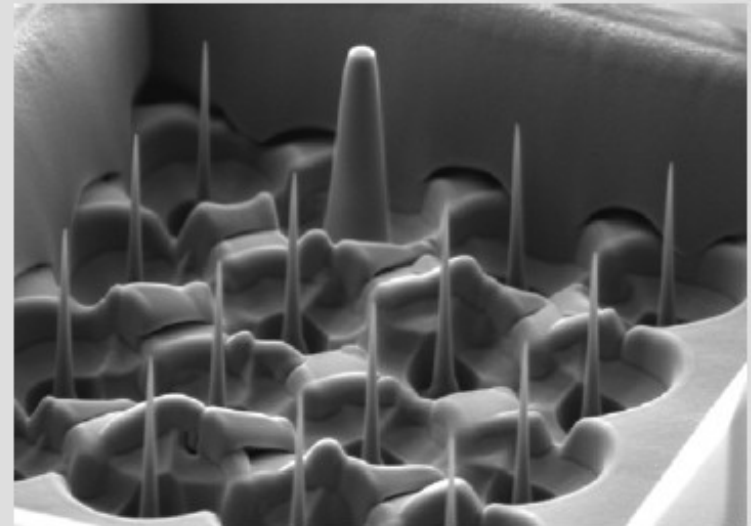
Usiner des guides de lumière, créer des cavités,
faire de la croissance de nanofils à proximité du guide
Injecter de la lumière in situ dans le FIB et observer le comportement du fil





»Flower«

Fine tips
generated by
parallel
processing



»NanObama«
patterned based
on greyscale
bitmap



Nanotube de ZnO

Echantillon E. Gautier

Découpe et extraction avec une pointe



FIB Imaging = SEM
NVision 40-27-49

As 

WD = 5.0 mm
EHT = 5.00 kV
Mag = 2.19 K X

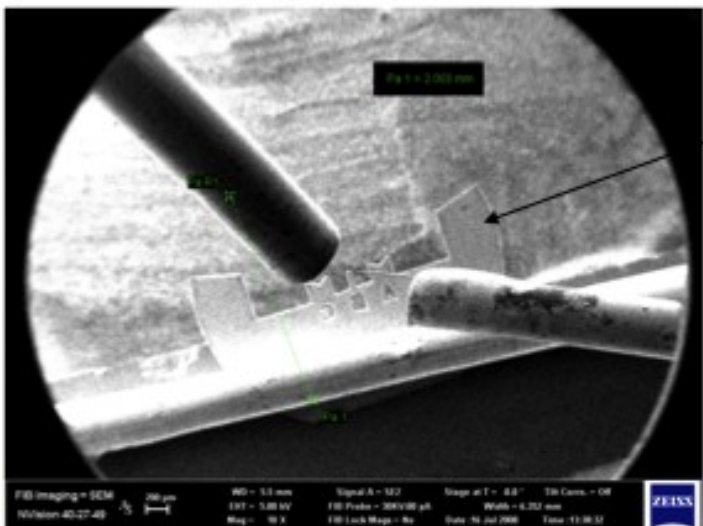
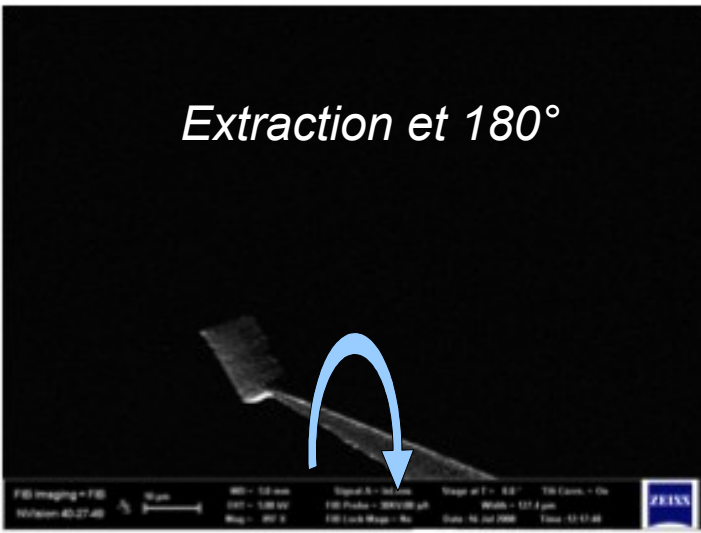
Signal A = InLens
FIB Probe = 30KV:80 pA
FIB Lock Mags = No

Stage at T = 55.5 ° Tilt Corr. = On
Width = 52.23 μm
Date :16 Jul 2008 Time :10:24:11



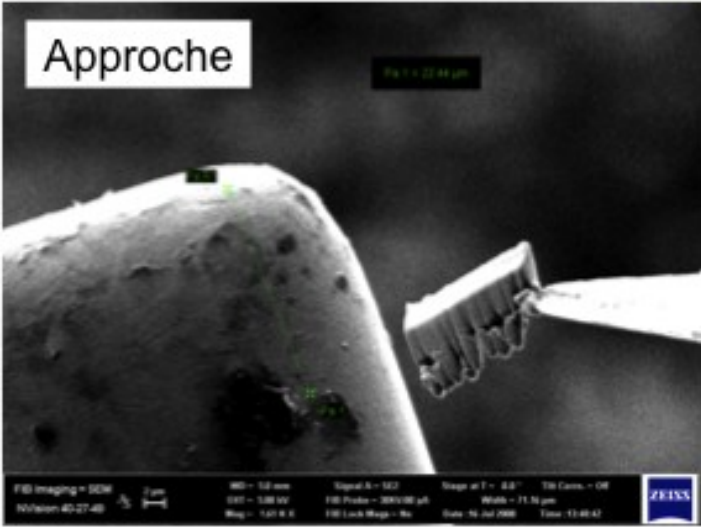
→ Nécessité d'amincir en partant du substrat pour éviter les effets d'ombrage

Extraction et 180°

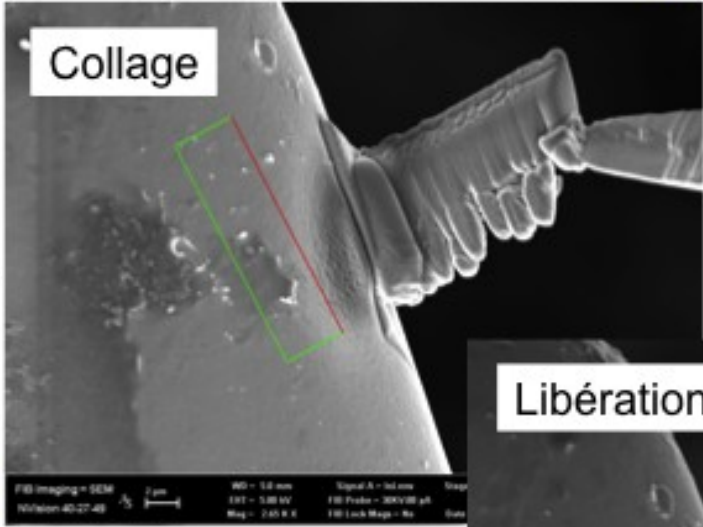


Porte-objet MET

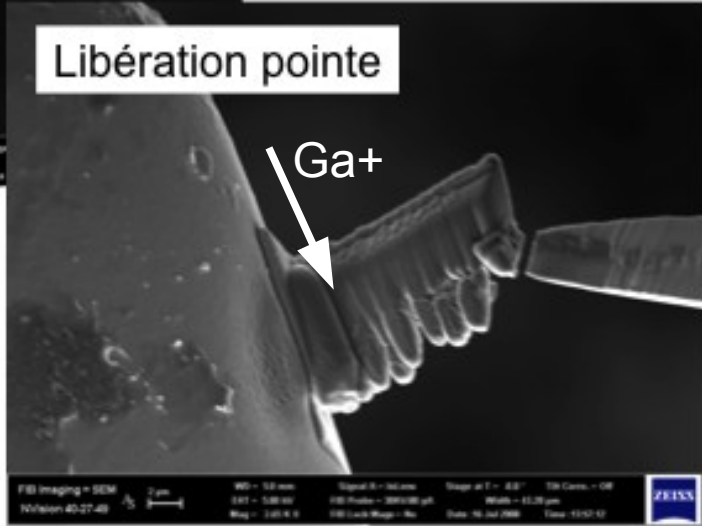
Approche



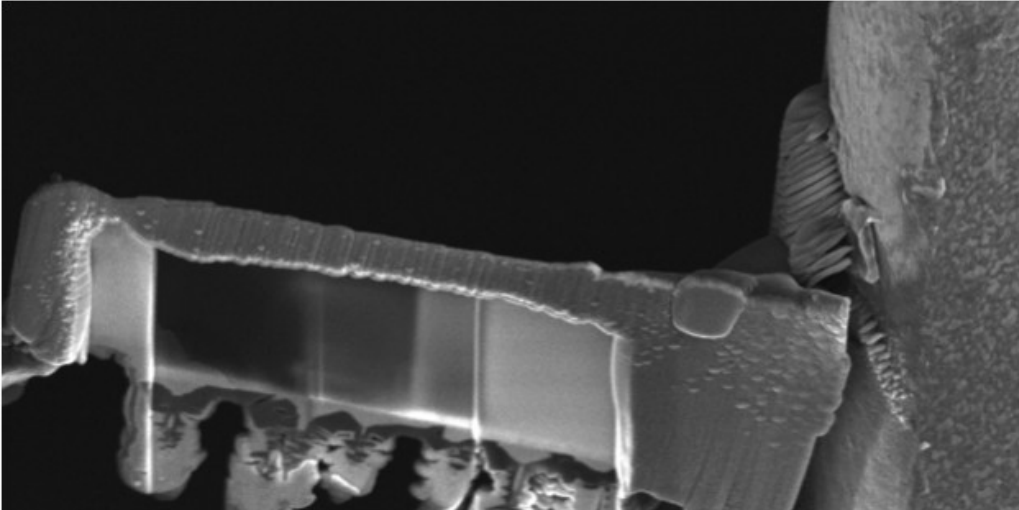
Collage



Libération pointe



Fixation sur porte-objet MET avant amincissement



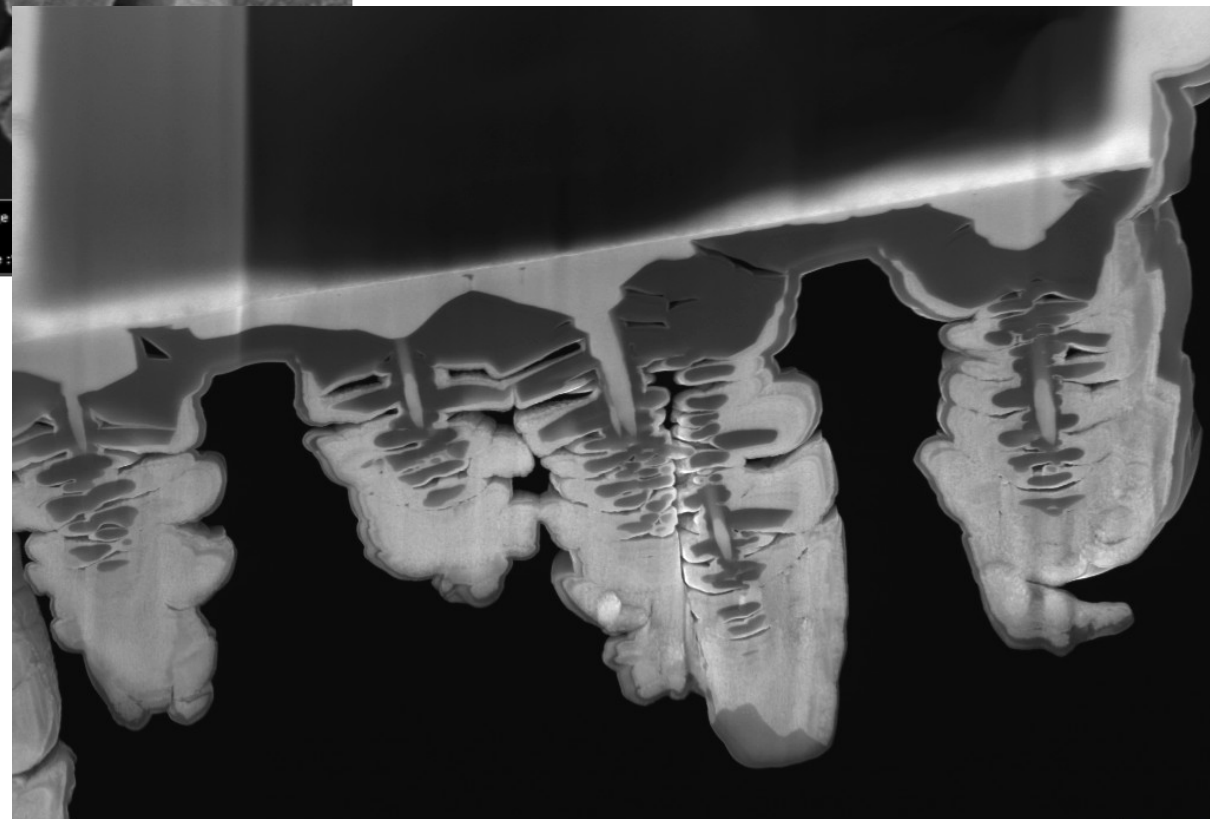
FIB Imaging = SEM
Nvision 40-27-49

1 μ m

WD = 5.0 mm
EHT = 5.00 kV
Mag = 5.48 K X

Signal A = InLens
FIB Probe = 2kV:25pA
FIB Lock Mags = No

Stage
Date :



FIB Imaging = SEM
Nvision 40-27-49

200 nm

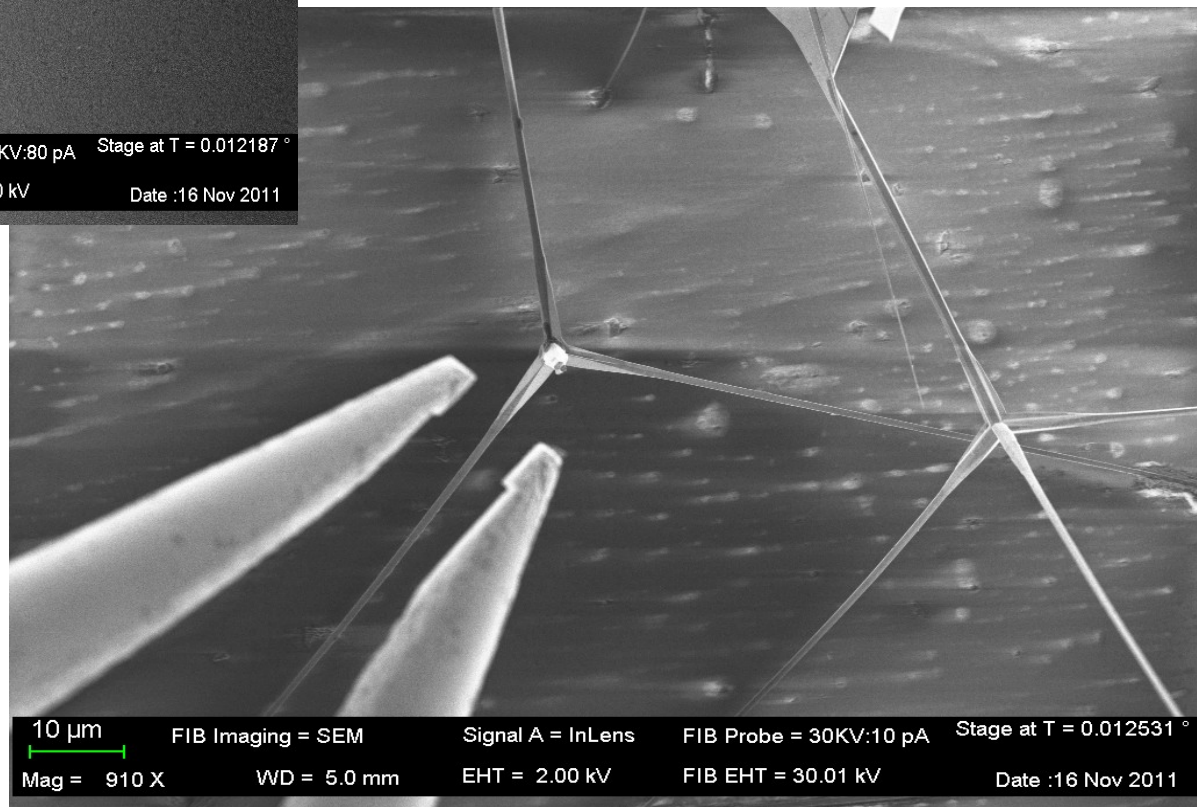
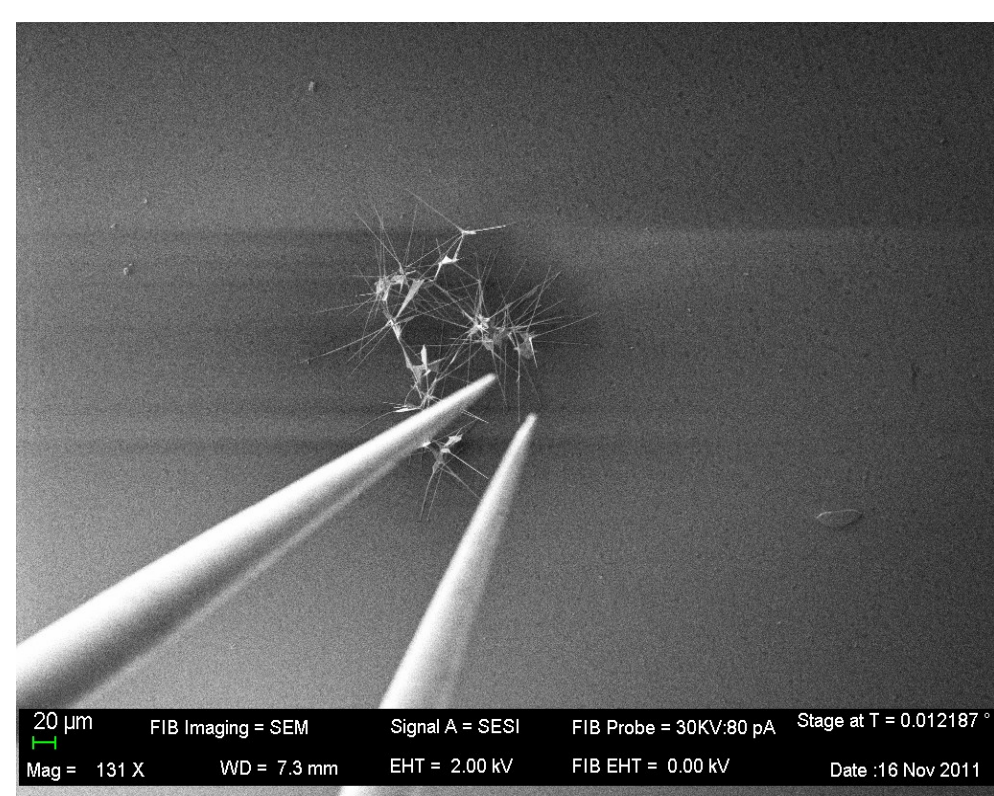
WD = 5.0 mm
EHT = 5.00 kV
Mag = 15.65 K X

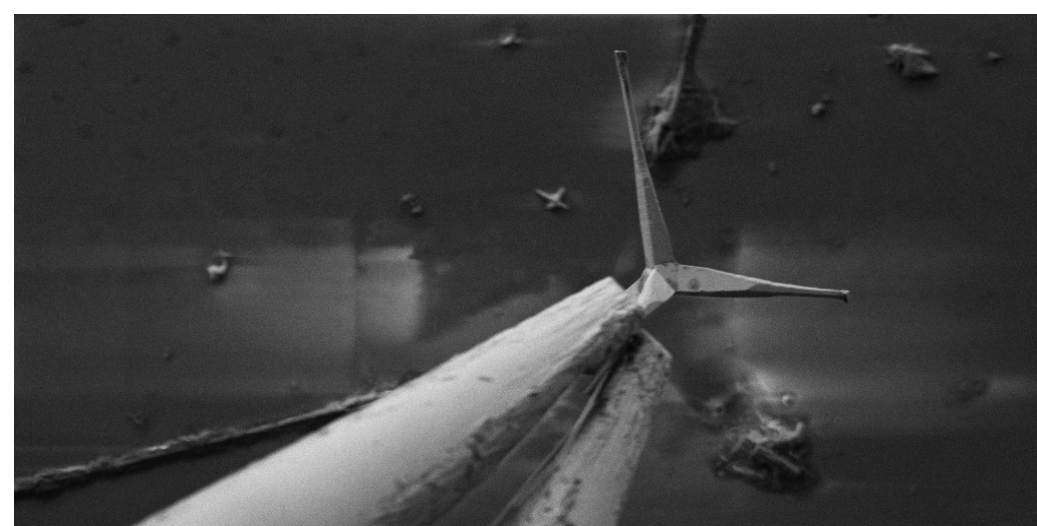
Signal A = InLens
FIB Probe = 2kV:25pA
FIB Lock Mags = No

Stage at T = 59.2 °
Width = 7.307 μ m
Date : 16 Jul 2008
Time : 16:16:48

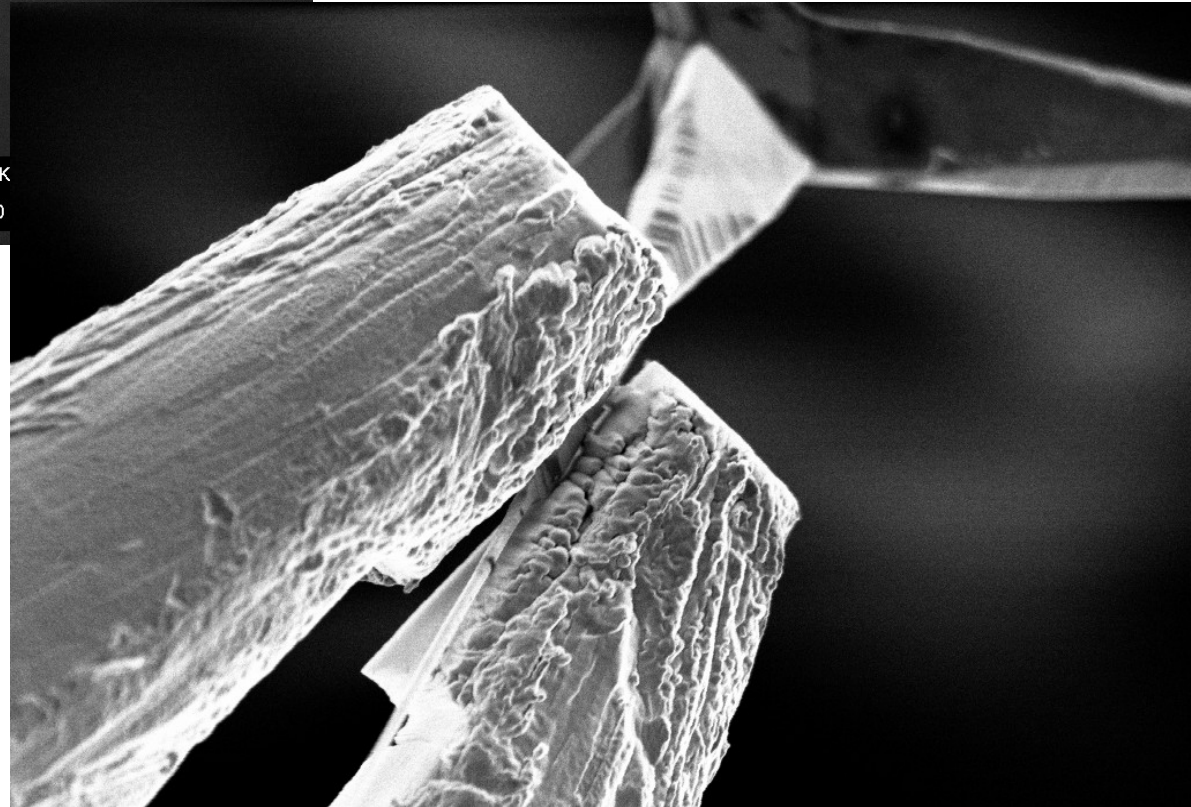
Tilt Corr. = Off







2 μm FIB Imaging = SEM Signal A = SESI FIB Probe = 30K
Mag = 1.57 K X WD = 7.3 mm EHT = 2.00 kV FIB EHT = 0.00



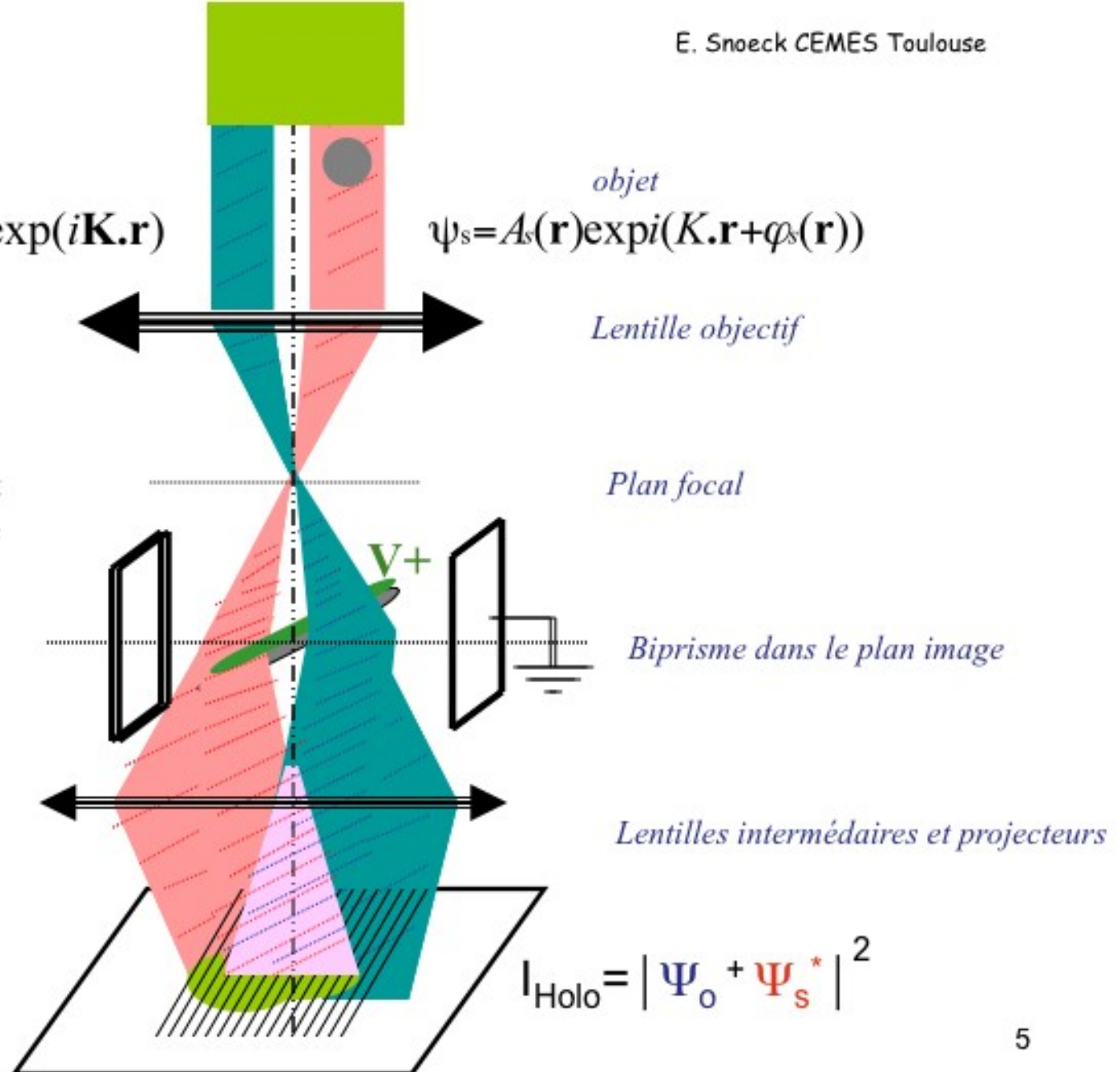
1 μm FIB Imaging = SEM Signal A = InLens FIB Probe = 30KV:80 pA Stage at T = 0.012187 °
Mag = 6.66 K X WD = 7.0 mm EHT = 2.00 kV FIB EHT = 0.00 kV Date :16 Nov 2011

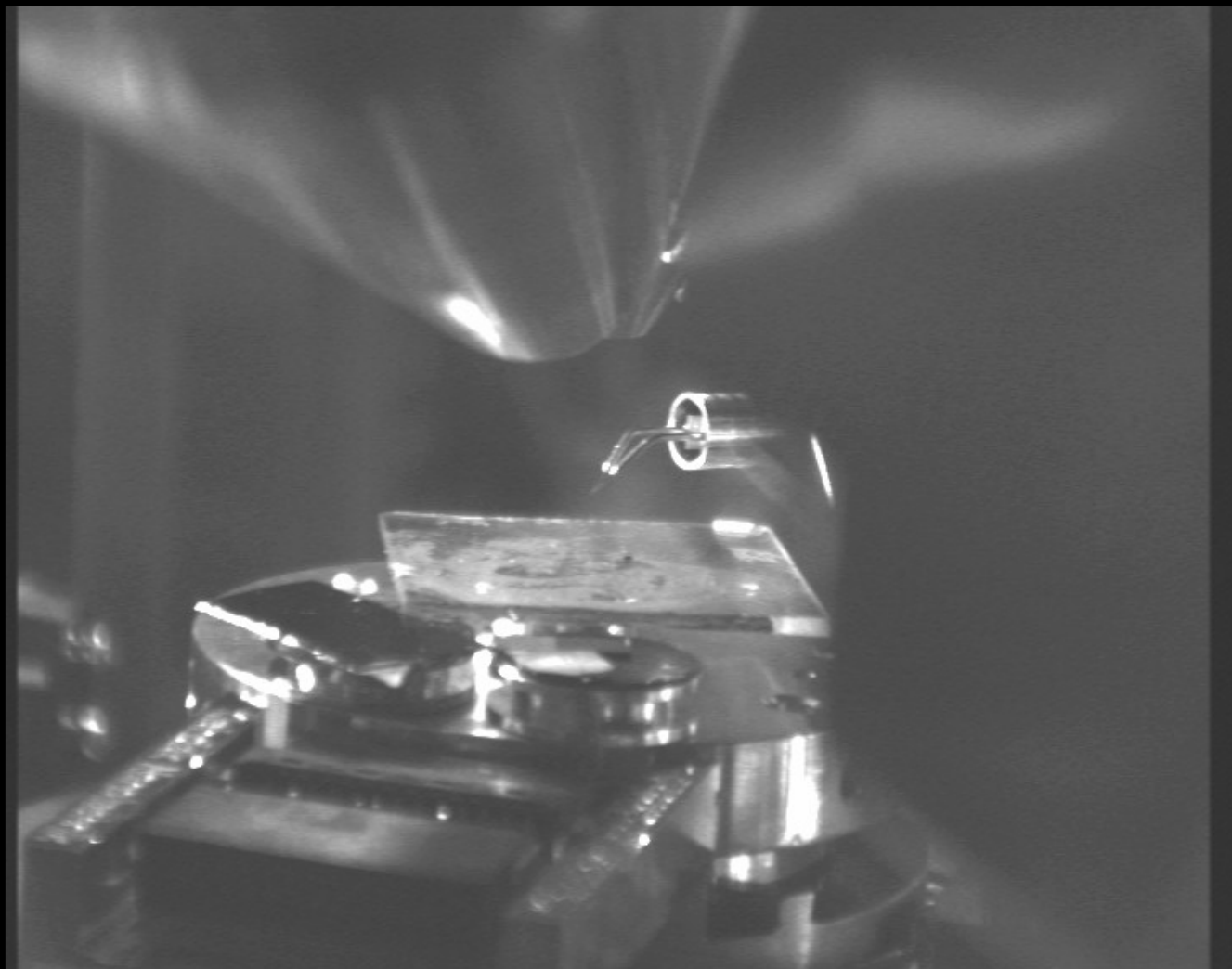
Holographie :

interférence entre une onde de référence Ψ_0 et une onde Ψ_s , de même longueur d'onde mais ayant subi un déphasage φ_s

$$\psi_o = \exp(i\mathbf{K} \cdot \mathbf{r})$$

$$\psi_s = A_s(\mathbf{r}) \exp(i(\mathbf{K} \cdot \mathbf{r} + \varphi_s(\mathbf{r})))$$





100 μm

FIB Imaging = SEM

Signal A = TV2

FIB Probe = 30KV:80 pA

Stage at T = 0.012187 °

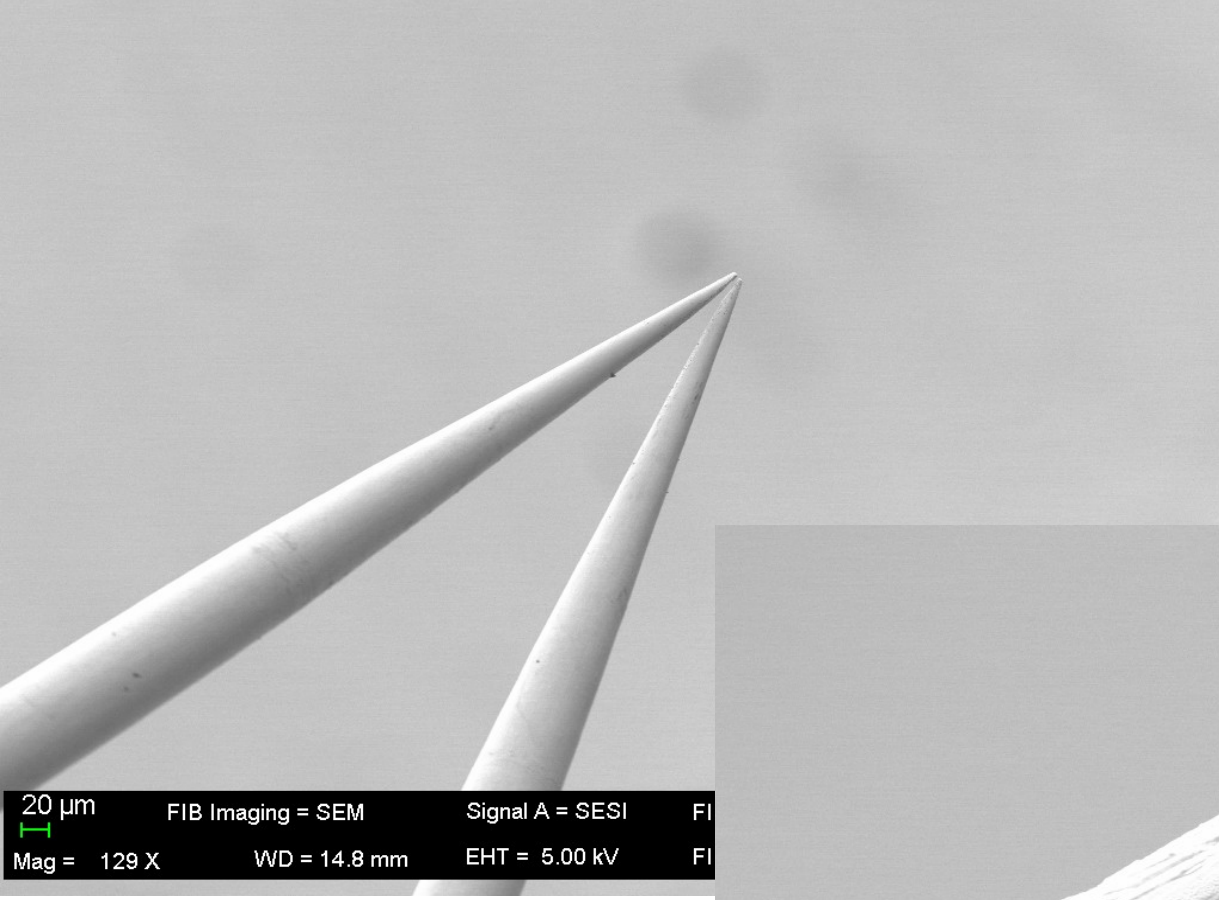
Mag = 114 X

WD = 8.7 mm

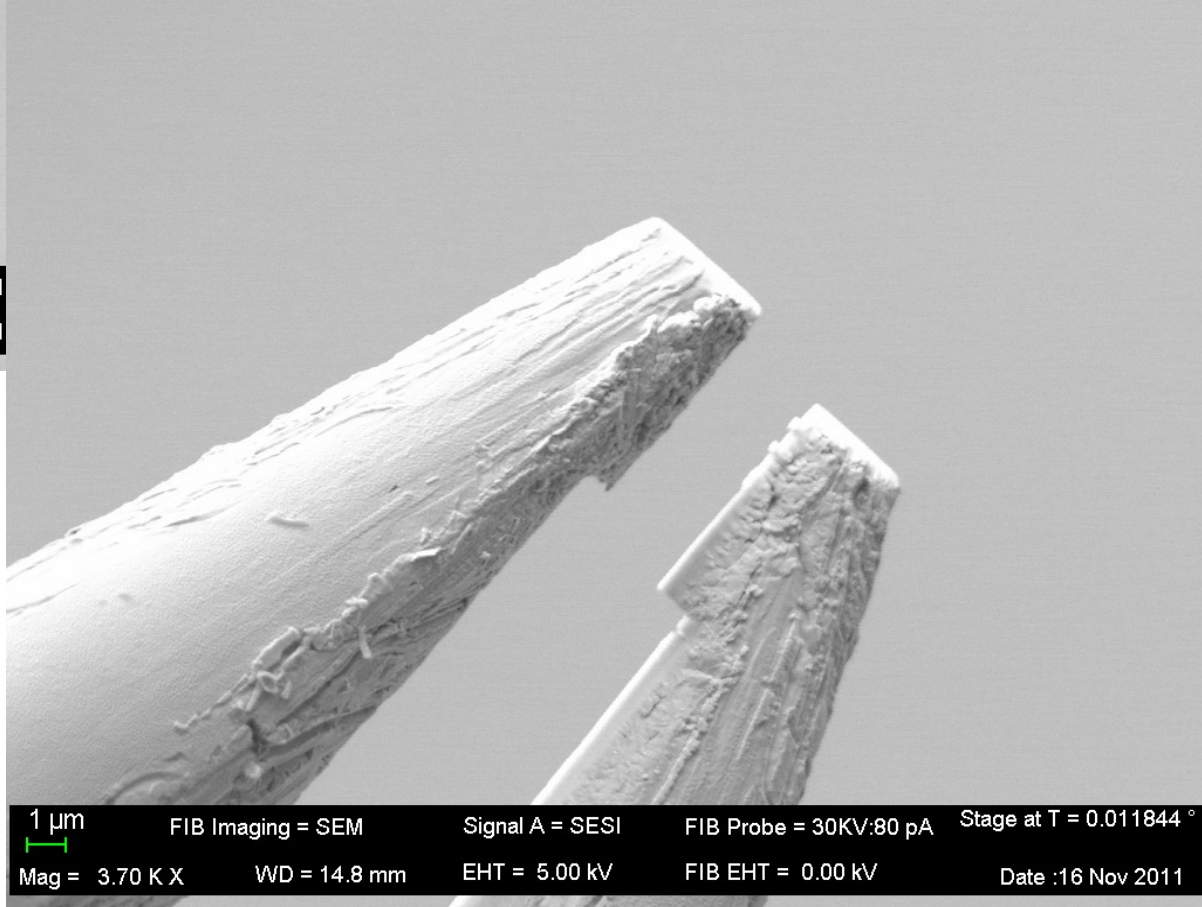
EHT = 5.00 kV

FIB EHT = 0.00 kV

Date :16 Nov 2011



20 μm FIB Imaging = SEM Signal A = SESI FI
Mag = 129 X WD = 14.8 mm EHT = 5.00 kV FI



1 μm FIB Imaging = SEM Signal A = SESI FIB Probe = 30KV:80 pA Stage at T = 0.011844 °
Mag = 3.70 K X WD = 14.8 mm EHT = 5.00 kV FIB EHT = 0.00 kV Date :16 Nov 2011