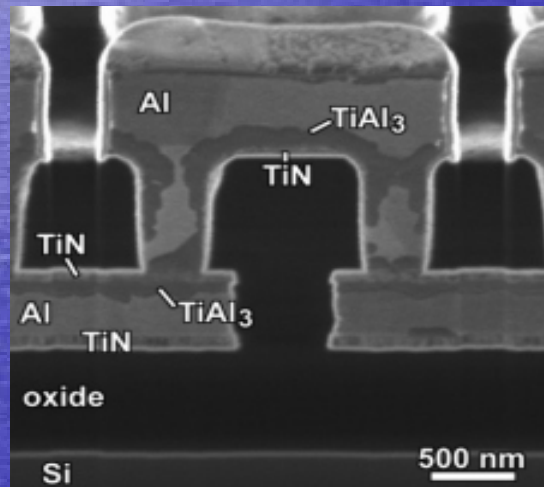
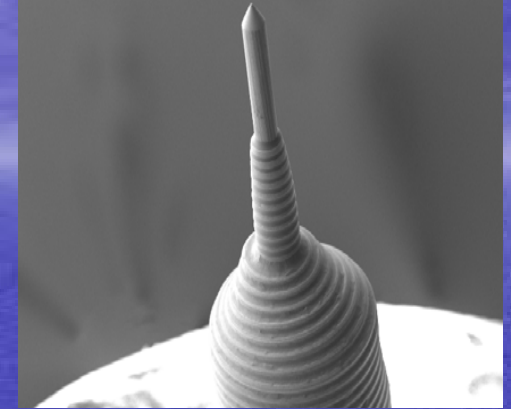


⇒ History of LMIS / FIB

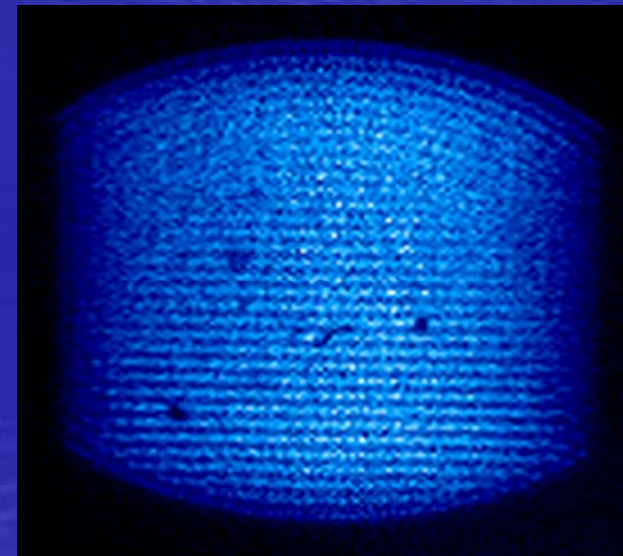
⇒ LMIS principles



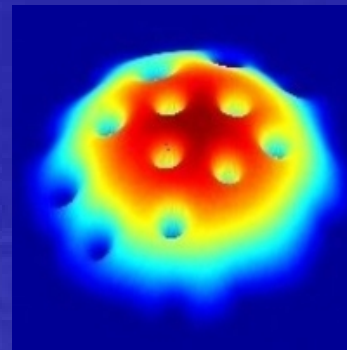
FIB cross-section through a hot Al via chain

© IMEC

⇒ F.I.B. technology



⇒ Future of FIB



History of Taylor cones

Gilbert (1600)
fluid under high tension forms a cone

Zeleny (1914)
Observed and filmed cones and jets

Taylor (1964)
exactly conical solution to equations of
Electro Hydro Dynamics (EHD)



Gilbert was the scientist (and probably lover) of Queen Elisabeth I, she was fond of physical phenomena.

**From Joakim Reuteler
ETH - DMATL**

THE
PHYSICAL REVIEW.

THE ELECTRICAL DISCHARGE FROM LIQUID POINTS, AND
A HYDROSTATIC METHOD OF MEASURING THE
ELECTRIC INTENSITY AT THEIR SURFACES.¹

BY JOHN ZELNY.

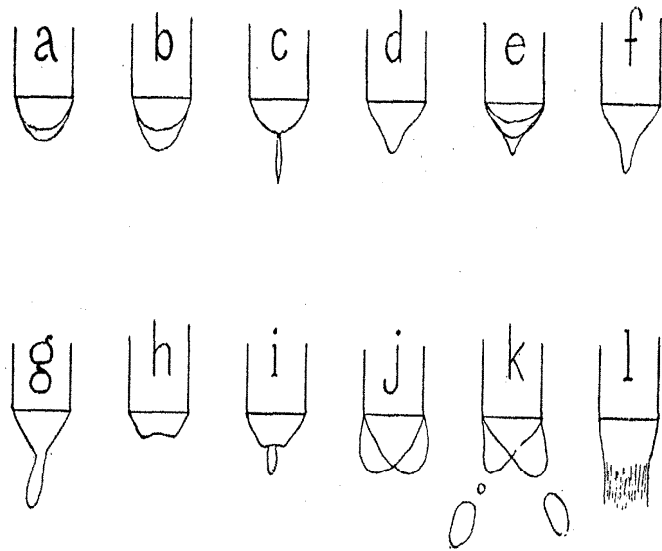


Fig. 3.

Oscillations of meniscus during intermittent discharge.

Zeleny 1914: he took excellent ultra fast pictures of TC moving the photo plaque with a rubber band! Inventor of Zeleny Electroscope (University of Minesota)

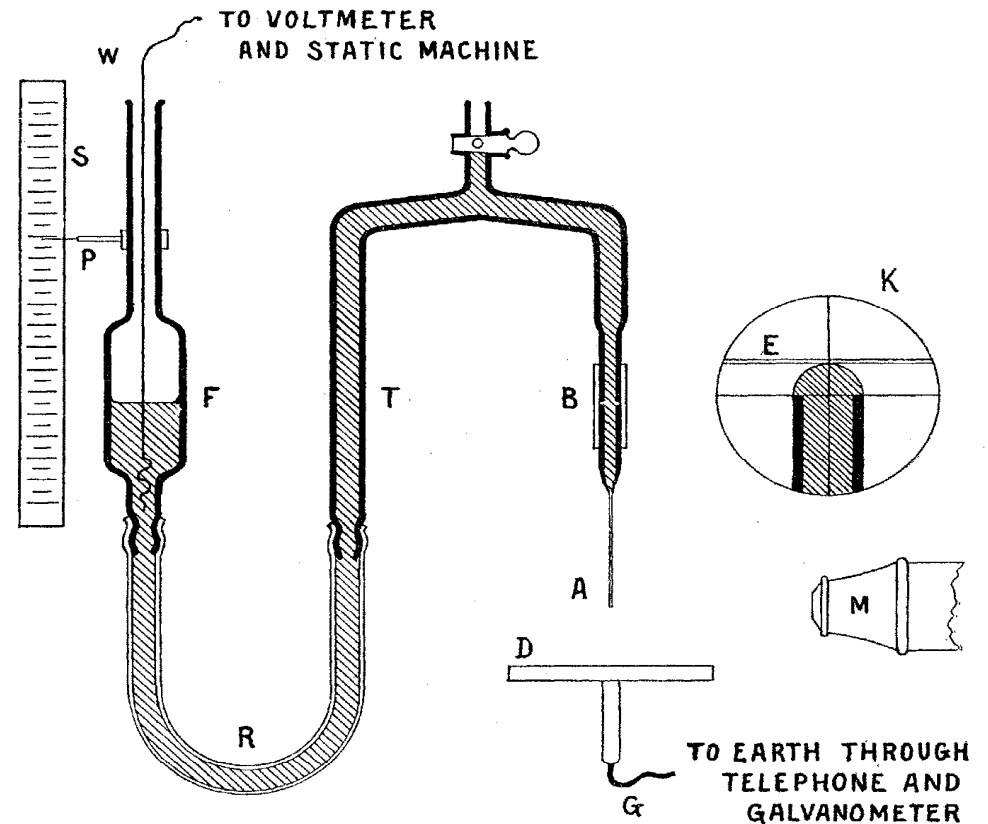
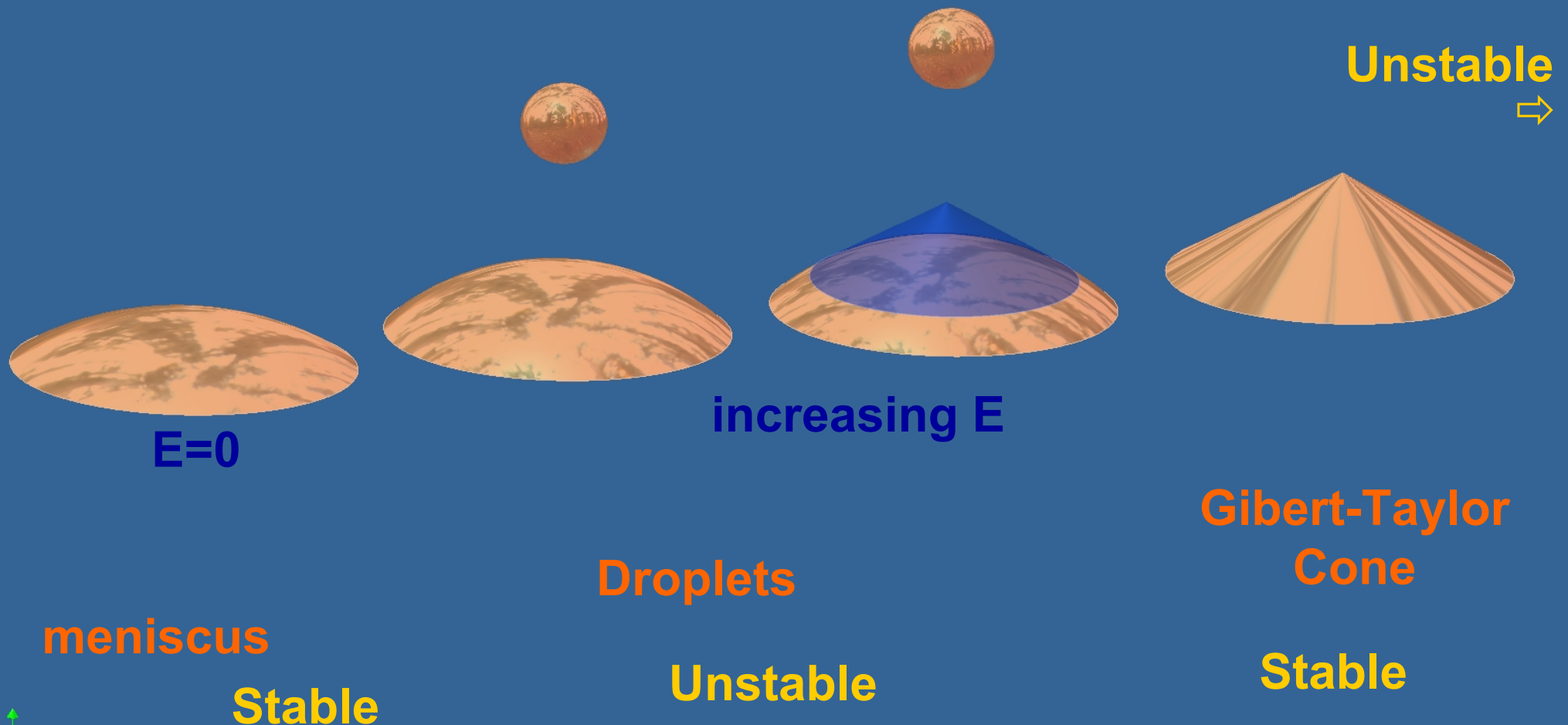


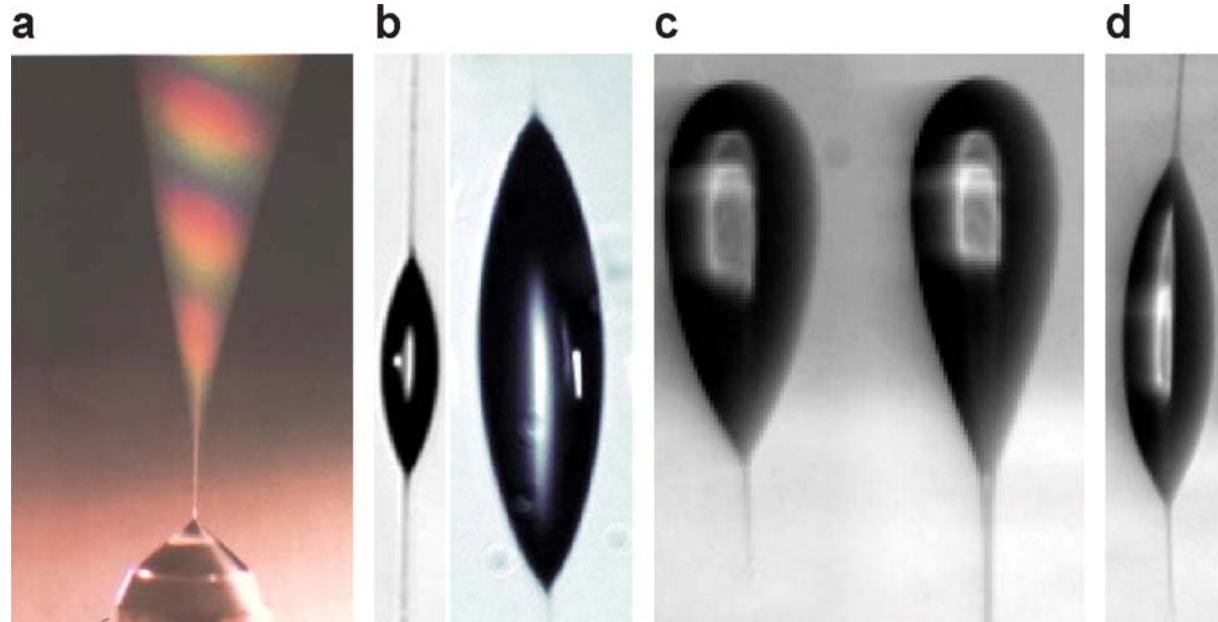
Fig. 1.


Diagram of apparatus.

⇒ Interaction Electric field - Liquid surface

Electrostatic energy and surface tension energy





 Fernández de la Mora J. 2007.
Annu. Rev. Fluid Mech. 39:217–43

a: TC on capillary

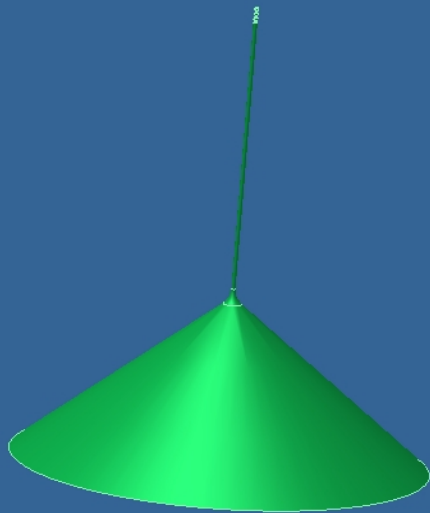
b: ethylene-glycol Rayleigh explosion no external field

c: idem plus external field

d: no charge only external field

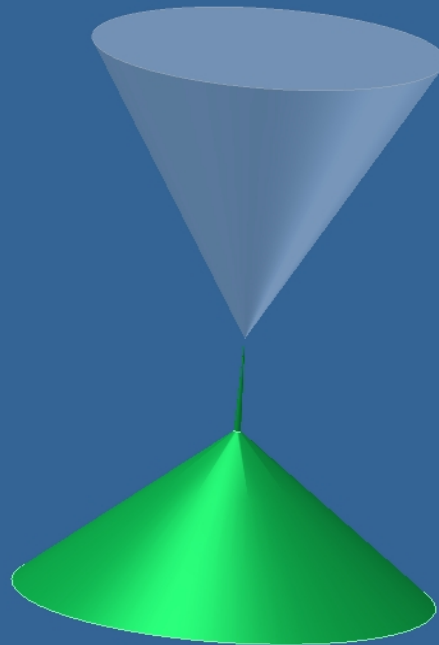
Role in thunderstorms formation!

insulators



(Printers)

Doped insulators

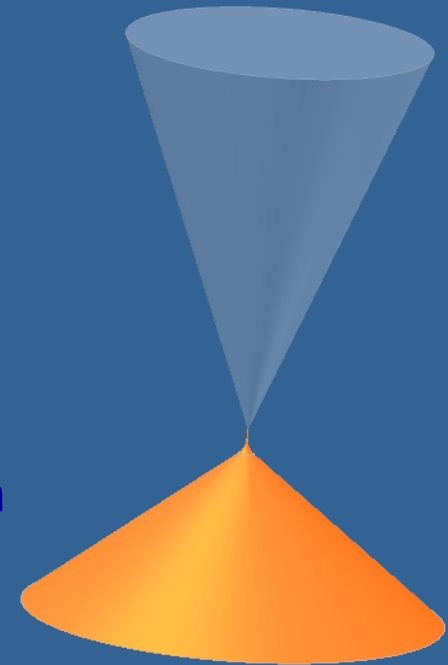


Electro-spray
MS

electrolytes

Metals

Space
propulsion



LMIS and FIB

Some pionners of LMIS & FIB

Mahoney (1969)

Krohn Ringo (University of Chicago) 1975

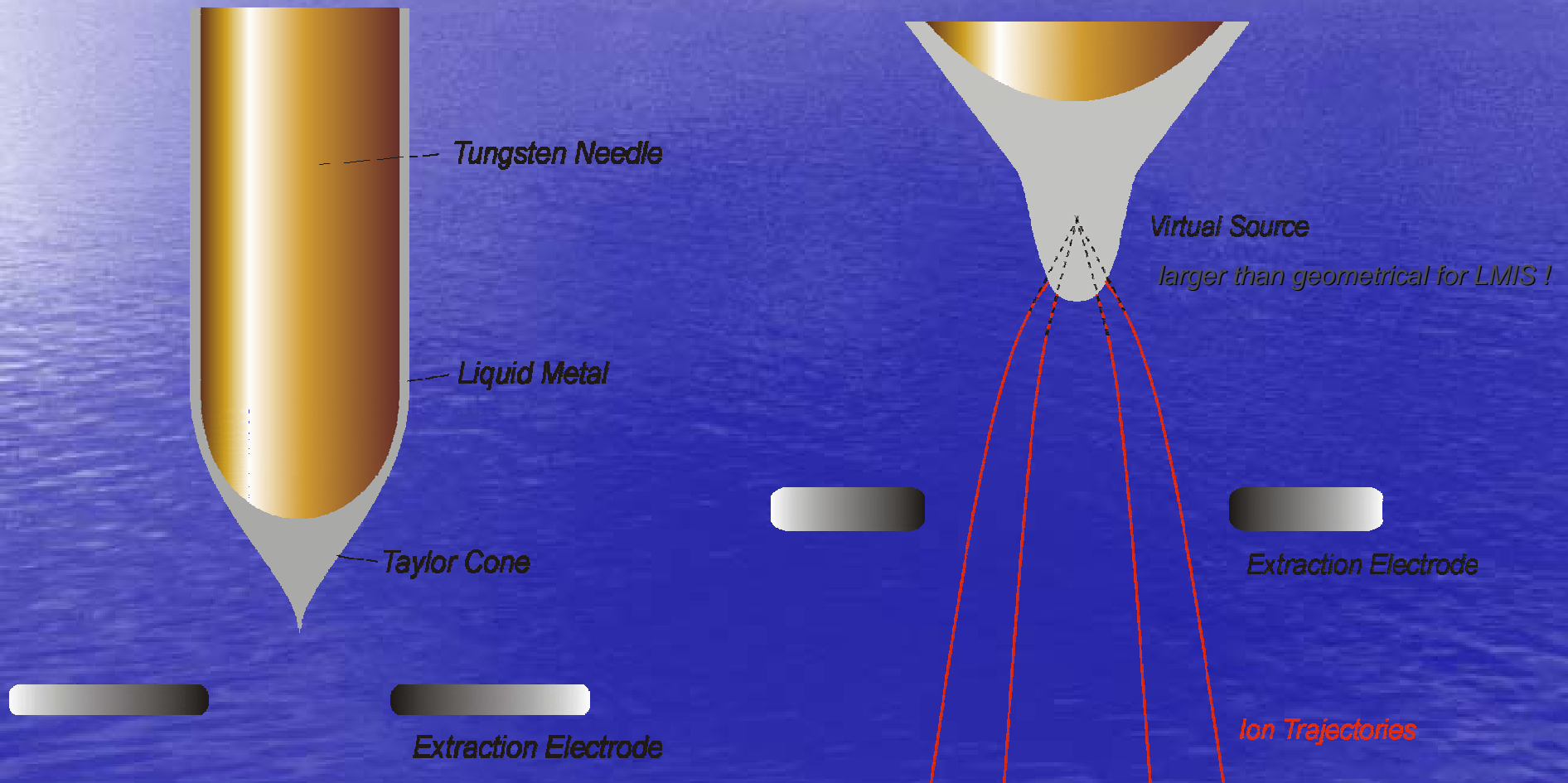
Sudraud et al Paris XI Orsay (1974)

University of Oxford Mair (1980)

Culham UK, Roy Clampitt Prewett (1980)

Oregon Graduate Center L. Swanson (1980)

The L.M.I.S. (Liquid Metal Ion Source)

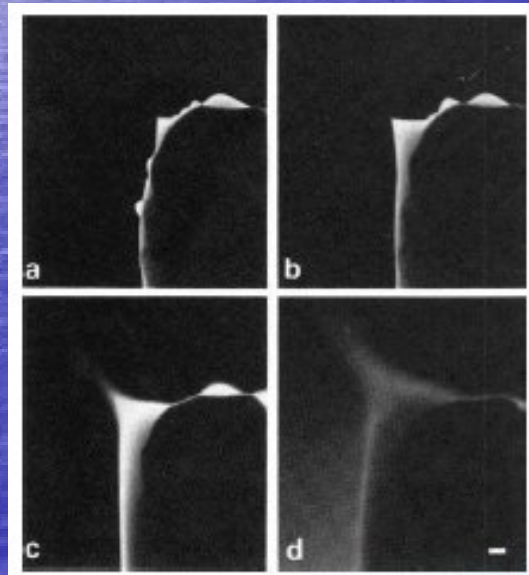
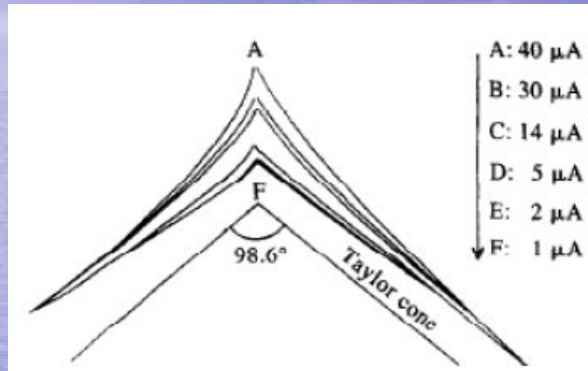


LMIS concept

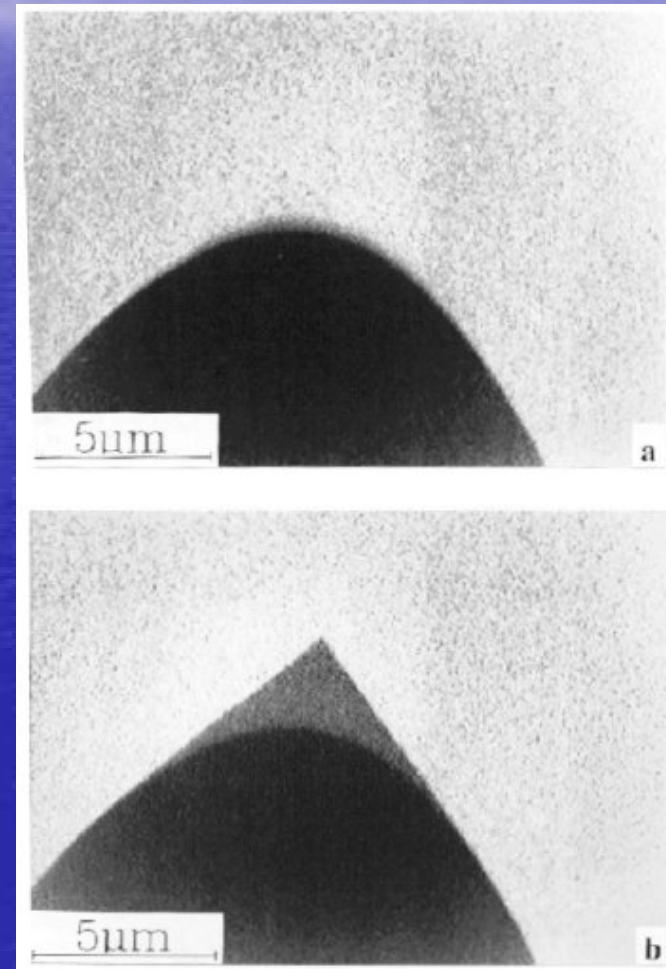
- ⇒ Substrate : Refractory, Wetting, insoluble, tip and reservoir
- ⇒ Temperature : Heater, T° higher than M_p
- ⇒ Liquid metal : low M_p , low vapor P, oxyde VP > metal VP
- ⇒ Tip : cone angle, apex radius
- ⇒ Liquid flow : surface compatibility
- ⇒ Reduced energy dispersion

Gallium is a very good element !

L.M.I.S. (Liquid Metal Ion Source)



*BenAssayag et al. – LPS Orsay
3 MeV TEM (1985)*



*Driesel et al. – MPI Halle
1MeV TEM (1996)*

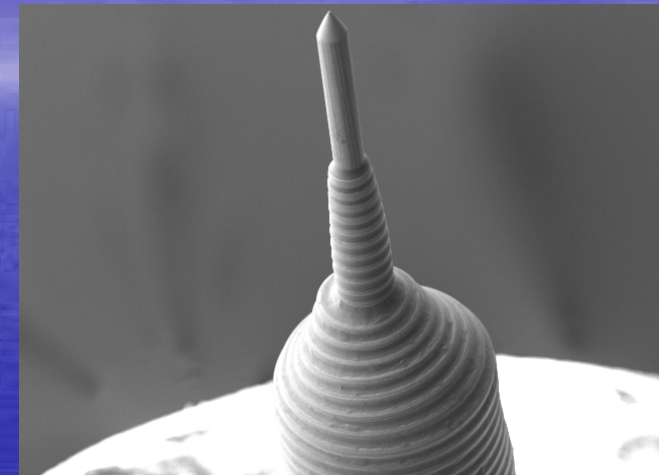
L.M.I.S. and L.M.A.I.S.



Denka Ga LMIS

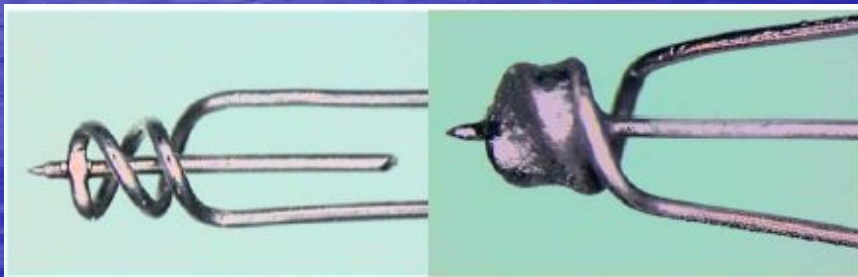


J.Gierak - LPN (F)



Orsay Physics Ga LMIS

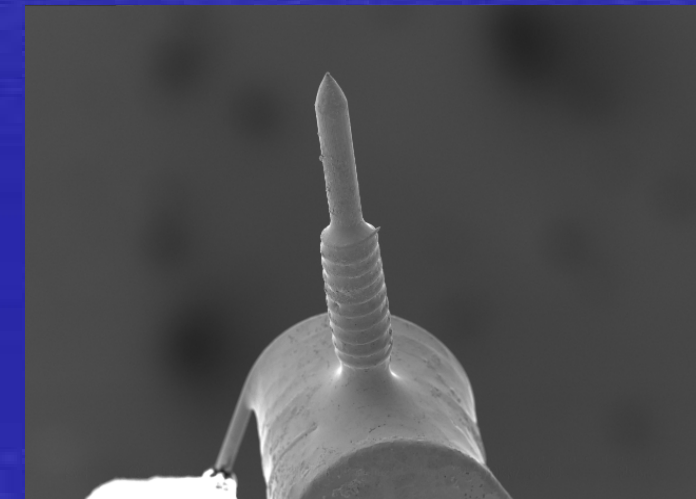
Some geometries



L.Bischoff - FZR Dresden (D)

Alloy: $\text{Co}_{36}\text{Nd}_{64}$

$T_m = 566 \text{ }^\circ\text{C}$



Orsay Physics alloy LMIS

Available Ion Species for Focused Ion Beam Implantation at Chair of Applied Solid State Physics of Ruhr-University of Bochum

Legend

Name: Magnesium
Symbol: Mg
Atomic Number: 12
Mass Number: 24,305
Number of Isotopes: 3
Nature Occurrence of Isotopes: 24, 26, 27
Melting Temperature (°C): 622

1A	2A	3A	4A	5A	6A	7A	8	9	10	11	12	13	14	15	16	17	18																																																																																
Hydrogen 1.0078 1 H 2 91.084 1.0078 1.008	Lithium 6.941 3 Li 7 7.016 99.999 403	Boron 10.811 5 B 10 10.811 100	Beryllium 9.0122 4 Be 9 9.0122 100	Sodium 22.9897 11 Na 23 22.9897 100	Magnesium 24.305 12 Mg 24 24.305 78.99 26 26.981 10.000 27 27.005 11.000	Aluminum 26.9815 13 Al 27 26.9815 100	Silicon 28.0855 14 Si 28 28.0855 99.999 29 29.024 0.001	Phosphorus 30.9738 15 P 31 30.9738 100	Sulfur 32.06 16 S 32 32.06 95.02 33 33.957 4.000 34 34.969 0.980	Chlorine 35.453 17 Cl 35 34.969 75.77 37 36.966 24.23	Argon 39.948 18 Ar 39 38.963 99.600 40 39.962 0.399	Potassium 39.0983 19 K 39 38.964 93.26 40 39.964 6.74	Calcium 40.078 20 Ca 40 39.962 96.909 42 41.958 3.091	Scandium 44.9559 21 Sc 45 44.9559 100	Titanium 47.88 22 Ti 48 47.88 99.98 49 48.928 0.02	Vanadium 50.942 23 V 51 50.942 100	Chromium 51.9961 24 Cr 52 51.9961 73.8 53 52.941 2.6 54 53.940 2.36	Manganese 54.938 25 Mn 55 54.938 100	Iron 55.845 26 Fe 56 55.845 91.754 57 56.935 2.119 58 57.935 0.106	Cobalt 58.933 27 Co 59 58.933 100	Nickel 58.71 28 Ni 58 57.935 68.077 59 58.933 26.223 60 60.004 4.699	Copper 63.546 29 Cu 63 62.929 69.17 65 64.927 30.83	Zinc 65.38 30 Zn 64 63.929 48.6 66 65.929 51.4	Gallium 69.723 31 Ga 69 68.926 77.000 71 70.925 23.000	Germanium 72.63 32 Ge 72 71.922 76.000 73 72.925 24.000	Arsenic 74.9216 33 As 75 74.9216 100	Selenium 78.96 34 Se 76 75.921 77.8 78 77.923 22.2	Bromine 79.904 35 Br 79 78.918 50.69 81 80.916 49.31	Krypton 83.80 36 Kr 80 79.901 73.8 82 81.905 26.2 84 83.905 0.0	Rubidium 85.468 37 Rb 85 85.468 72.04 87 87.476 27.96	Strontium 87.62 38 Sr 86 85.468 99.05 88 87.62 0.95	Yttrium 88.906 39 Y 89 88.906 100	Zirconium 91.224 40 Zr 90 89.904 51.75 91 90.905 48.25	Niobium 92.906 41 Nb 93 92.906 100	Molybdenum 95.94 42 Mo 95 94.904 97.906 96 95.906 2.094	Technetium 98.906 43 Tc 98 97.906 0	Ruthenium 101.07 44 Ru 100 101.07 100	Rhodium 102.905 45 Rh 103 102.905 100	Palladium 106.36 46 Pd 105 104.86 100	Silver 107.868 47 Ag 108 107.868 100	Cadmium 112.40 48 Cd 111 112.404 73.82 112 112.404 26.18	Indium 114.82 49 In 113 114.818 95.72 115 114.818 4.28	Tin 118.710 50 Sn 116 115.909 93.93 117 116.905 0.07	Antimony 121.757 51 Sb 121 121.757 63.02 123 122.904 36.98	Tellurium 127.60 52 Te 126 125.904 78.49 128 127.905 21.51	Iodine 126.905 53 I 127 126.905 100	Xenon 131.29 54 Xe 129 128.905 17.04 130 129.905 22.94 131 130.905 4.07 132 131.905 16.13	Cesium 132.905 55 Cs 133 132.905 100	Barium 137.327 56 Ba 135 134.905 6.86 137 136.905 93.14	Lanthanides	Lutetium 174.967 71 Lu 175 174.967 100	Hafnium 178.49 72 Hf 177 176.926 100	Tantalum 180.948 73 Ta 181 180.948 100	Tungsten 183.85 74 W 182 183.85 100	Rhenium 186.21 75 Re 186 186.21 100	Osmium 190.23 76 Os 190 190.23 100	Iridium 192.22 77 Ir 192 192.22 100	Platinum 195.08 78 Pt 195 195.08 100	Gold 196.967 79 Au 197 196.967 100	Mercury 200.59 80 Hg 199 198.970 95.966 201 200.970 4.034	Thallium 204.38 81 Tl 203 202.973 82.65 205 204.974 17.35	Lead 207.19 82 Pb 204 203.973 26.46 206 205.974 73.54	Bismuth 208.98 83 Bi 209 208.980 100	Polonium 209 84 Po 209 209 0	Astatine 210 85 At 210 210 0	Radon 222 86 Rn 222 222 0	Francium 223 87 Fr 223 223 0	Radium 226 88 Ra 226 226 0	Actinides	Lanthanum 138.905 57 La 139 138.905 100	Cerium 140.12 58 Ce 138 137.905 88.50 140 139.905 11.50	Praseodymium 140.907 59 Pr 141 140.907 100	Neodymium 144.24 60 Nd 142 141.905 73.1 144 143.905 26.9	Promethium 145 61 Pm 145 145 0	Samarium 150.36 62 Sm 147 146.905 15.73 149 148.905 84.27	Europium 151.964 63 Eu 151 150.919 100	Gadolinium 157.25 64 Gd 155 154.922 77.8 157 156.922 22.2	Terbium 158.925 65 Tb 159 158.925 100	Dysprosium 162.50 66 Dy 161 160.924 74.22 163 162.925 25.78	Holmium 164.930 67 Ho 163 162.925 67.3 165 164.926 32.7	Erbium 167.26 68 Er 164 163.924 96.36 166 165.926 3.64	Thulium 168.930 69 Tm 169 168.930 100	Ytterbium 173.04 70 Yb 171 170.935 89.48 173 172.935 10.52	Actinium 207 89 Ac 207 207 0	Thorium 232.04 90 Th 232 232.04 100	Protactinium 231 91 Pa 231 231 0	Uranium 238.03 92 U 235 235.043 99.274 238 238.029 99.726	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

contact:

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Lanthanides

Lanthanum 138.91 57 La 139 138.91 100	Cerium 140.12 58 Ce 138 137.91 88.5 140 139.91 11.5	Praseodymium 140.91 59 Pr 141 140.91 100	Neodymium 144.24 60 Nd 142 141.91 73.1 144 143.91 26.9	Promethium 145 61 Pm 145 145 0	Samarium 150.36 62 Sm 147 146.91 15.73 149 148.91 84.27	Europium 151.96 63 Eu 151 150.92 100	Gadolinium 157.25 64 Gd 155 154.92 77.8 157 156.92 22.2	Terbium 158.93 65 Tb 159 158.93 100	Dysprosium 162.50 66 Dy 161 160.92 74.22 163 162.92 25.78	Holmium 164.93 67 Ho 163 162.92 67.3 165 164.92 32.7	Erbium 167.26 68 Er 164 163.92 96.36 166 165.92 3.64	Thulium 168.93 69 Tm 169 168.93 100	Ytterbium 173.04 70 Yb 171 170.93 89.48 173 172.93 10.52
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Actinides

Actinium 207 89 Ac 207 207 0	Thorium 232.04 90 Th 232 232.04 100	Protactinium 231 91 Pa 231 231 0	Uranium 238.03 92 U 235 235.04 99.274 238 238.029 99.726	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
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Non-exhaustive list of LMIS and LMAIS

Prof. A. Wieck - RUB

Other alloys, such as

AuSi, AuGe, GaBi, GaBiLi,

AsPdBi, CoNd, MgGa,

GePd (Mühle et al, ETH)

etc...

are also available.

	Type of LMIS	Most intensive fraction of ions
1	AgGe	Ge ⁺⁺ , Ge ⁺ , Ag ⁺
2	AgAuGe	Ge ⁺⁺ , Ge ⁺ , Ag ⁺ (Au ⁺⁺), Au ⁺ , AuGe ⁺
3	AuBeSi	Be ⁺⁺ , Be ⁺ , Si ⁺⁺ , Si ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
4	AuBGeNi	Ni ⁺⁺ , Ni ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
5	AuCeSi	Si ⁺⁺ , Si ⁺ , Ce ⁺⁺⁺ , Ce ⁺⁺ , Ce ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
6	AuCoGe	Co ⁺⁺ , Co ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
7	AuCrGe	Cr ⁺⁺ , Cr ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
8	AuDyGe	Ge ⁺⁺ , Ge ⁺ , Dy ⁺⁺⁺ , Dy ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺
9	AuDySi	Si ⁺⁺ , Si ⁺ , Dy ⁺⁺⁺ , Dy ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , Au ₂ ⁺
10	AuErSi	Si ⁺⁺ , Si ⁺ , Er ⁺⁺⁺ , Er ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
11	AuEuSi	Si ⁺⁺ , Si ⁺ , Eu ⁺⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
12	AuFeGe	Fe ⁺⁺ , Fe ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
13	AuGdSi	Si ⁺⁺ , Si ⁺ , Gd ⁺⁺⁺ , Gd ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
14	AuGeMn	Mn ⁺⁺ , Mn ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , AuGe ⁺ , Au ₂ ⁺ , Au ₂ Ge ⁺
15	AuGeNi	Ni ⁺⁺ , Ni ⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
16	AuGeV	V ⁺⁺ , Ge ⁺⁺ , Ge ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺ , AuGe ⁺ , Au ₂ Ge ⁺
17	AuHoSi	Si ⁺⁺ , Si ⁺ , Ho ⁺⁺⁺ , Ho ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
18	AuLaSi	Si ⁺⁺ , Si ⁺ , La ⁺⁺⁺ , La ⁺⁺ , La ⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
19	AuNdSi	Si ⁺⁺ , Si ⁺ , Nd ⁺⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
20	AuSbSi	
21	AuSiSm	Si ⁺⁺ , Si ⁺ , Sm ⁺⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
22	AuSiTb	Si ⁺⁺ , Si ⁺ , Tb ⁺⁺⁺ , Tb ⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
23	AuSiTm	Si ⁺⁺ , Si ⁺ , Tm ⁺⁺⁺ , Au ⁺⁺ , Au ⁺ , Au ₂ ⁺
24	BPt	B ⁺⁺ , B ⁺ , Pt ⁺⁺⁺ , Pt ⁺⁺
25	Bi	Bi ⁺⁺ , Bi ⁺ , Bi ₃ ⁺⁺⁺ , Bi ₂ ⁺⁺ , Bi ₅ ⁺⁺⁺ , Bi ₃ ⁺⁺ , Bi ₄ ⁺⁺ , Bi ₅ ⁺⁺
26	BiGaIn	Ga ⁺ , Bi ⁺ , In ⁺
27	CoDy	Co ⁺⁺⁺ , Co ⁺⁺ , Dy ⁺⁺⁺ , Dy ⁺⁺
28	CuP	P ⁺ (Cu ⁺⁺), Cu ⁺
29	CuPPt	P ⁺⁺⁺ , P ⁺⁺ (Cu ⁺⁺), Cu ⁺ , Pt ⁺⁺⁺ , PtP ⁺⁺⁺ , PtP ⁺⁺ , Pt ⁺
30	DyNi	Ni ⁺⁺⁺ , Ni ⁺⁺ , Dy ⁺⁺⁺ , Dy ⁺⁺
31	Ga	Ga ⁺
32	GaIn	Ga ⁺ , In ⁺
33	GaZn	
34	GeNiTi	Ti ⁺⁺⁺ , Ni ⁺⁺⁺ , Ge ⁺⁺⁺ , Ti ⁺⁺ , Ni ⁺⁺ , Ge ⁺⁺
35	HoNi	Ni ⁺⁺⁺ , Ni ⁺⁺ , Ho ⁺⁺⁺
36	In	In ⁺
37	Sn	Sn ⁺⁺⁺ , Sn ⁺⁺ , Sn ₂ ⁺⁺⁺ , Sn ₃ ⁺⁺⁺ , Sn ₄ ⁺⁺⁺ , Sn ₅ ⁺⁺⁺

Probe formation

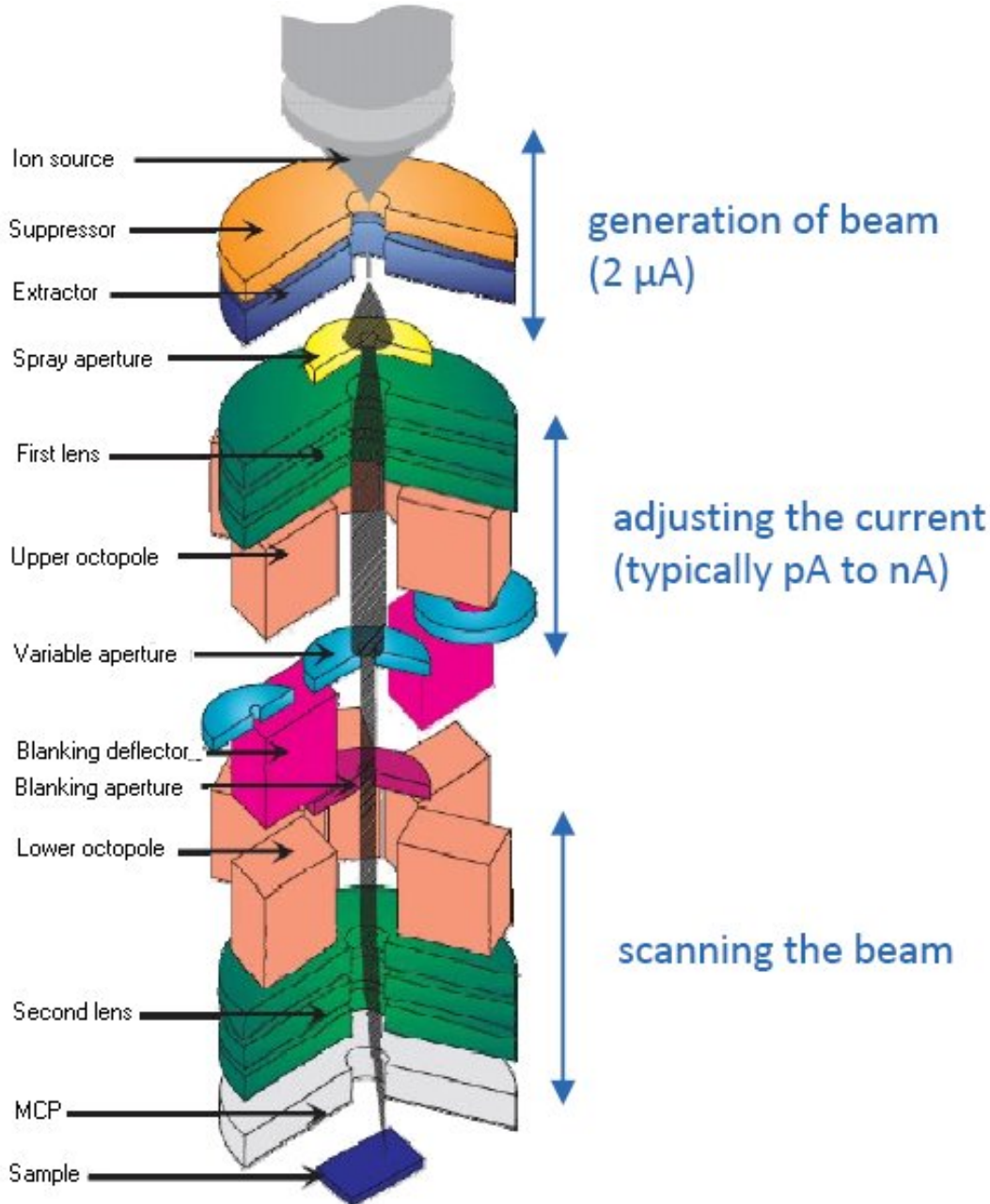
- ⇒ Minimize radius
- ⇒ Maximize current
- ⇒ Optimize I distribution
- ⇒ Beam purity

Ion optics

- ⇒ Minimize lenses aberrations
- ⇒ Chromatic linked with source ΔE
- ⇒ Spherical (large I)
- ⇒ Coma, alignment

Environment optimization

- ⇒ Electric and magnetic noises
- ⇒ Vibrations, acoustic noise
- ⇒ Thermal shifts (long working times)
- ⇒ Software automation



Other FIB columns :

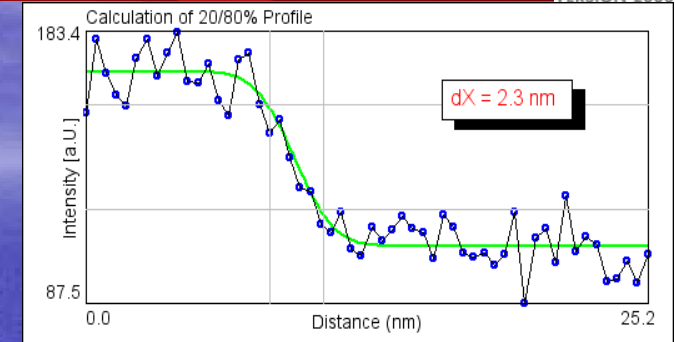
-Sidewinder from FEI

-Cobra-FIB from OP

Typical FIB column geometry
(SII Zeta) from J.Reuteler
ETH Zürich

Resolution measurement ?

- ⇒ SEM separation (subjective) of two objects
- ⇒ FIB more difficult
- ⇒ Fast scan: bad signal to noise ratio
- ⇒ Slow scan: milling while imaging
- ⇒ Measured in % of contrast:

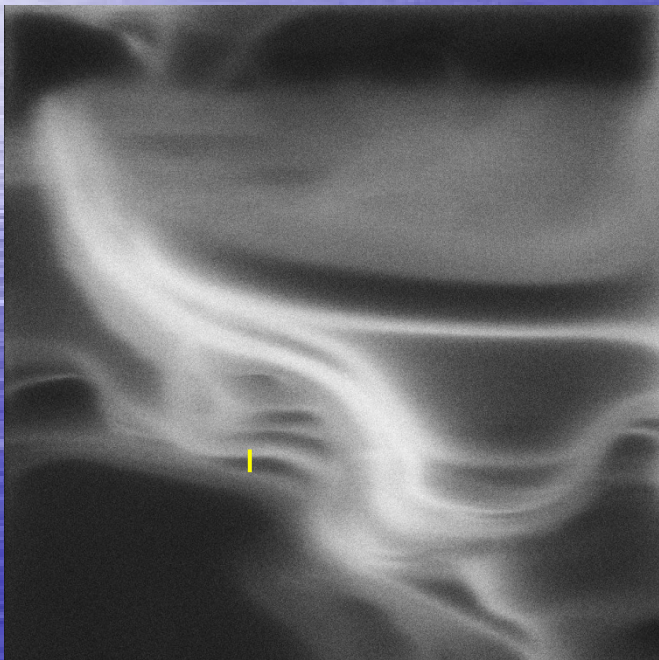


35/65%; 16/84%; 20/80%; 25/75% or Δx_{50}

- ⇒ $E = 30 \text{ kV}$
- ⇒ 1 pA probe current

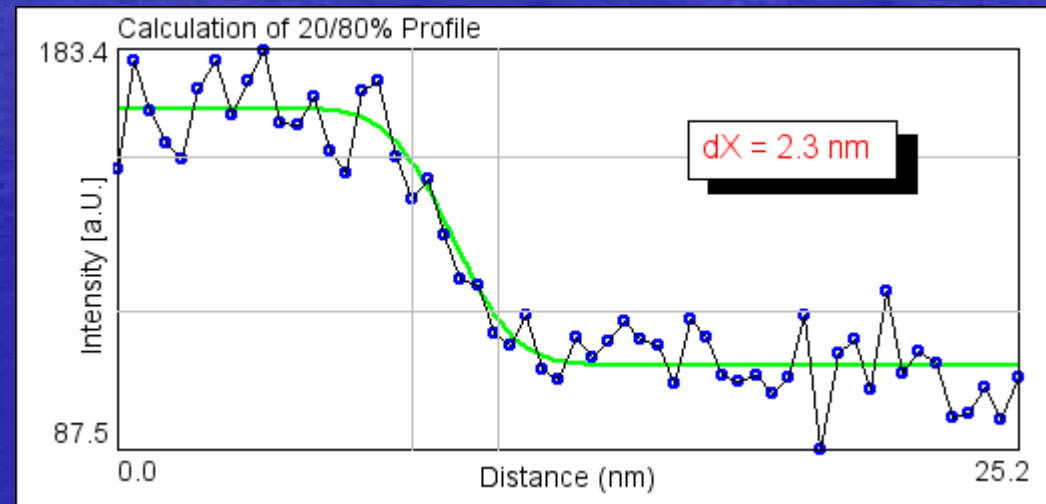
New COBRA-FIB column

Dr. Anne Delobbe
Dr. Bernard Rasser



⇒ $\text{FOV} = 780 \text{ nm}$

⇒ Resolution $< 2.5 \text{ nm}$



1,7 nm resolution has been performed at 20-80 with Cobra-FIB

Resolution measurement

« It is interesting that you should be running into beam-specimen interactions that limit resolution. Mark Utlaut, Lyn Swanson and I, made prediction for imaging resolution for a Ga FIB based on specimen damages and S/N considerations. This issue becomes even more acute now that beam sizes decrease so much. »

From Jon Orloff to P.Sudraud, June 26, 2008

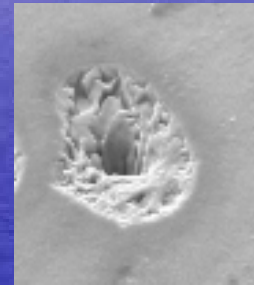
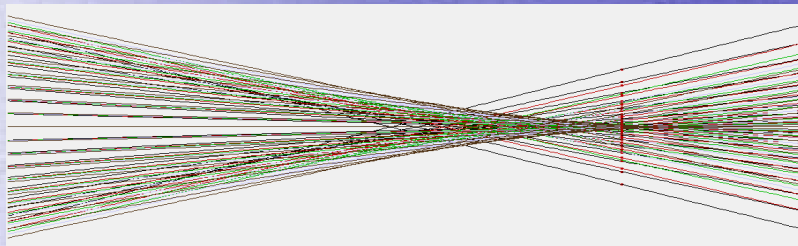
Resolution and current with gaussian distribution

Contrast	D/sigma	I/It
10-90%	2,565	0,561
12-88%	2,355	0,5
16-84%	1,989	0,39
20-80%	1,685	0,299
25-75%	1,35	0,204
35-65%	0,771	0,072

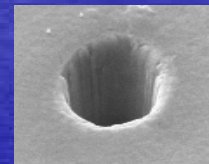
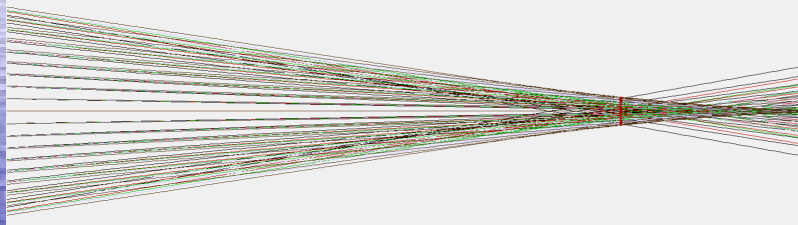
15 nA

Focusing adjustment

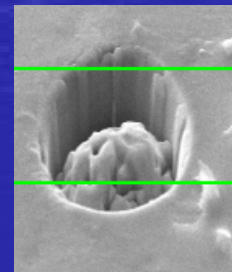
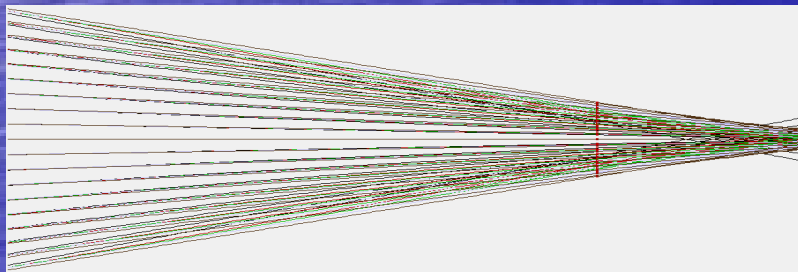
Dr. Anne Delobbe
Dr. Bernard Rasser



a) focus



b) - 60 V



c) - 110 V

In a) imaging resolution is optimum but milling is not sharp

In b) imaging resolution is poor, but milling is optimum.

Ion-solid interaction at some keV:
It involves mostly elastic collisions.
A very small quantity of heat is produced.

One could imagine that it is a « quiet »
mechanism??



Ion-solid interaction is not so quiet !

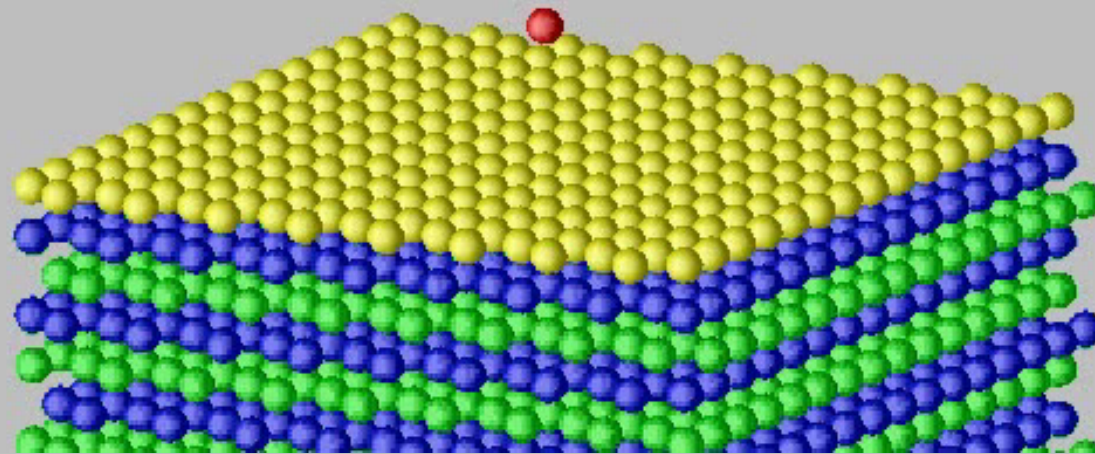


Lets see some simulations from Prof. Dr A.Wucher group
at Duisburg Universität to be convinced !

Kate's Video Converter (Free)

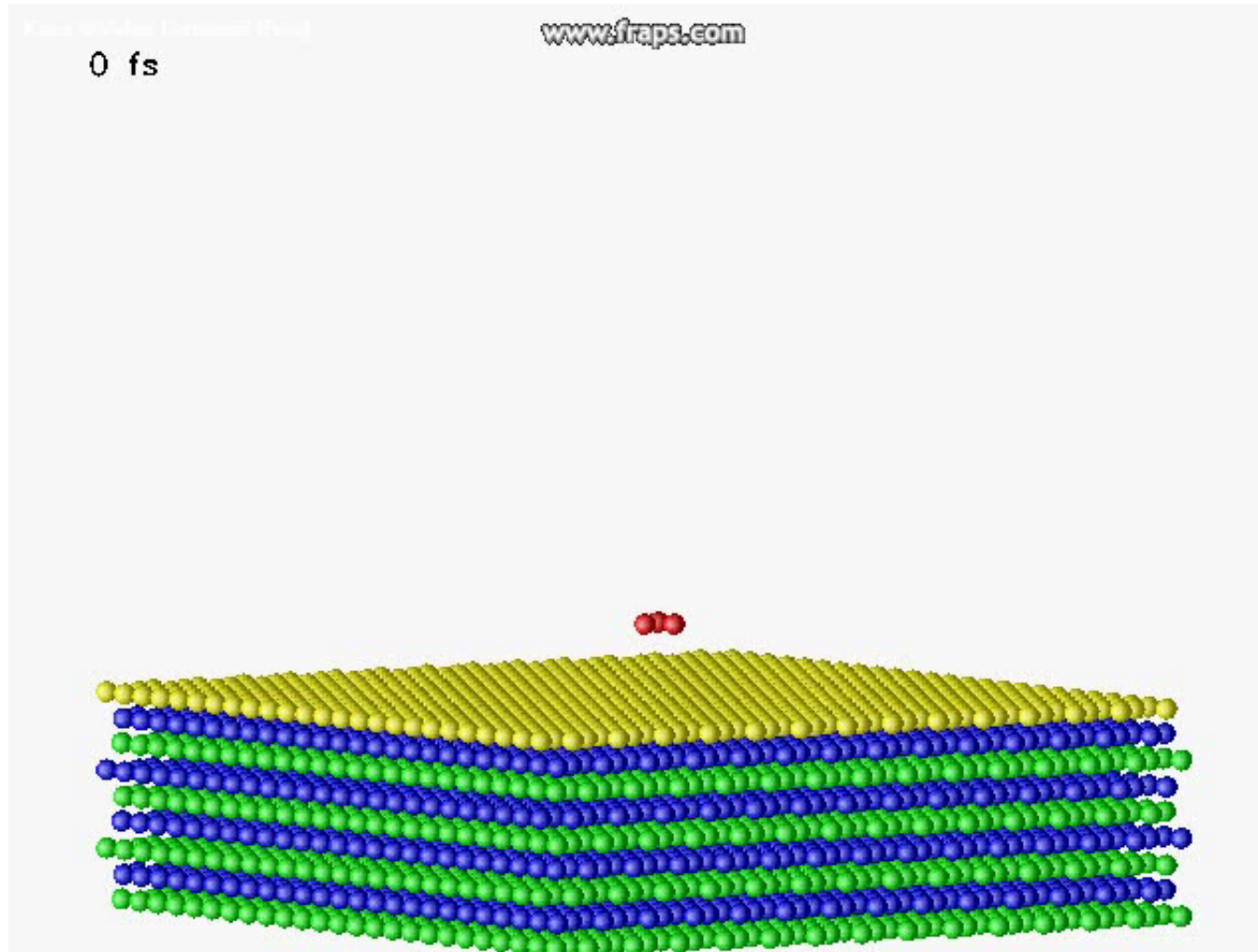
www.fraps.com

0 fs



5 keV Ag on Ag (111)

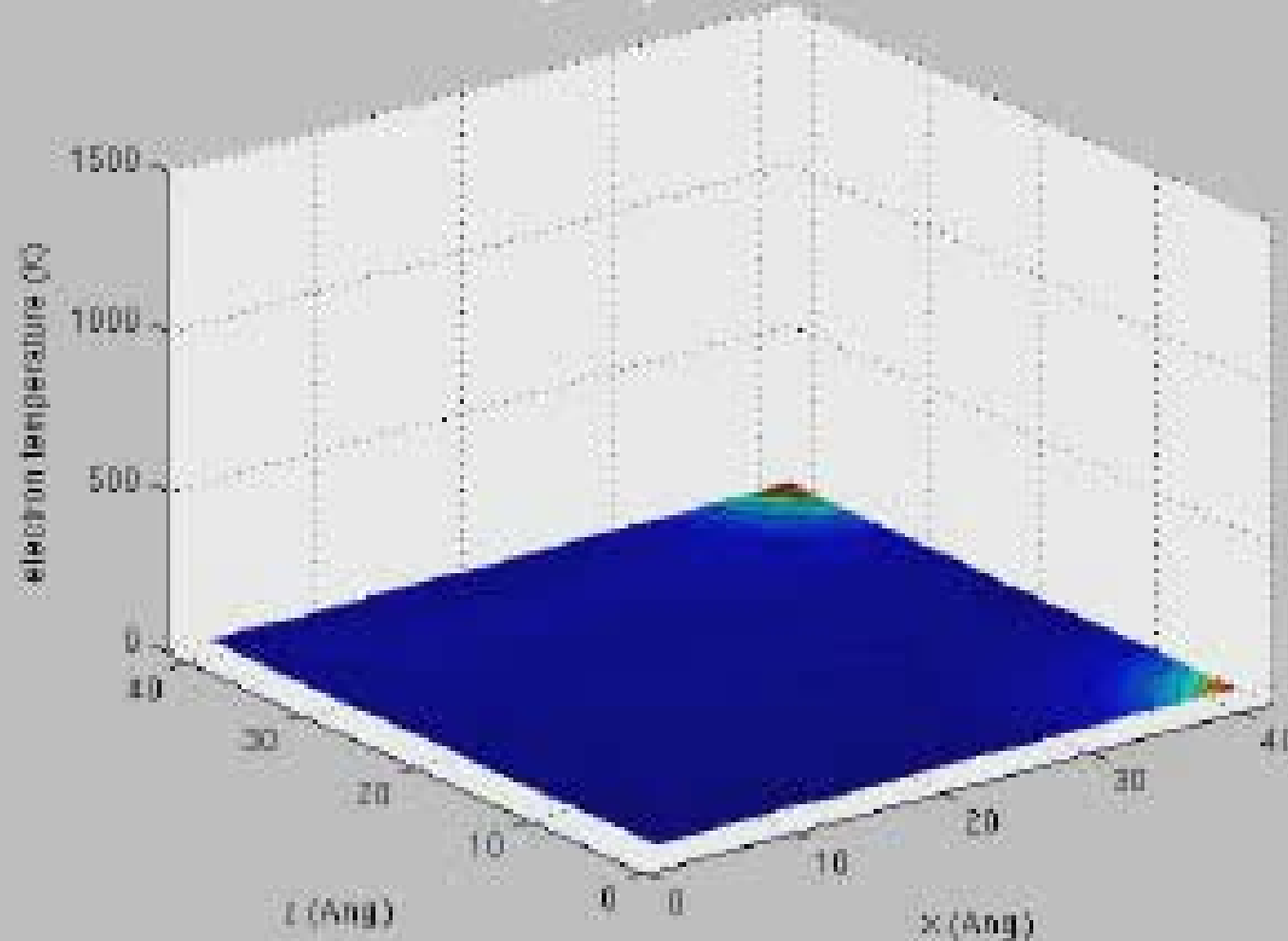
Prof. Dr A.Wucher group – Duisburg Universität



6 keV Ag_3 on Ag (111)

Prof. Dr A.Wucher group – Duisburg Universität

Kate's Video Converter (Free) Electron Temperature in Layer 1 at time 1 fs



Electronic excitation

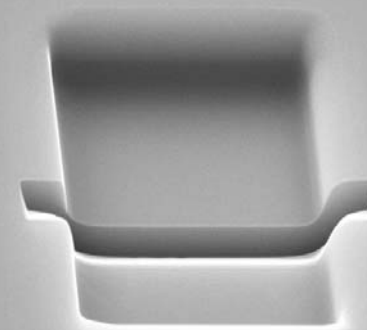
Milling rate at 5kV

50 scans x 30 s



271 pA
10 μm x 10 μm

100 x 30 s



70 x 30 s



Sputtering rate
measurement

3 different times
For linearity control

2 μm
Mag = 43.06 K X System Vacuum = 8.39e-007 mBar Sig
WD = 5 mm Stage at Z = 49.763 mm Stage at T = 54.0° E

3.09 K X System Vacuum = 8.02e-007 mBar Signal A = SE2 Date :9 Apr 2008
5 mm Stage at Z = 49.763 mm Stage at T = 54.0° EHT = 20.00 kV Time :11:21:10

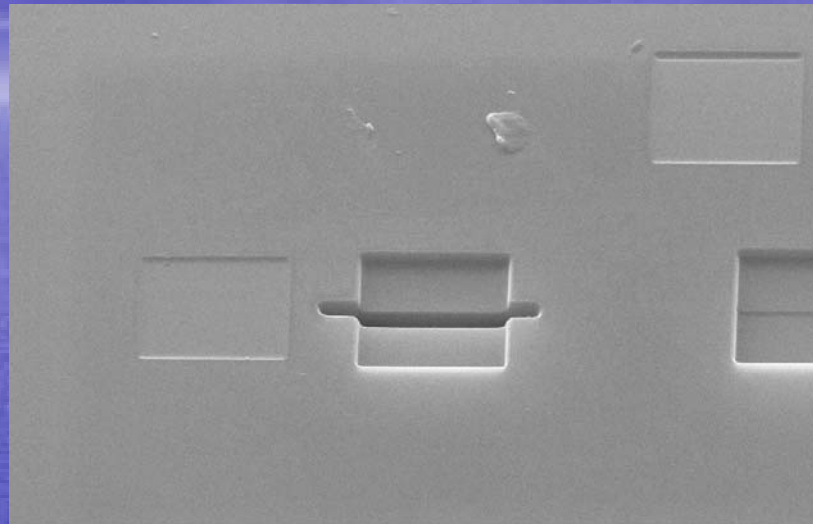
2 μm
Mag = 51.92 K X System Vacuum = 8.07e-007 mBar Signal A = SE2 Date :9 Apr 2008
WD = 5 mm Stage at Z = 49.763 mm Stage at T = 54.0° EHT = 20.00 kV Time :11:07:05

⇒ Ga⁺ on Si

- ⇒ 30 kV : 2.4 atoms/ion
- ⇒ 15 kV : 2.0 atoms/ion
- ⇒ 5 kV : 1.4 atoms/ion

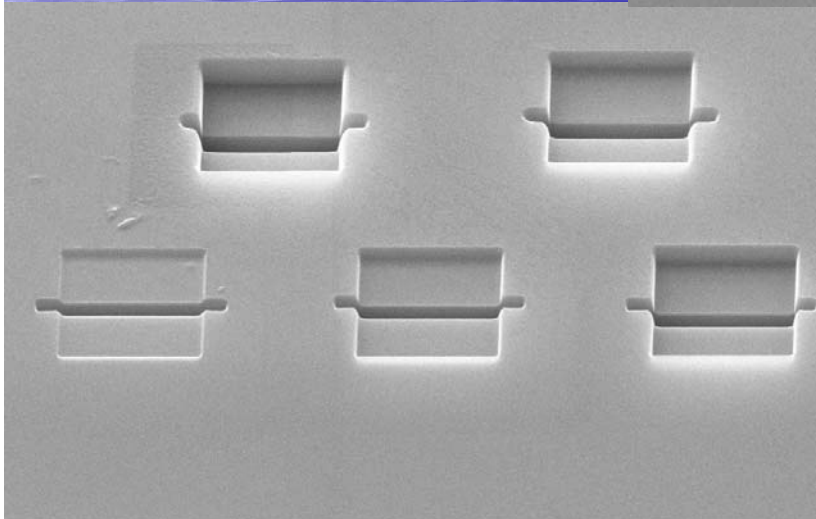
Au milling rate on Si

Au⁺ sur Si



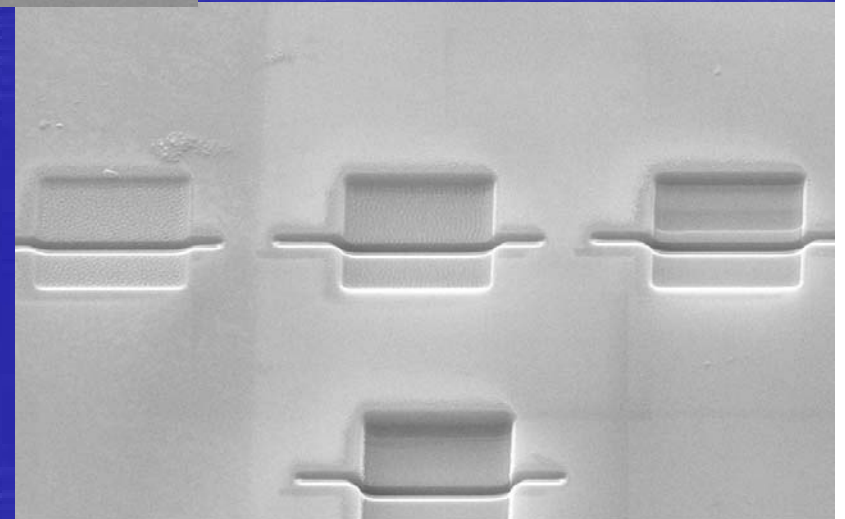
1µm* Mag = 39.35 K X System Vacuum = 1.04e-006 mBar Signal A = SE2 Date :2 Jun 2008
WD = 5 mm Stage at Z = 49.963 mm Stage at T = 54.0° EHT = 20.00 kV Time :12:52:49

Au⁺⁺ sur Si



1µm* Mag = 37.75 K X System Vacuum = 1.04e-006 mBar Signal A = SE2 Date :2 Jun 2008
WD = 5 mm Stage at Z = 49.963 mm Stage at T = 54.0° EHT = 20.00 kV Time :14:14:54

Au₂⁺ sur Si

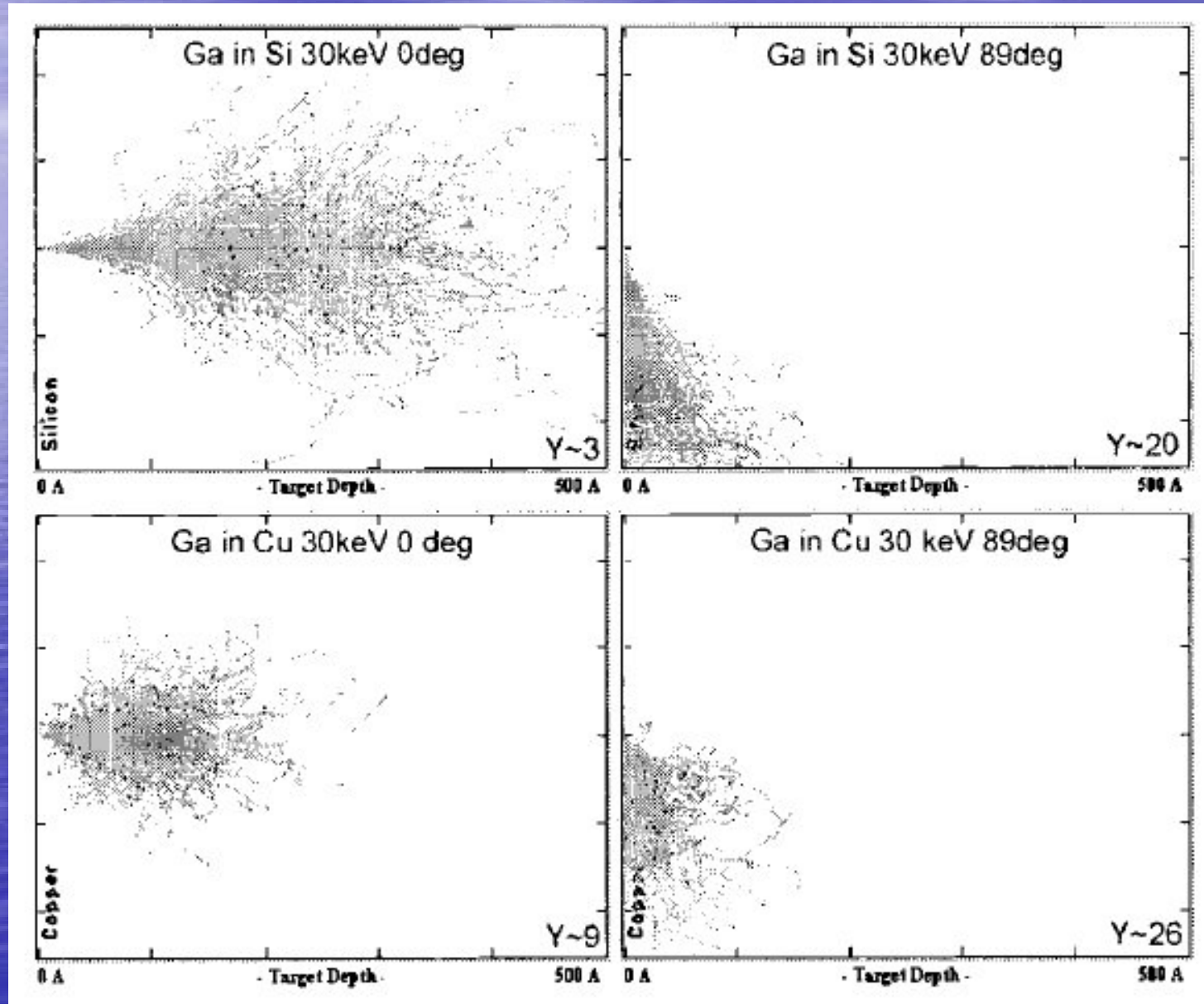


2µm* Mag = 39.35 K X System Vacuum = 1.06e-006 mBar Signal A = SE2 Date :2 Jun 2008
WD = 5 mm Stage at Z = 49.963 mm Stage at T = 54.0° EHT = 20.00 kV Time :15:21:30

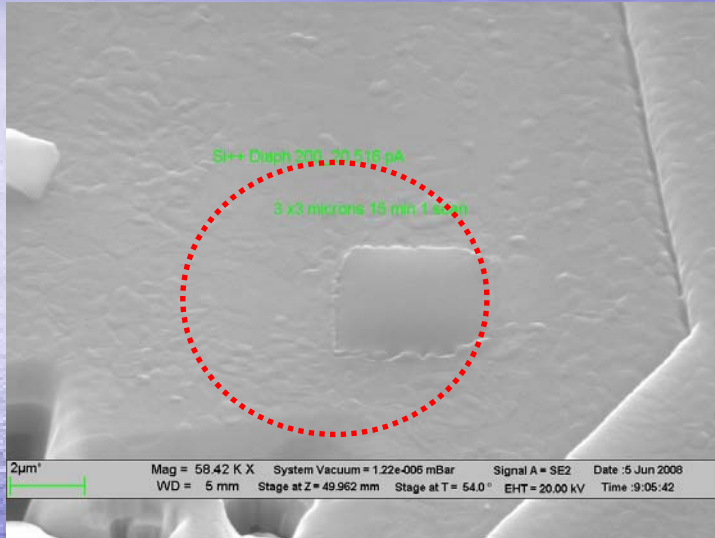
⇒ Au on Si
Incidence angle 90°

- ⇒ Au^+ : 5.2 atoms/ion
- ⇒ Au^{++} : 5.6 atoms/ion
- ⇒ Au_2^+ : 9.5 atoms/ion

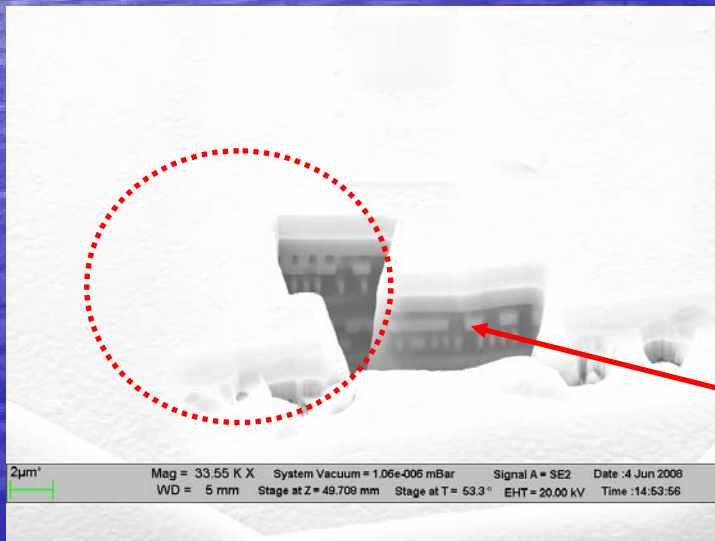
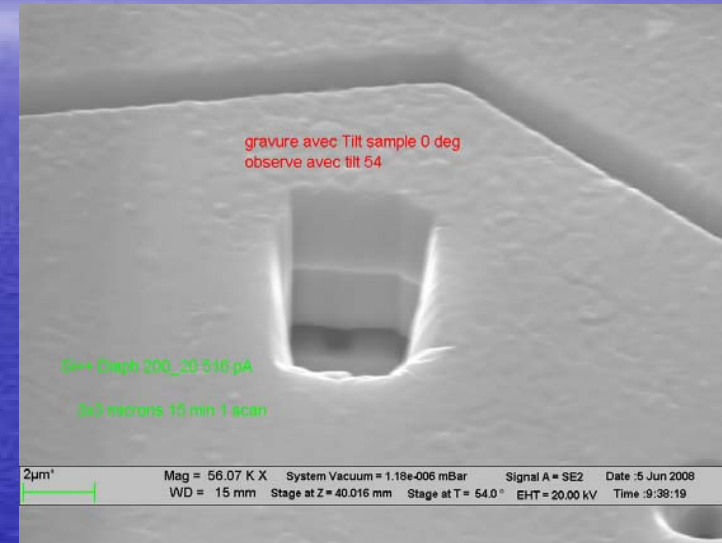
Milling rate at 30 keV



90 ° incidence



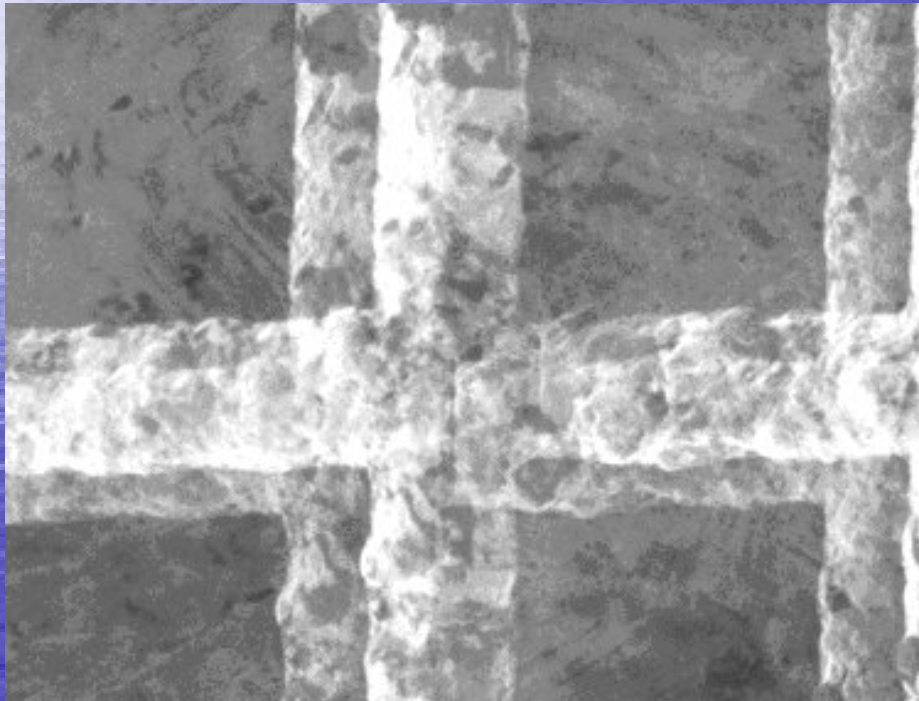
36 ° incidence



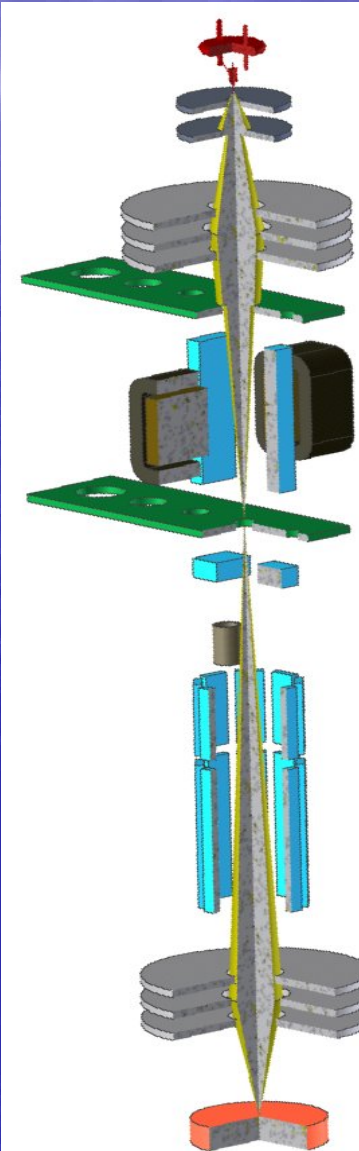
Same conditions
at different angles

Polishing of existing
cross section

CANION 31X FIB column



Separation of the two Ga isotopes



- Ion source
- Extraction electrodes
- Condensor lens
- Ion current selection aperture
- Wien filter
- Mass selection aperture
- Blanking
- Faraday cup
- Scanning and Stigmation octupole
- Objective lens
- Sample

OPTIFIB column

- ✓ Patented concept
- ✓ Coaxial ion / photon beams
- ✓ Visible and I.R. imaging capabilities
Resolution < $0,5 \mu\text{m}$
F.O.V. = $250 \times 250 \mu\text{m}^2$
- ✓ Ion resolution < 8 nm
F.O.V. = $400 \times 400 \mu\text{m}^2$
Beam current : 1 pA to 20 nA



Some FIB manufacturers



DCG
Systems



Applied Materials
Revolutionizes Defect
Review with Industry's
First Automated In-Line
SEM/FIB System. (Photo:
Business Wire)



APPLIED MATERIALS®



ZEISS



FEI COMPANY™



ULVAC
ULVAC-PHI, INC.



TESCAN
DIGITAL MICROSCOPY IMAGING



Raith
INNOVATIVE SOLUTIONS FOR NANOFABRICATION AND
SEMICONDUCTOR NAVIGATION



HITACHI
Inspire the Next



SII



JEOL

Some industrial requirements

Non reactive elements (in-line FIB)

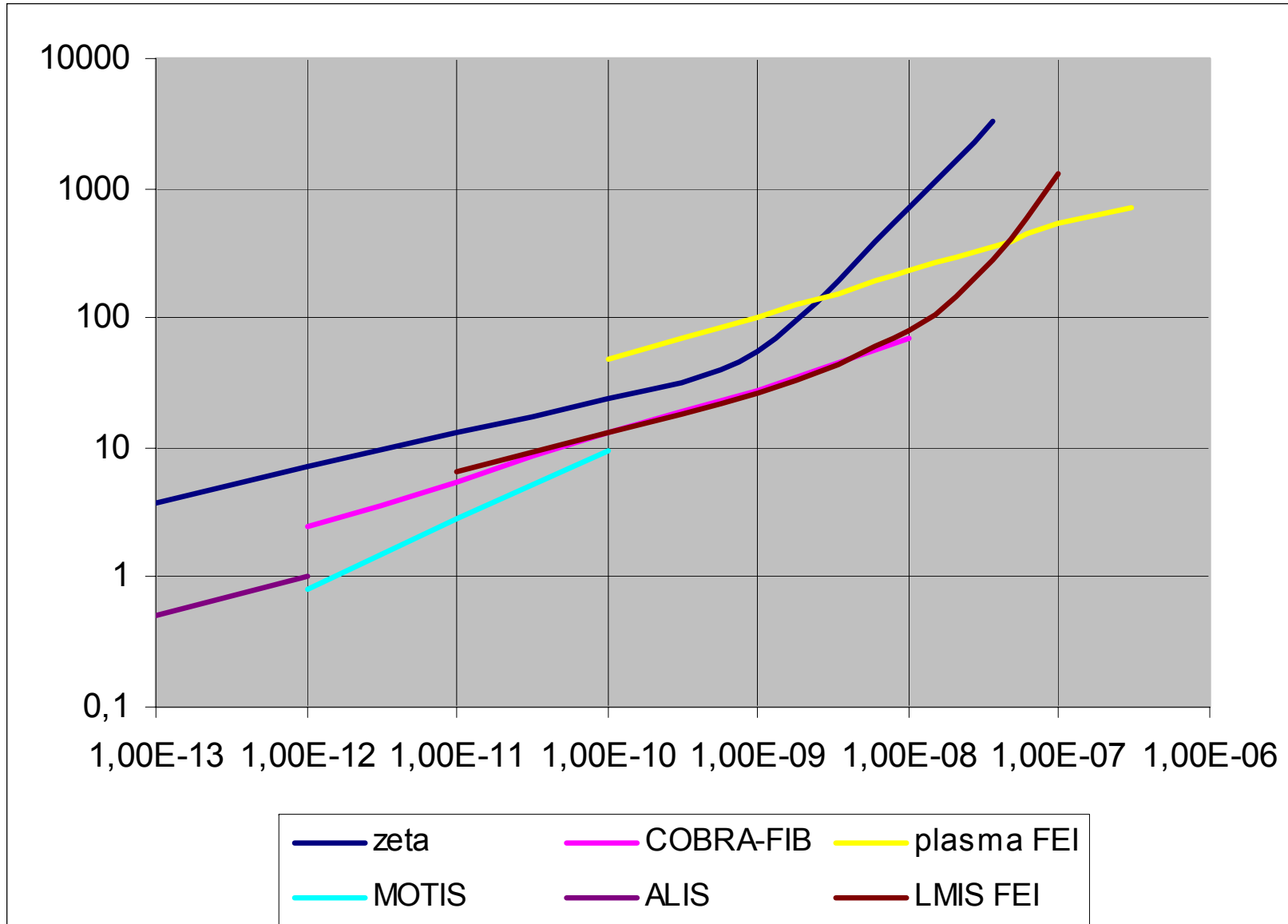
Low energy FIB (M.Rauscher's work)

Nanometric and atomic (?) scale

Large volumes (MEMS)

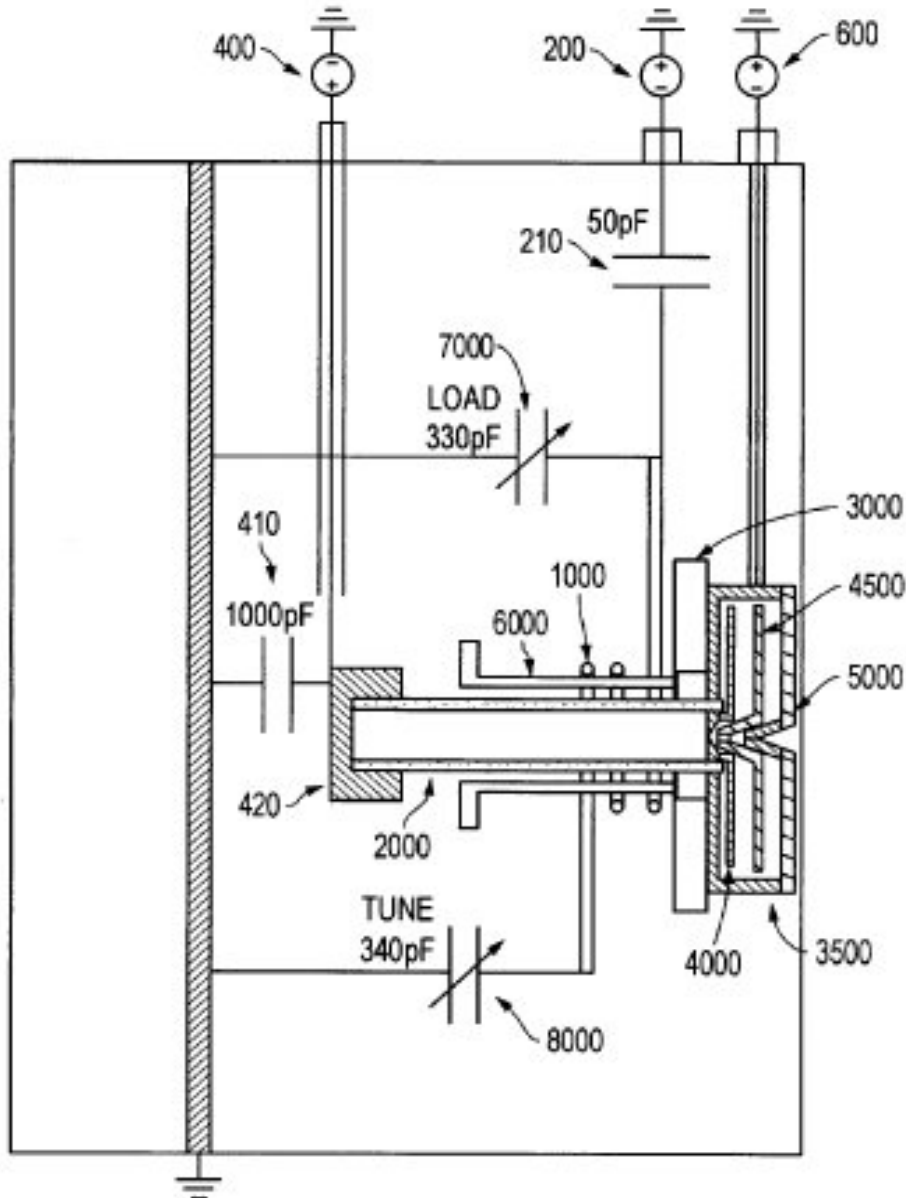
Very reactive elements (SIMS, local chemistry)

Light elements (imaging, analysis)



Current and future FIB Technology

Future of FIB High currents



Patent J. Keller N.Smith et al
(FEI)

Inductively coupled plasma

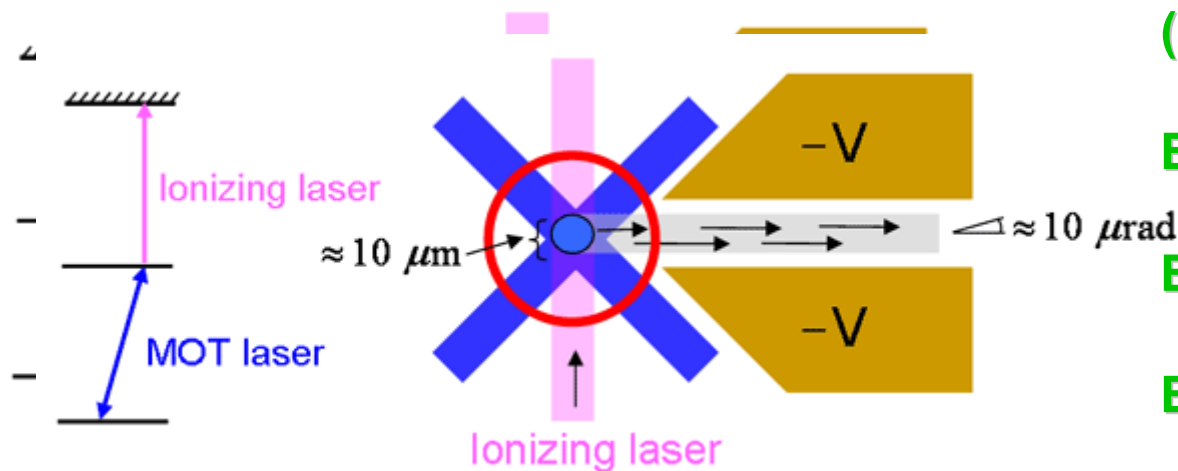
Argon or Xenon (clean FIB)

ΔE 7 eV (Xenon)

Angular intensity $\times 10^3$ LMIS

For $I > 50\text{nA}$ better than LMIS

Magneto optical trap ion source (motis)



Enlarges ion pannel
(reactive & non-reactive)

Extremely low ΔE (0.1eV)

Extremely low divergence

Brightness $> 10^5 \text{A m}^{-2} \text{sr}^{-1} \text{V}^{-1}$

Expensive

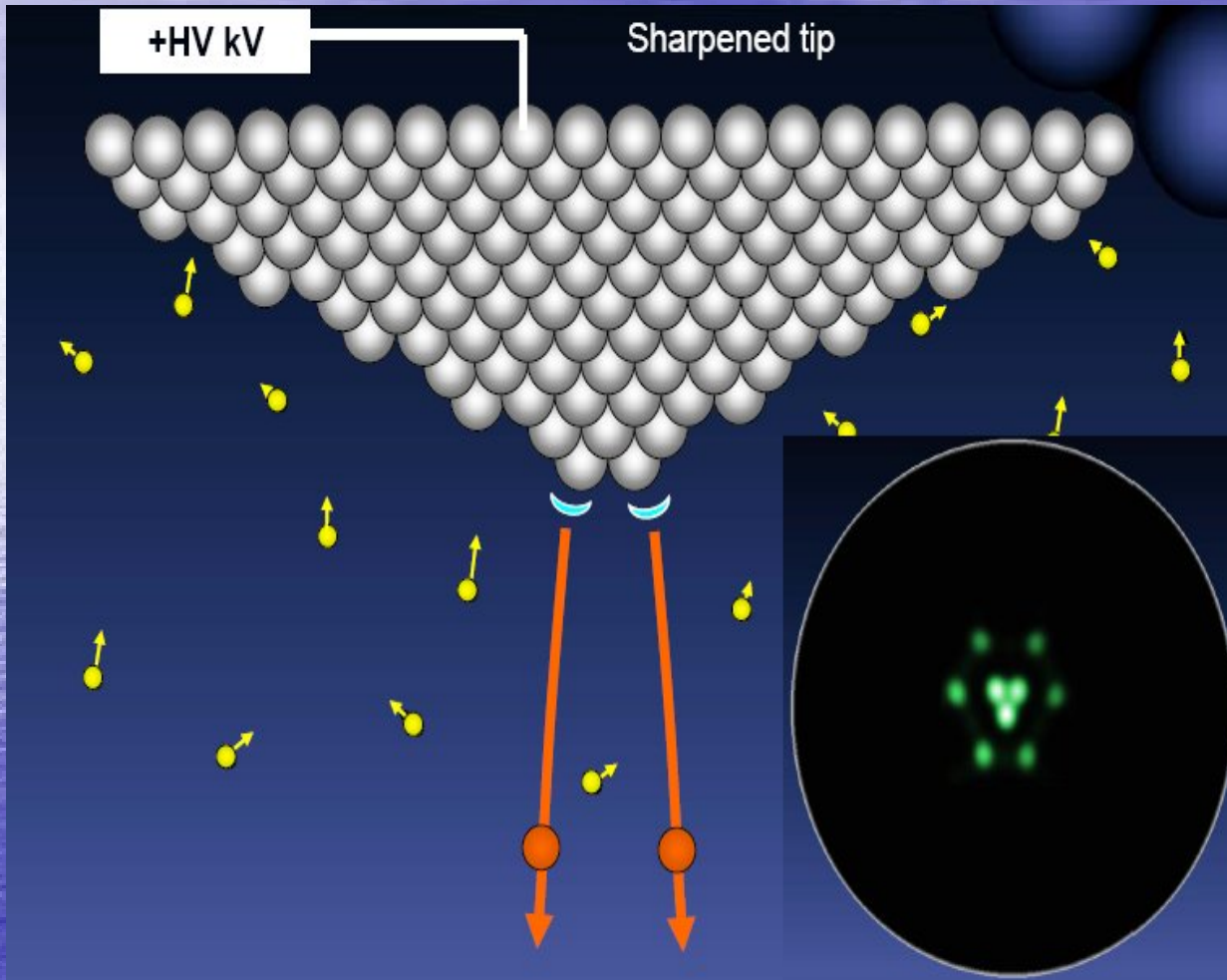
CNST – NIST

Orsay-Physics - Orsay Paris XI Univ.

Dept of Applied Physics Eindhoven Univ.

FEI

Future of FIB GFIS Alis – Zeiss Orion



Very High Brightness

Atomic Virtual Source Size

Low energy spread

Diffraction < SEM

Sub nanometric d

Helium ions

Low current

Limited number ion species

Patented



Microscopic Liquid Ionic Compound Ion Source



*MI.LICIS provides
reactive ions*

Both polarities



High brightness

$$B \approx 10^5 \text{A.cm}^2.\text{sr}^{-1}$$



Olivier Salord
Dr. A. Houel
Dr. Pierre Sudraud

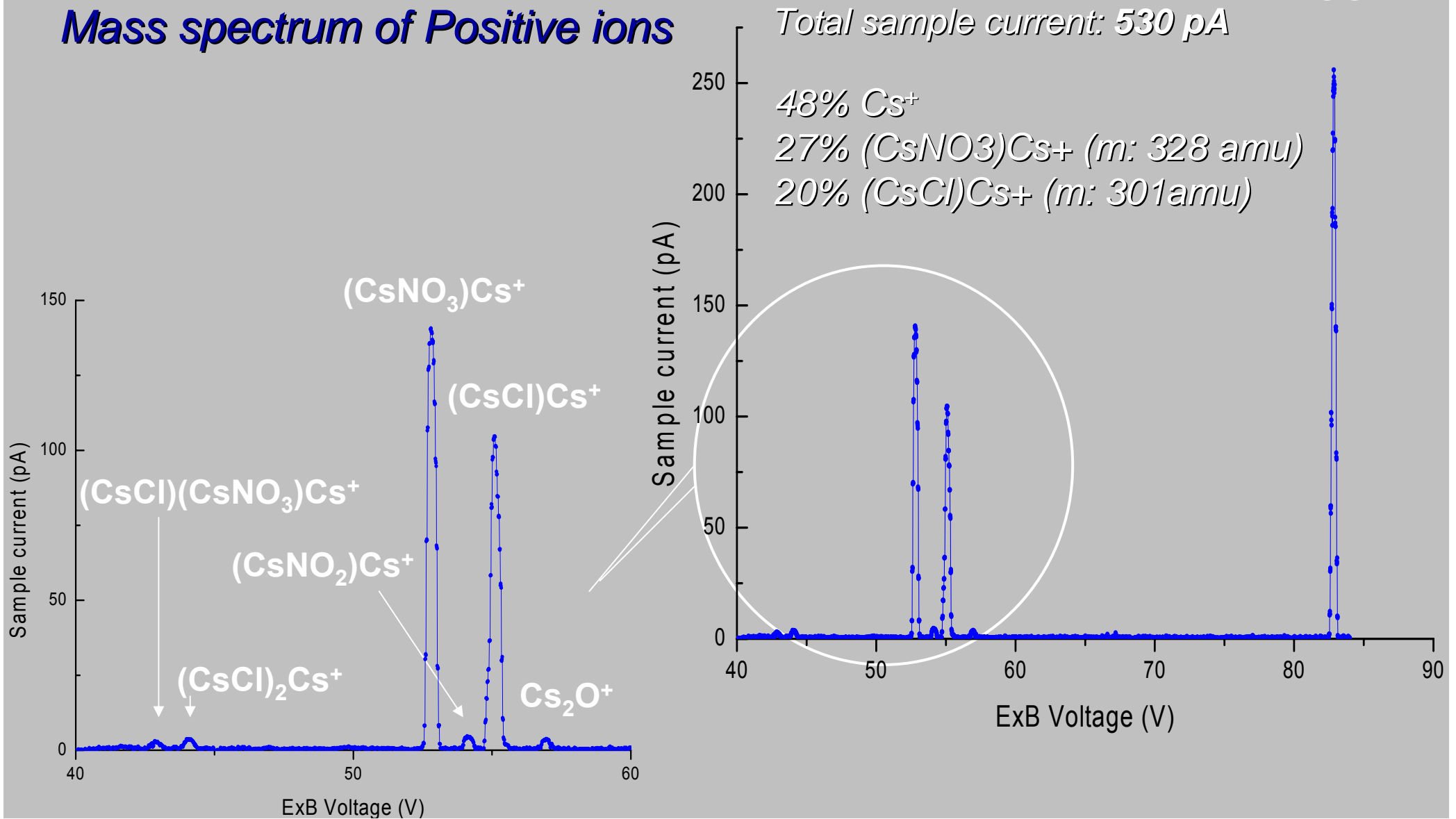
Patented



MI.L.I.C.I.S



Mass spectrum of Positive ions



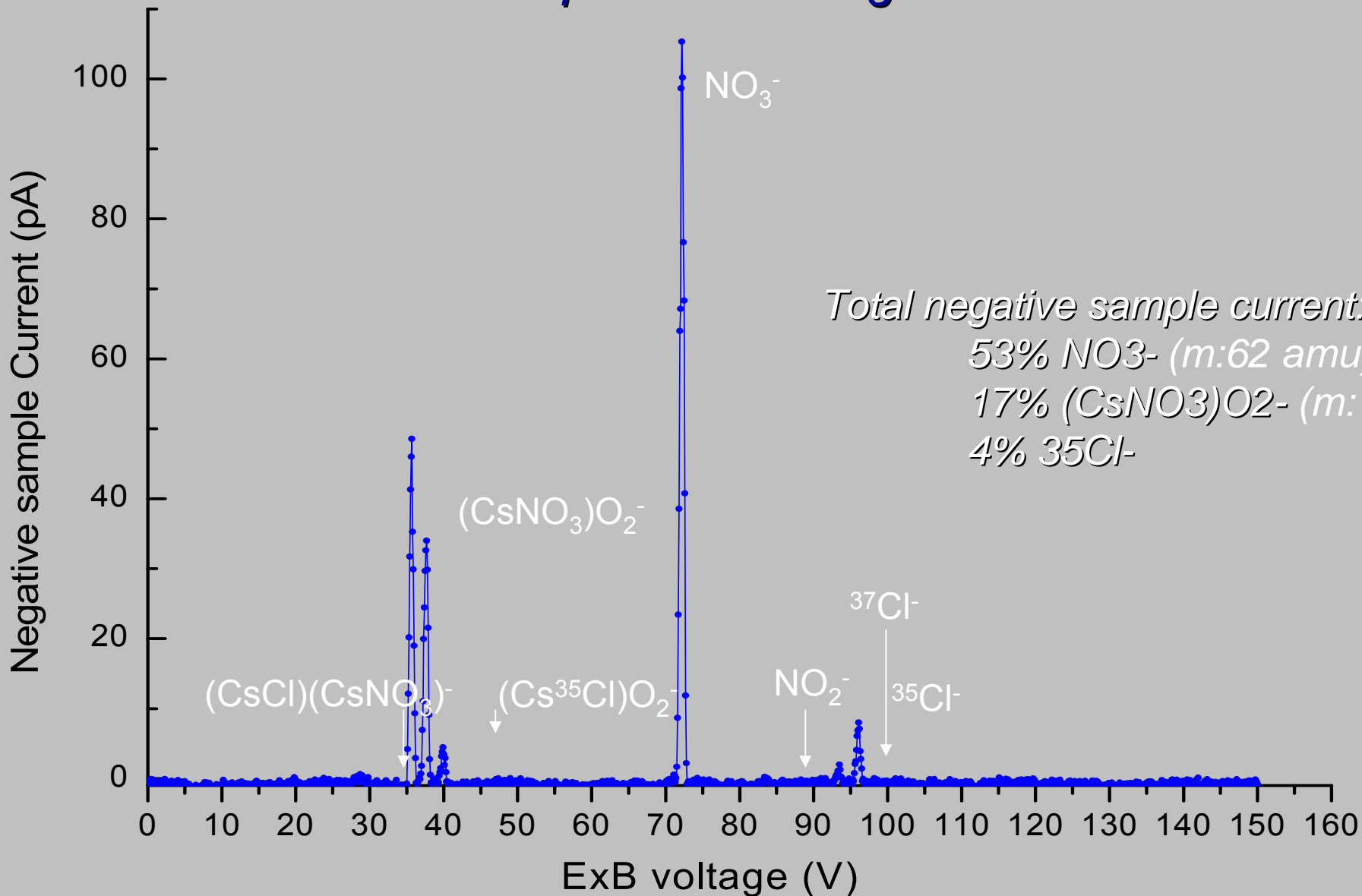
Patented



MI.L.I.C.I.S



Mass spectrum of Negative ions



Total negative sample current: 200 pA
53% NO_3^- (m:62 amu)
17% $(\text{CsNO}_3)\text{O}_2^-$ (m: 227 amu)
4% $^{35}\text{Cl}^-$

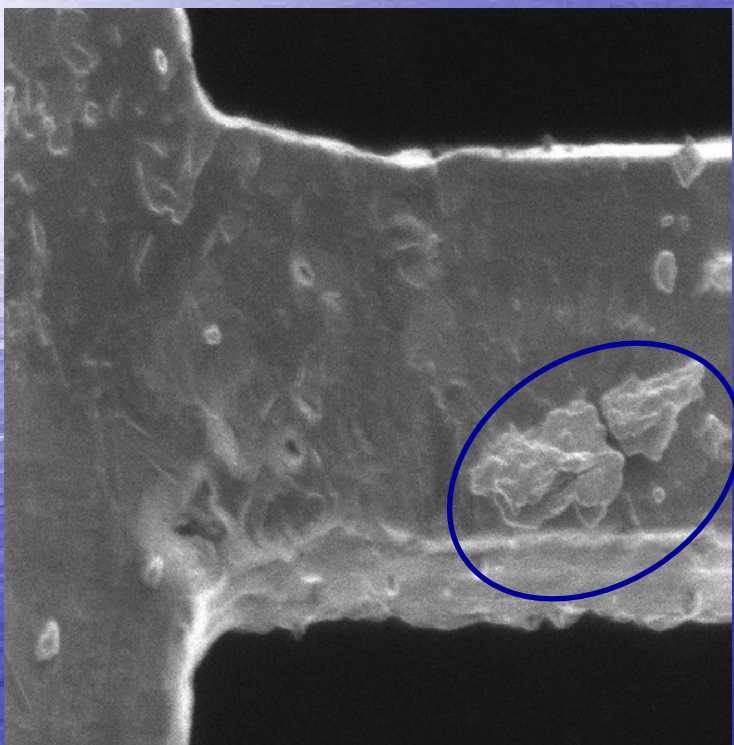
Patented



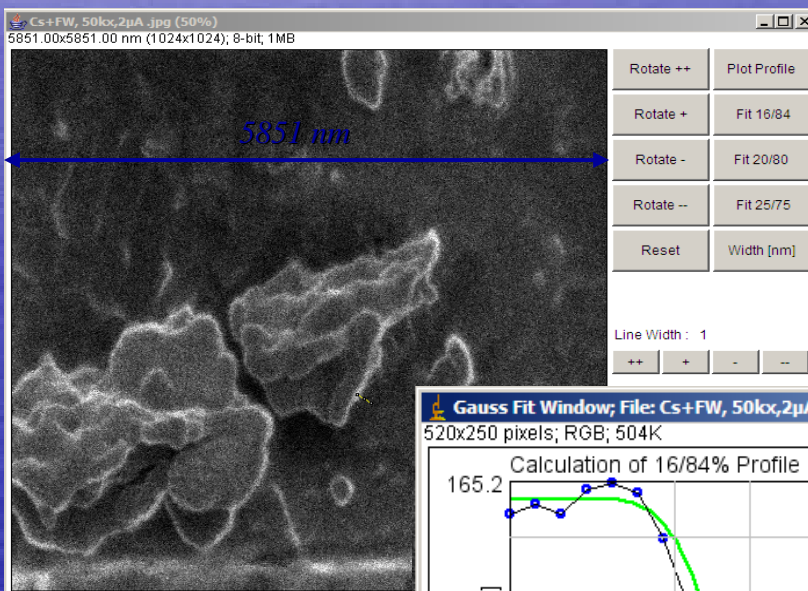
MI.L.I.C.I.S



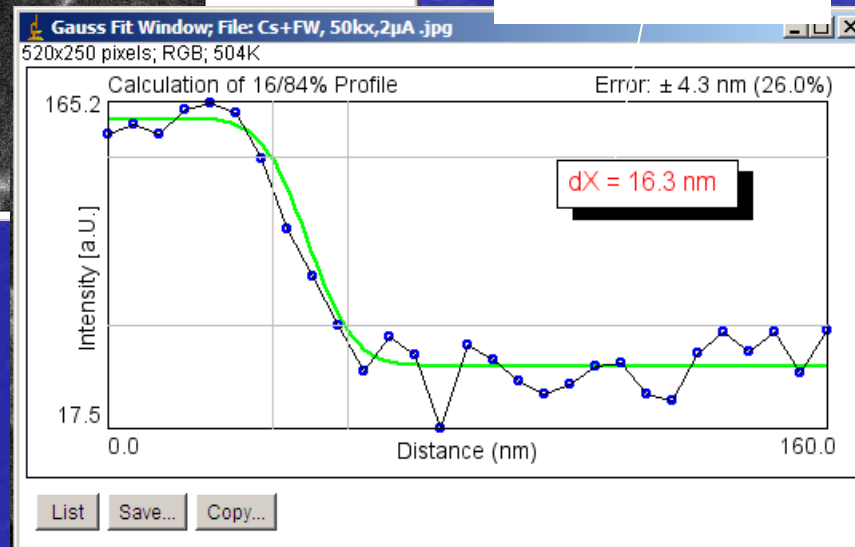
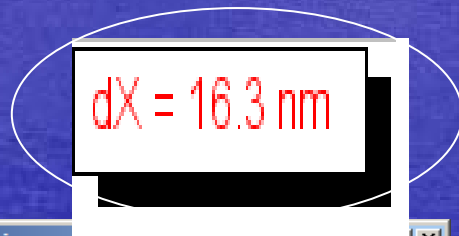
Resolution at **30kV** obtained with experimental setup
Positive ion beam filtered by O.P ExB Wien filter: Cs^+ imaging



Mag 20kx

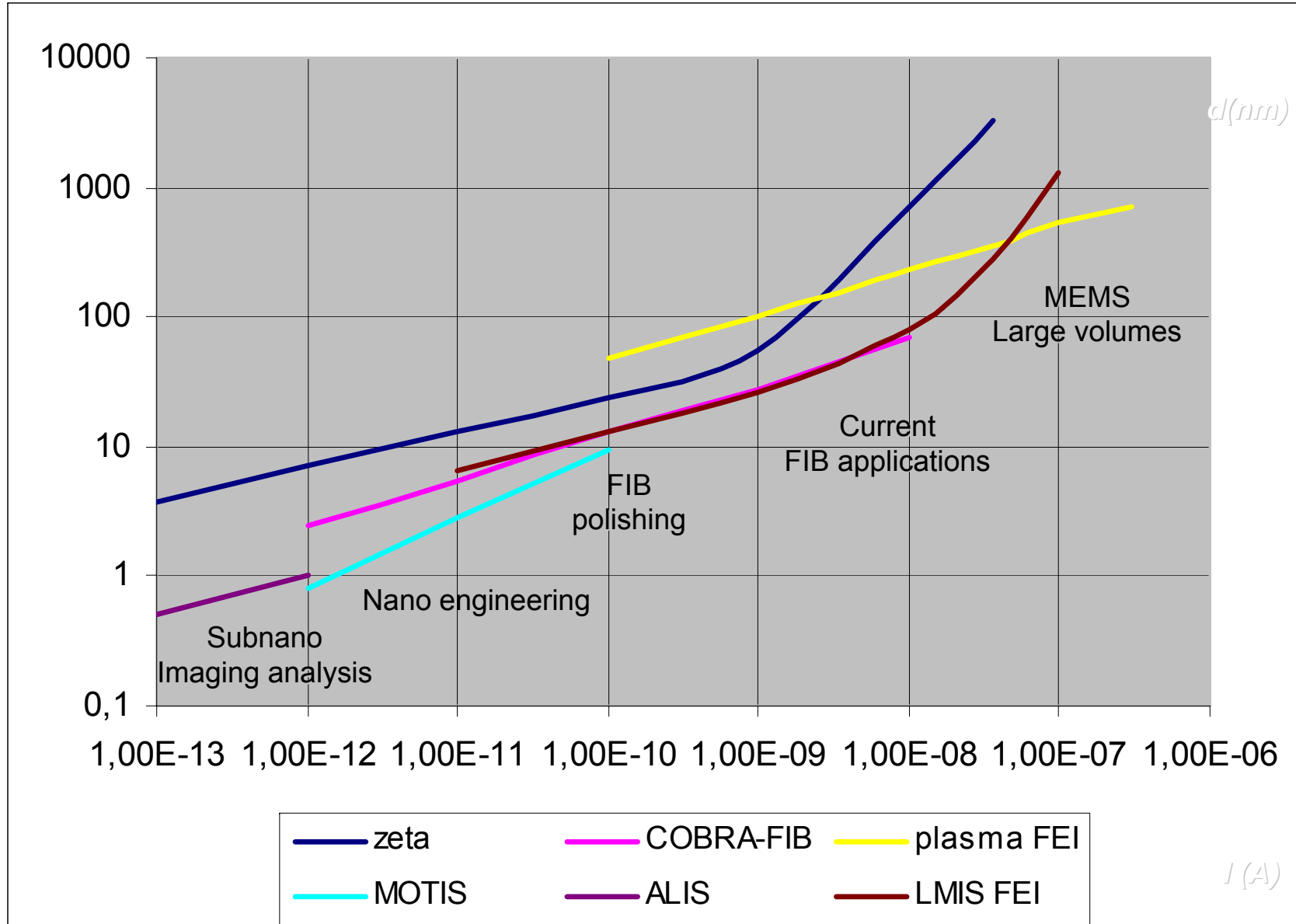


Mag 50kx



Nominal energy: 30kV
Acceptance aperture : 150 μ m, Mass aperture: 20 μ m
 $I_{sample} = 10pA$; $I_{em} = 2\mu A$

Olivier Salord



Current and future FIB Technologies

Prospective of FIB: a panel of complementary technologies ?

ICRF plasma for clean high currents FIB

LMIS FIB could kept many applications

**MOTIS for clean low energy nanometric FIB
MOTIS and MILICIS for HR SIMS**

**GFIS FIB for imaging analysis and assisted
processing at sub-nanometric scale**

Thank you for your attention