

Gallium free FIB and applications

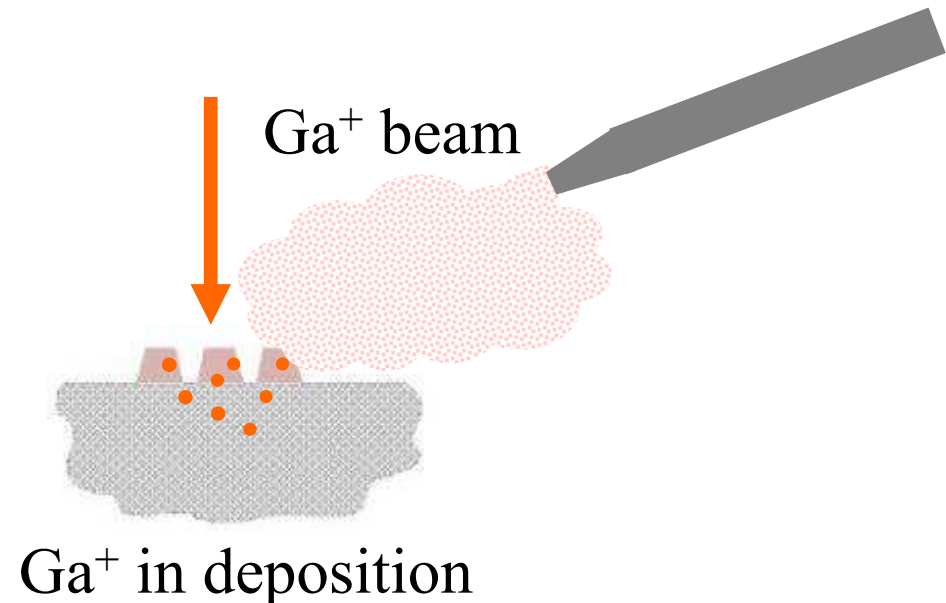
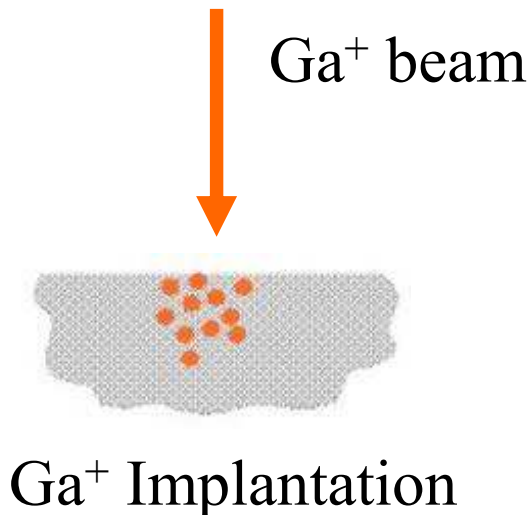
B.Rasser, A.Delobbe

- ⇒ Limitations of conventionnal Ga^+ FIB
- ⇒ Instrumentation
- ⇒ Mass filtered FIB Applications

- ⇒ most FIB use Gallium LMIS

- ⇒ Ga limitations:
 - . contamination (AsGa, InGaAs,...)
 - . large amorphisation effect
 - . medium sputtering efficiency
 - . poor secondary ionization efficiency
 - ...

⇒ Implantation in sample or/and in deposition



modification of :

- electrical properties
- chemical properties
- cristallographic properties (amorphisation)

⇒ drawbacks of Ga can be avoided by using other ions:

- Si^+ , Si^{++} : no dopant effect
- Au_n^+ , Au_n^{++} (clusters) : heavier elements
- and also : Co, Mn, Fe, Ge, Bi....⁽¹⁾

⇒ Ions are created from Alloy Sources

⇒ Need of mass filtering (element, isotope, cluster)

⁽¹⁾ L.Bischof, Rosendorf Institute, Dortmund

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 ⁺

Mass selection on COBRA-FIB

2.5 nm resolution high current spots

Energy range : 1 – 30 kV

Beam current : 1pA – 50 nA

13 motorised aperture positions

Max. current density > 20 A/cm²

Ga source lifetime : 1500 μ A.h



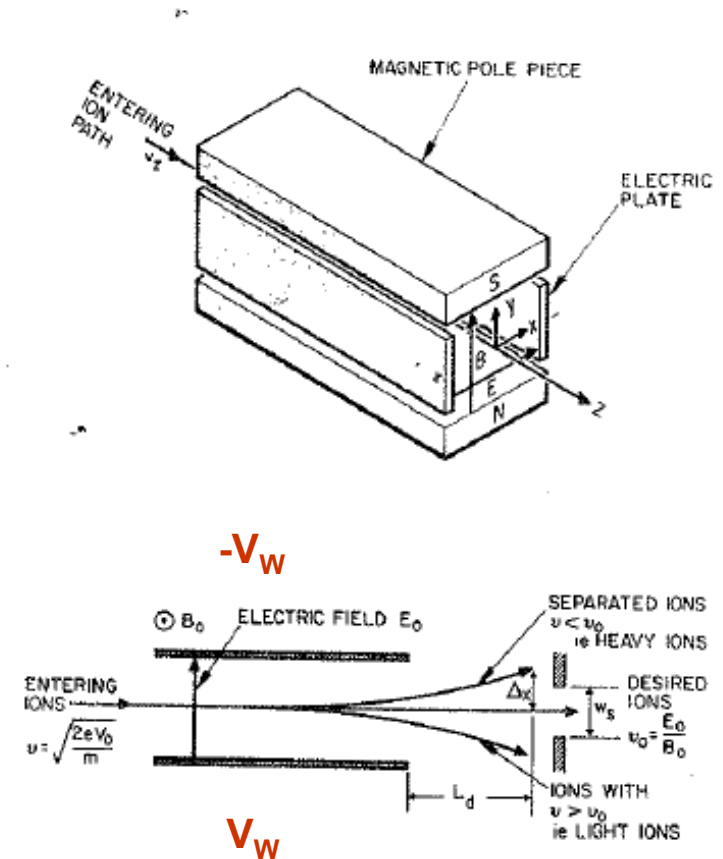
Mass selection by **Wien filter**

$$v = E/B$$

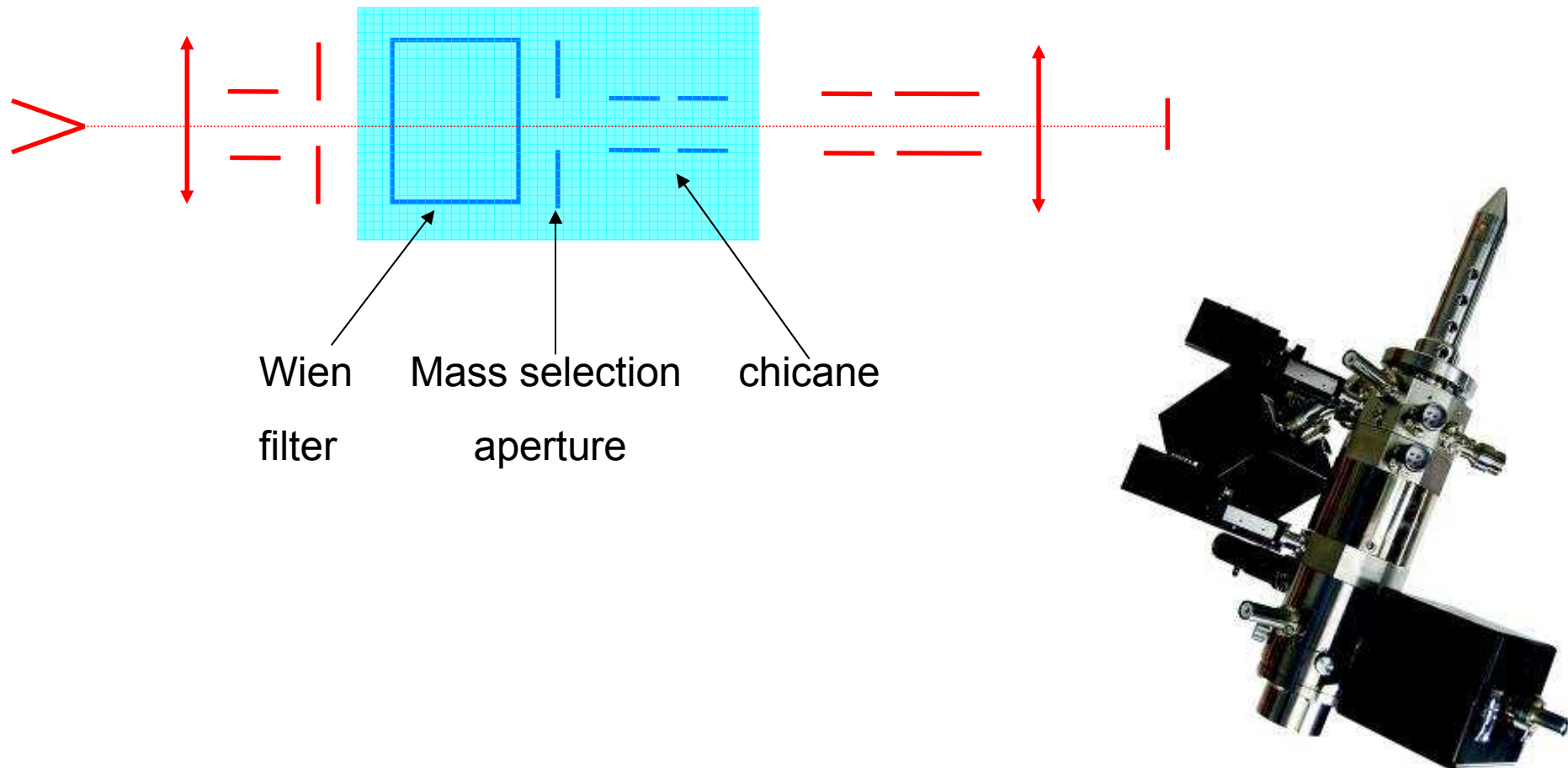
$$m/q = kV_0(I/V_W)^2$$

E or B scan

$$\Delta X = \frac{V_W}{V_0} \frac{L_m}{d} \left(\frac{L_m}{2} + D \right) \frac{dM}{M}$$

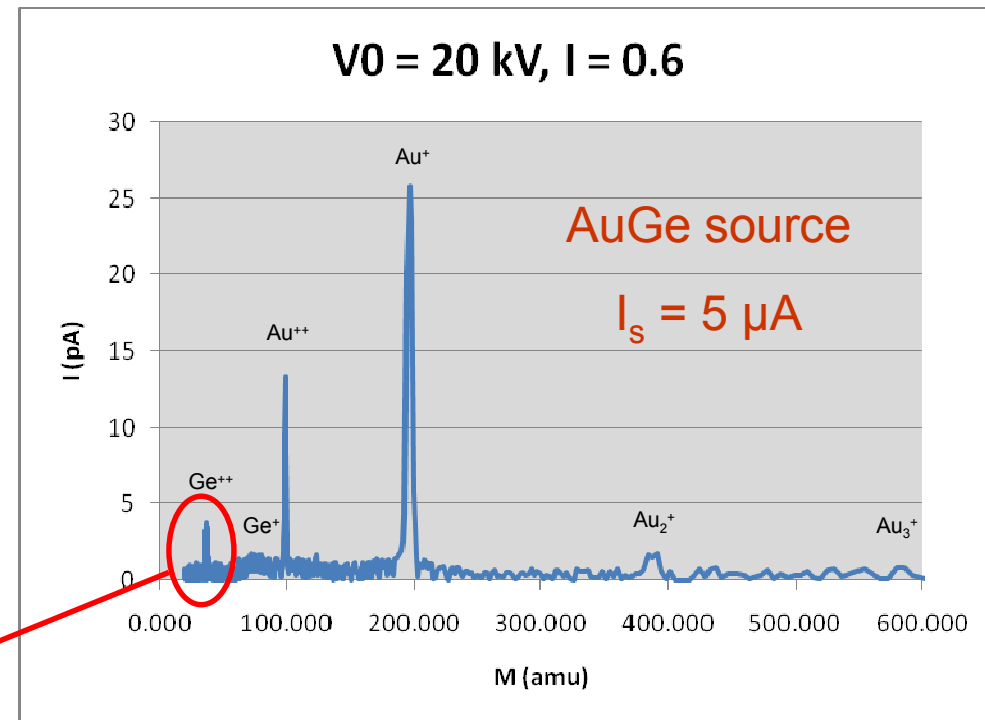
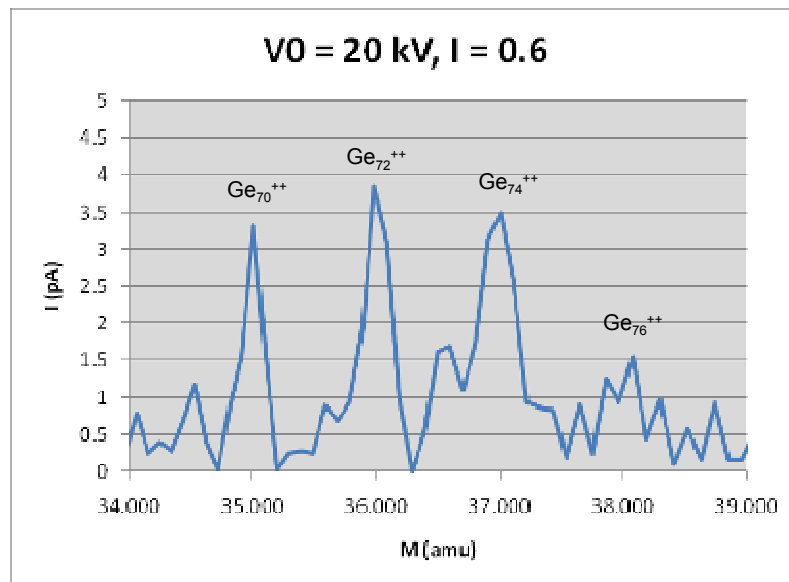


integration of Wien filter in COBRA-FIB:

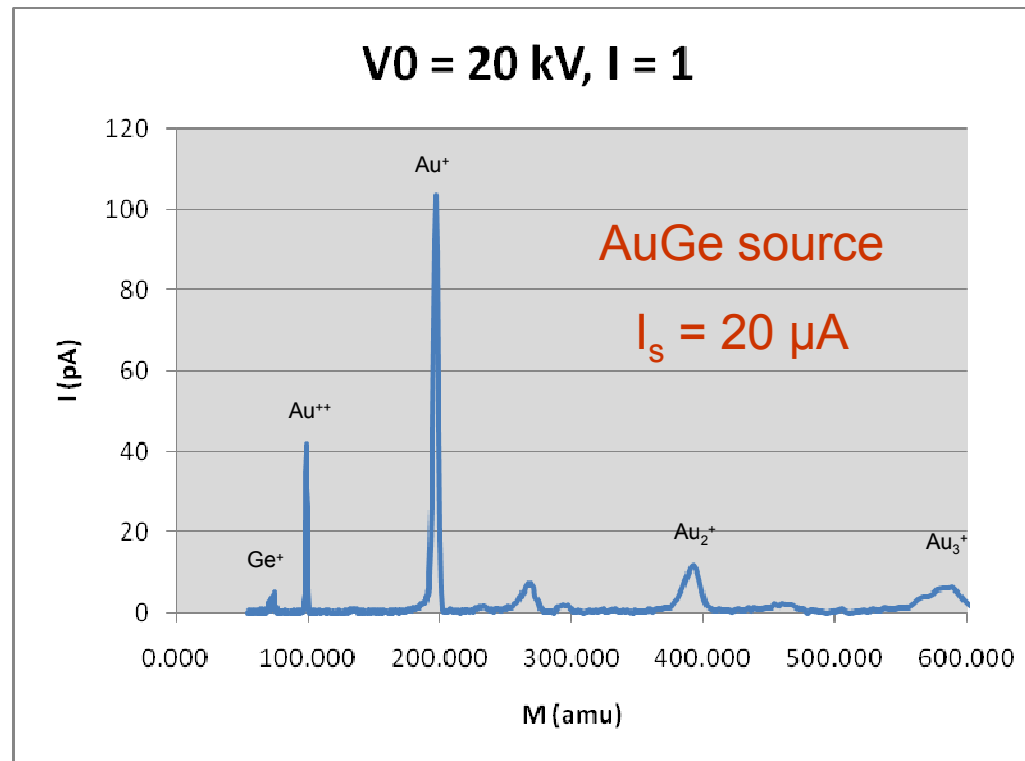


performances: mass range

M_{\max} up to 1000

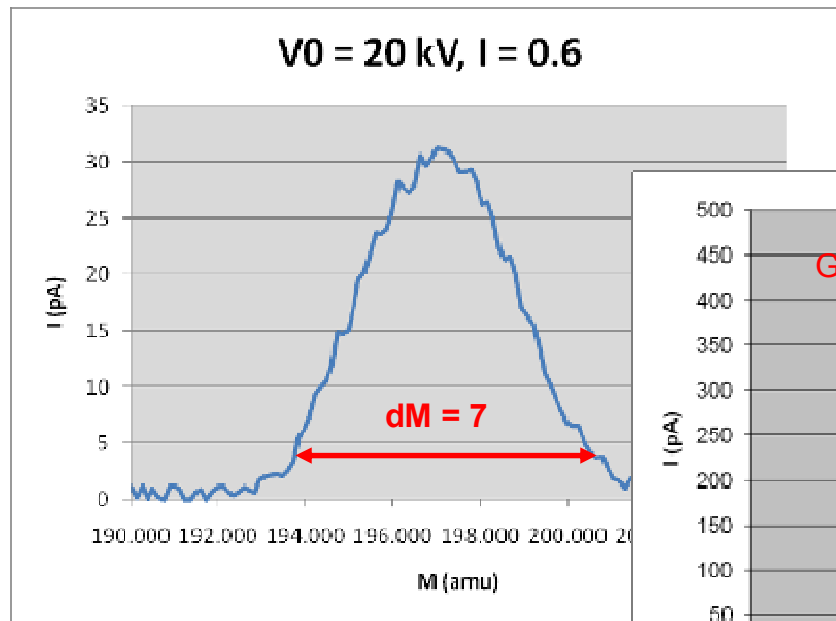


performances: mass range

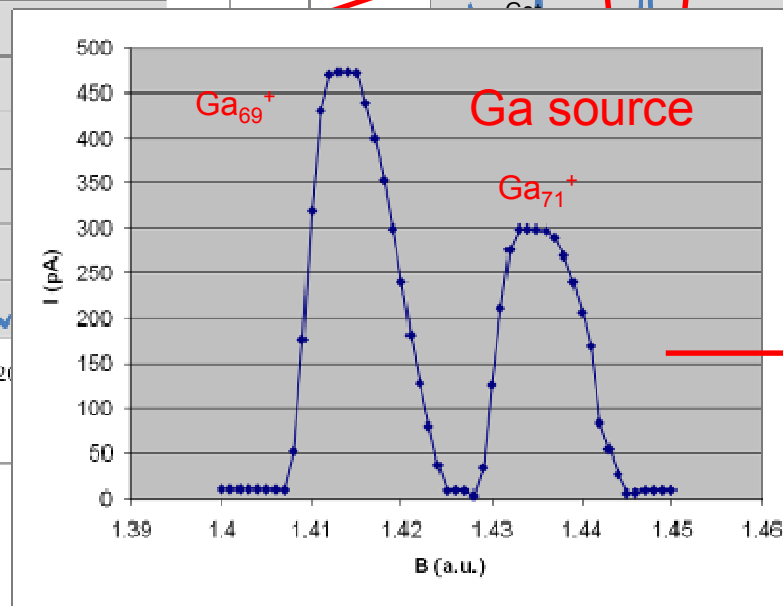
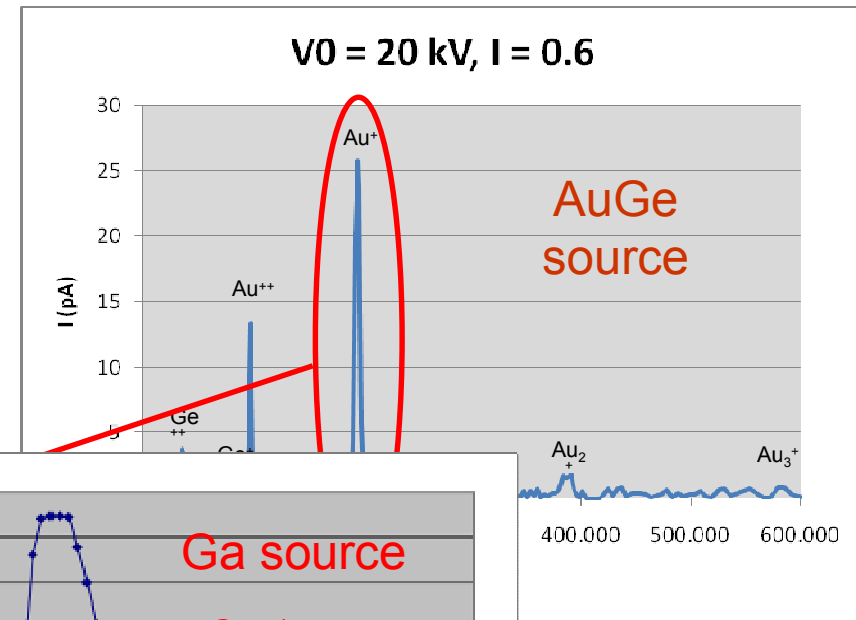


performances: mass resolution

$$R_m (10\%) = M/dM > 50$$



$R_m = 28$

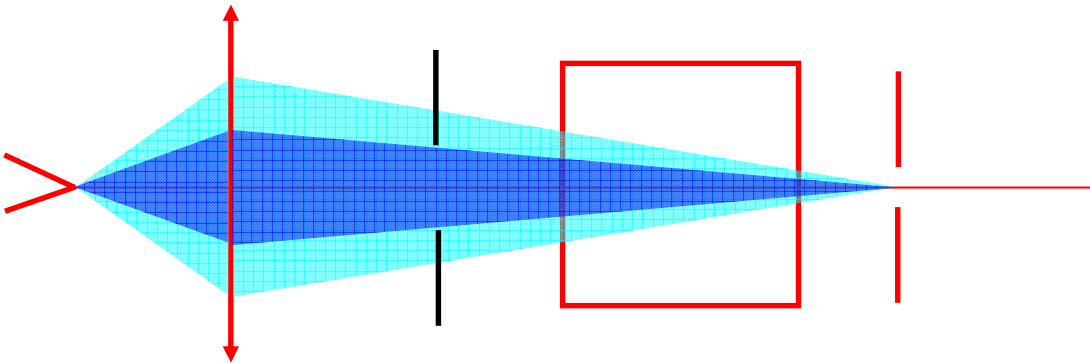


$R_m = 52$

performances: current range

from 6 pA to 40 nA

(Ga 30 kV)



probe aperture diameter (μm)	probe current (pA)
10	6
20	26
30	58
50	162
100	648
200	2591
400	10364
600	23319
800	41455

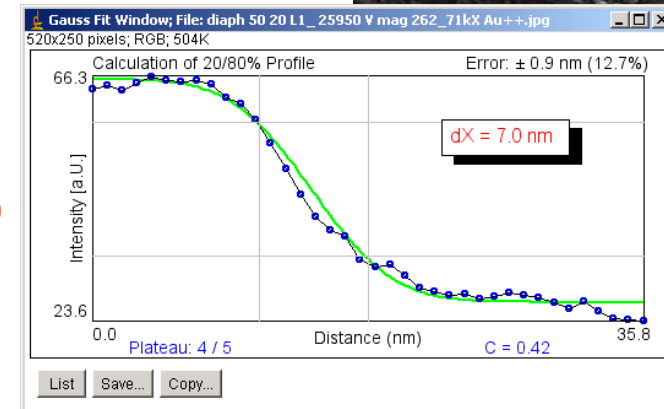
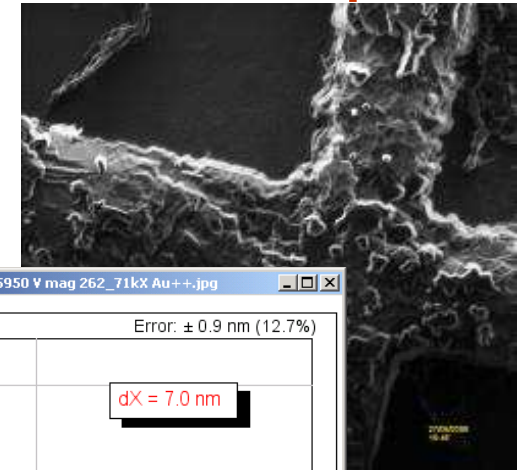
performances: lateral resolution

⇒ resolution with mass filtered
COBRA-FIB for AuSi source

Si beam < 10 nm at $I > 10$ pA (20-80 %)
Au beam < 10 nm at $I > 10$ pA (20-80 %)

⇒ *Filter OFF Ga⁺ source*

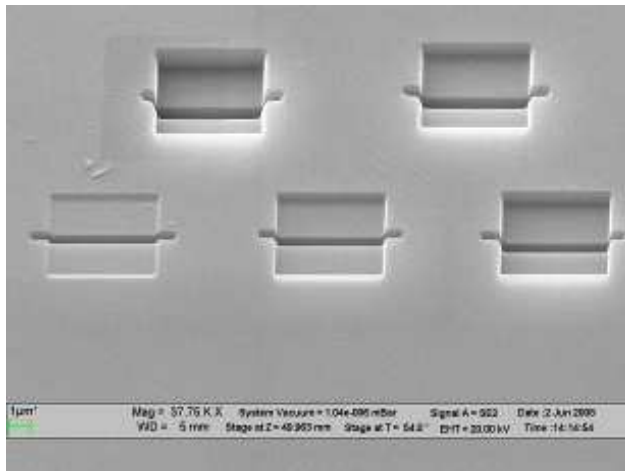
FOV : 26 μ m



<i>I probe</i>	<i>1 pA</i>	<i>10 pA</i>	<i>50 pA</i>
<i>Image resolution (20-80 %)</i>	<i><< 5.0 nm</i>	<i>15 nm</i>	<i>30 nm</i>

⇒ Sputtering rate :

Example of Au beam on Si sample (30 kV) / incidence angle : 90°

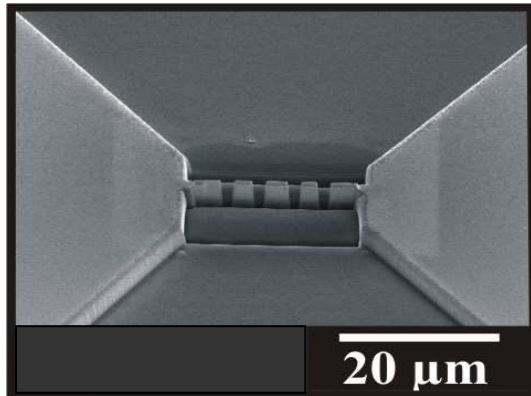


- ⇒ Au^+ : 5.2 atoms/ion ($0.63 \mu\text{m}^3/\text{nA.s}$)
- ⇒ Au^{++} : 5.6 atoms/ion ($0.70 \mu\text{m}^3/\text{nA.s}$)
- ⇒ Au_2^+ : 9.5 atoms/ion ($1.19 \mu\text{m}^3/\text{nA.s}$)

For comparison :

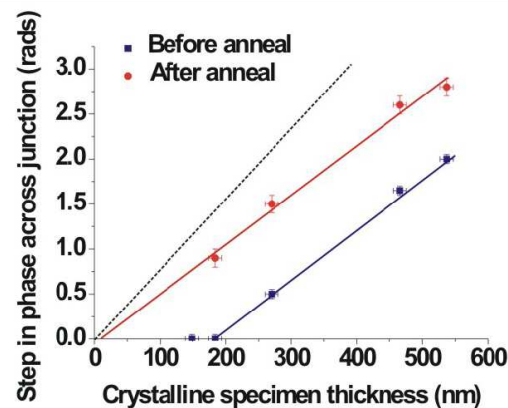
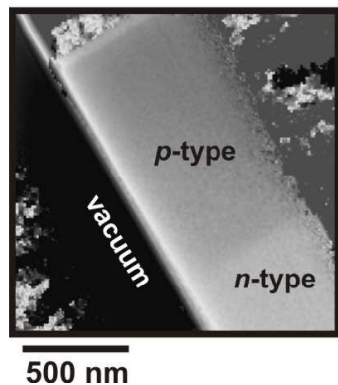
Ga^+ 30 kV : 2.2 atoms/ion ($0.26 \mu\text{m}^3/\text{nA.s}$)

⇒ preparation of samples for off-axis electron holography (mapping of dopant concentration) G. BenAssayag et al., MNE 2009



Amorphous surface layer
⇒ Low energy ion beam
⇒ interest of low energy performances of wien filter cobra FIB

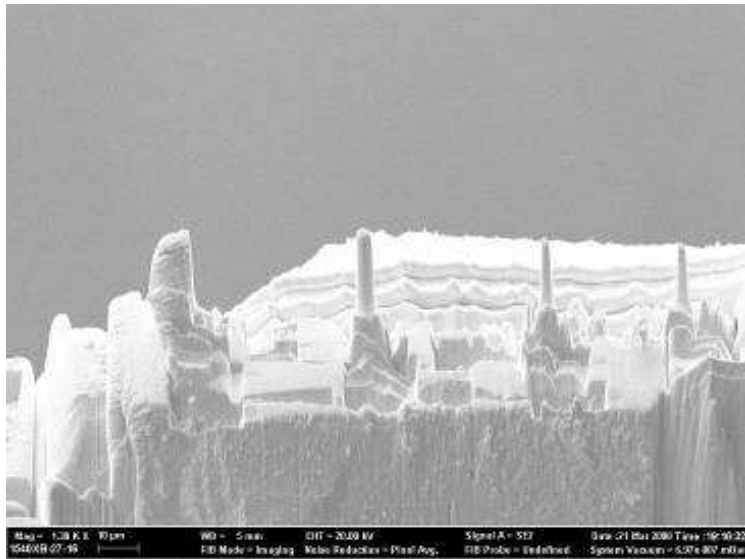
near-surface electrically inactive region
⇒ annealing at low temperature



Gallium is a dopant in silicon
⇒ Use of Silicon ion beam

⇒ Micro-compression tests of Gold single crystal micropillars

- pillars oriented along their $\langle 123 \rangle$ axis, diameters from 1 to 3 microns



⇒ Ga FIB Milling for pillars fabrication



- high dislocation density near the surface
- but also : Ga implantation, amorphisation, intermetallic formation...(Appl.Phys. Lett 91, 111915 (2007))



Modification of mechanical properties

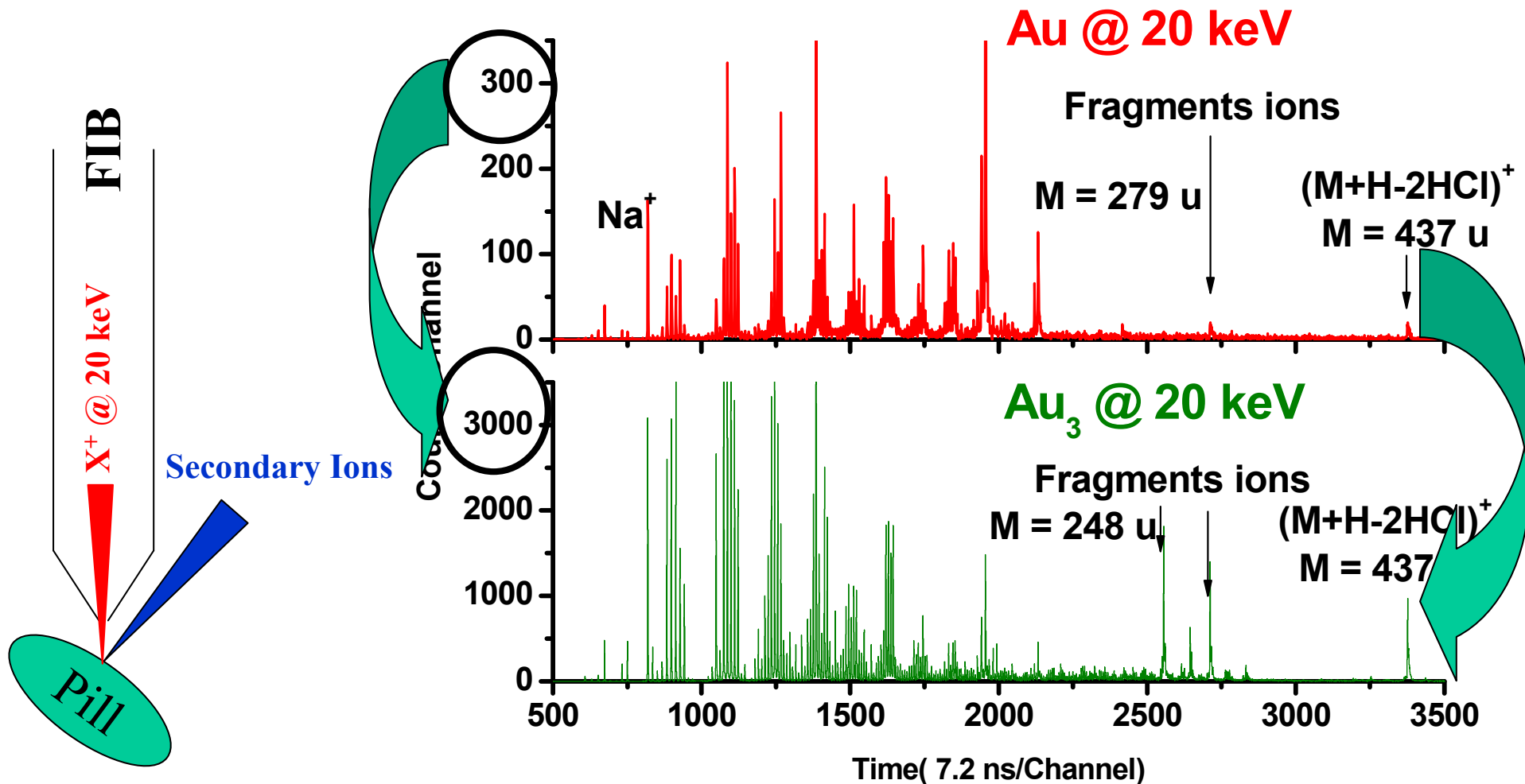
- M. Legros CEMES (filtered Orsay Physics column in Toulouse)
- Swiss light source (Paul Scherrer Institut synchrotron).

⇒ Experiment (under study) of Gold FIB Milling

MASS FILTERED FIB Applications

analysis: advantage of a FIB with Wien Filter mass selection for ToF Mass Spectrometry

S.Della Nagra, B.Rasser, J.P.Thomas: to be published



- ⇒ mass filtered column to avoid Ga inconvenients in FIB applications
- ⇒ integration of Wien Filter in COBRA-FIB
- ⇒ excellent performances
 - . mass resolution
 - . current range
 - . lateral resolution
- ⇒ extended fields of application

thank you