Gallium free FIB and applications

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Outline

⇨ Limitations of conventionnal Ga^+ FIB

⇨ Instrumentation

⇨ Mass filtered FIB Applications

Limitations of Ga FIB

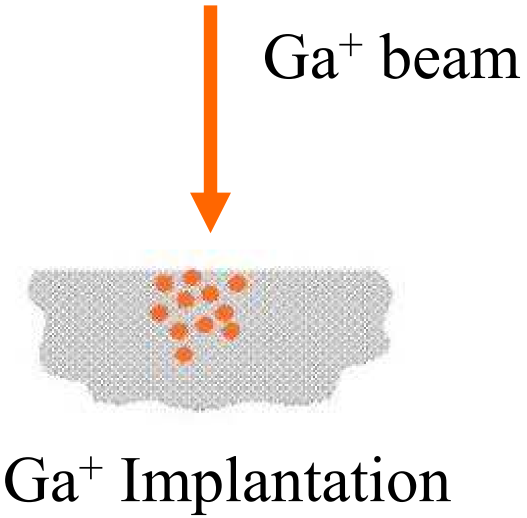
⇨ most FIB use Gallium LMIS

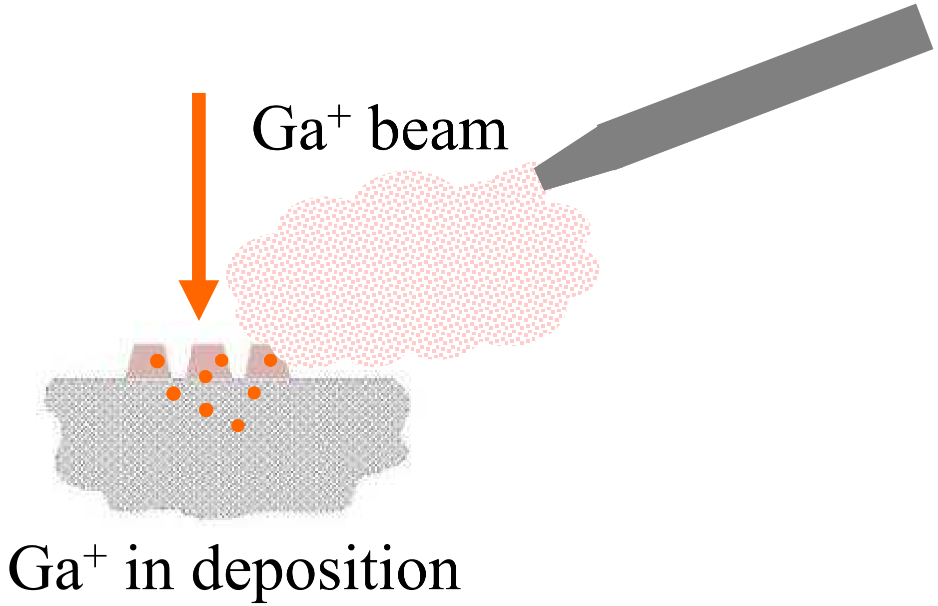
⇨ Ga limitations:

. contamination (AsGa, InGaAs,…)
. large amorphisation effect
. medium sputtering efficiency
. poor secondary ionization efficiency
…

Limitations of Ga FIB

⇨ Implantation in sample or/and in deposition





modification of :

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

Limitations of Ga FIB

⇨ 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

NANOSOLUTIONS by ORSAYPHYSICS

Limitations of Ga FIB

Non-exhaustive list of LMIS and LMAIS

Prof. A.Wieck - RUB

Other alloys, such as

AuSi, AuGe, GaBi, GaBiLi,

AsPdB, 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	$Ni^{++}, Ni^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
5	AuCeSi	$Si^{++}, Si^{+}, Ce^{+++}, Ce^{++}, Ce^{+}, Au^{++}, Au^{+}, Au_2^{+}$
6	AuCoGe	$Co^{++}, Co^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
7	AuCrGe	$Cr^{++}, Cr^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
8	AuDyGe	$Ge^{++}, Ge^{+}, Dy^{+++}, Dy^{++}, Au^{++}, Au^{+}, Au_2^{+} AuGe^{+}$
9	AuDySi	$Si^{++}, Si^{+}, Dy^{+++}, Dy^{++}, Au^{++}, Au^{+}, Au_3^{++}, Au_2^{+}$
10	AuErSi	$Si^{++}, Si^{+}, Er^{+++}, Er^{++}, Au^{++}, Au^{+}, Au_2^{+}$
11	AuEuSi	$Si^{++}, Si^{+}, Eu^{++}, Au^{++}, Au^{+}, Au_2^{+}$
12	AuFeGe	$Fe^{++}, Fe^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
13	AuGdSi	$Si^{++}, Si^{+}, Gd^{+++}, Gd^{++}, Au^{++}, Au^{+}, Au_2^{+}$
14	AuGeMn	$Mn^{++}, Mn^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, AuGe^{+}, Au_2^{+}, Au_2Ge^{+}$
15	AuGeNi	$Ni^{++}, Ni^{+}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
16	AuGeV	$V^{++}, Ge^{++}, Ge^{+}, Au^{++}, Au^{+}, Au_2^{+}, AuGe^{+}, Au_2Ge^{+}$
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

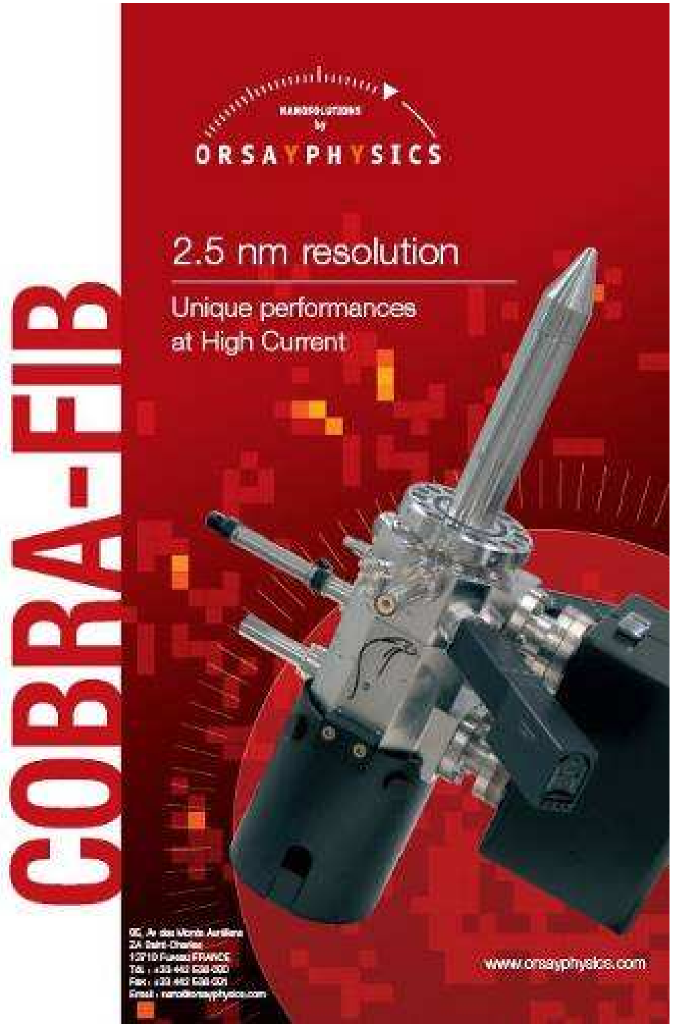
Energy range : 1 – 30 kV

Beam current : 1pA – 50 nA

13 motorised aperture positions

Max. current density > 20 A/cm^2

Ga source lifetime : 1500 µA.h



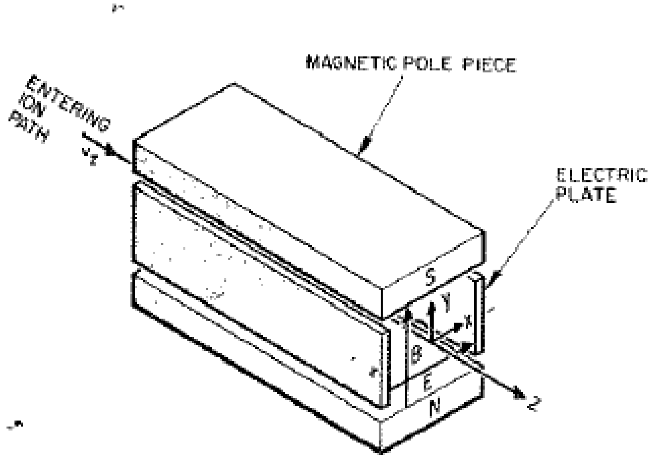
Mass selection by **Wien filter**

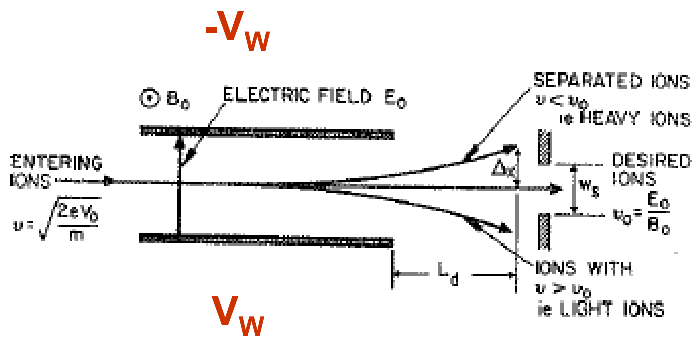
$v = E/B$

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

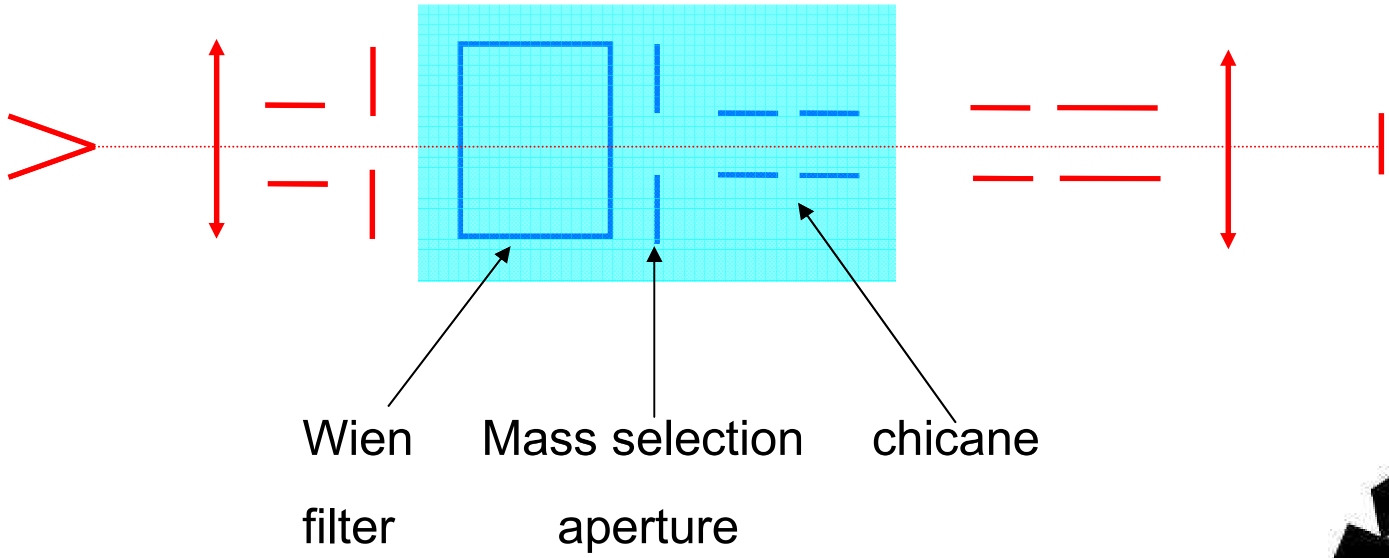
E or B scan

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



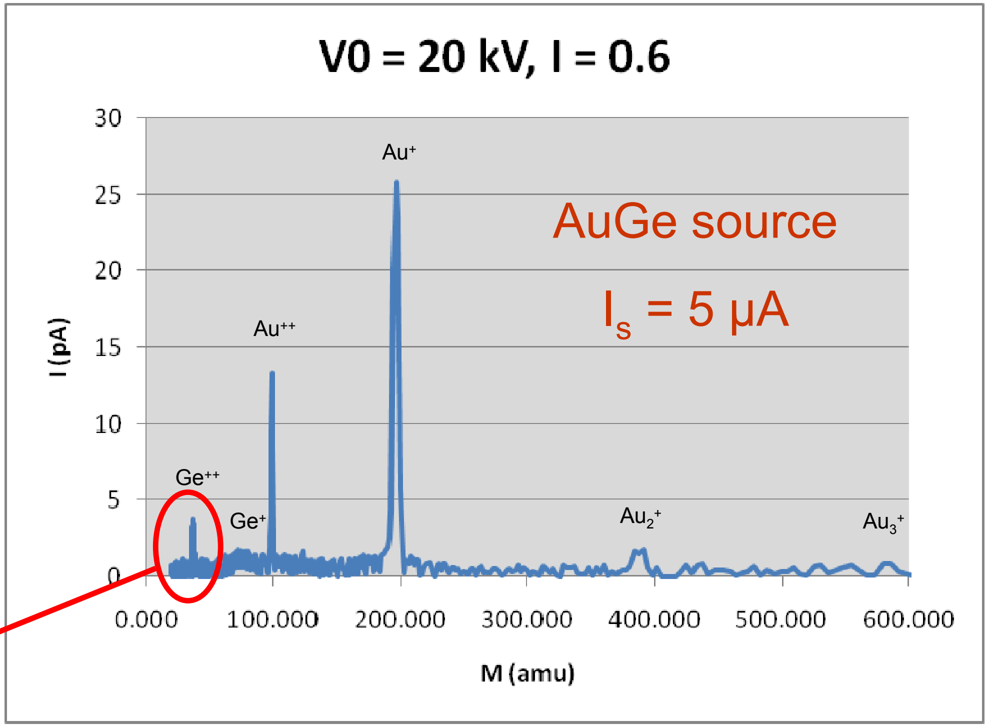


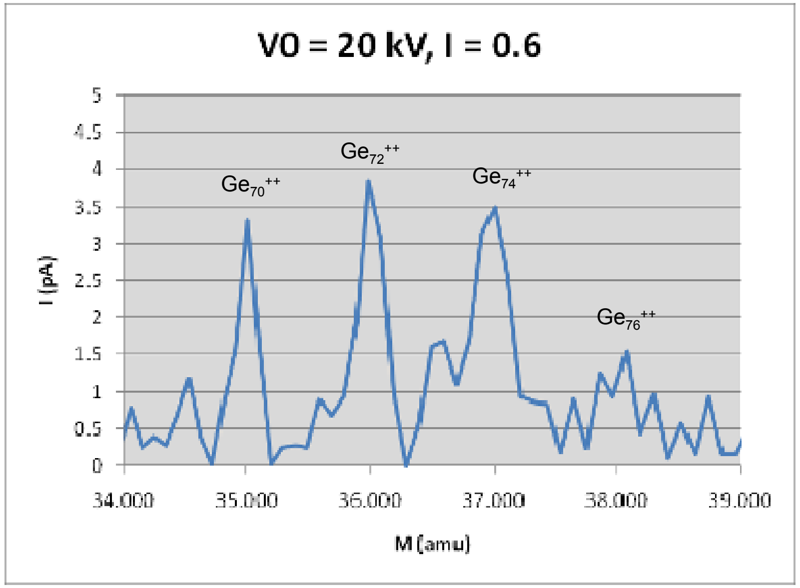
integration of Wien filter in COBRA-FIB:



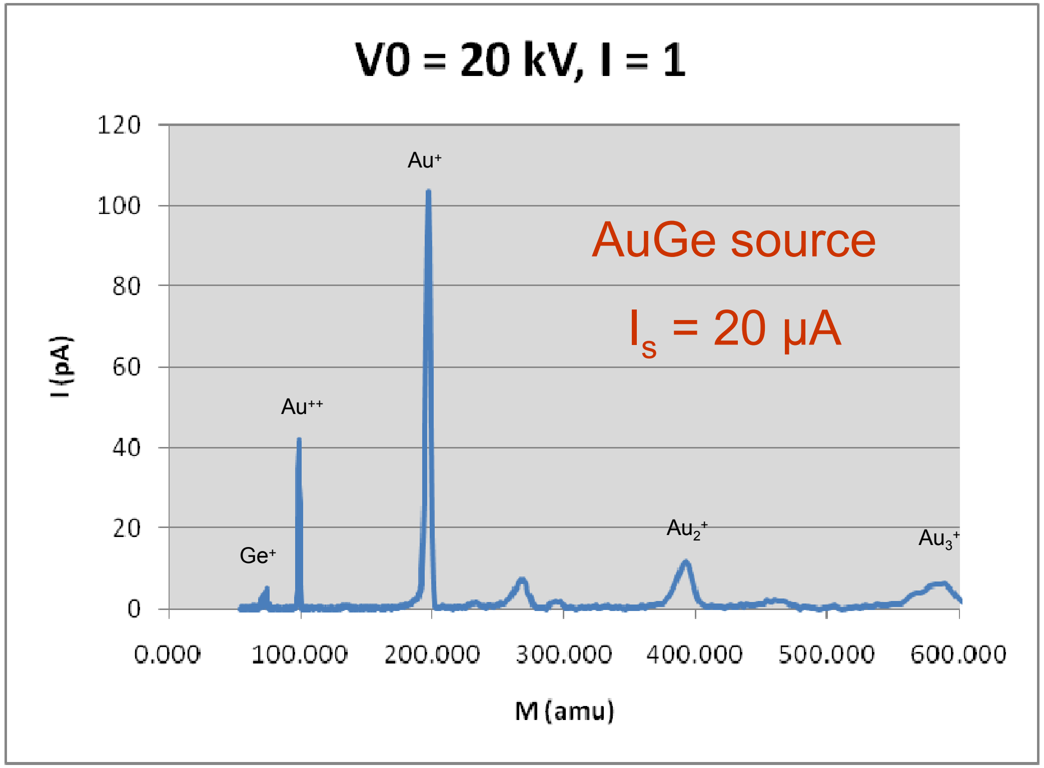
performances: mass range

M_{max} up to 1000



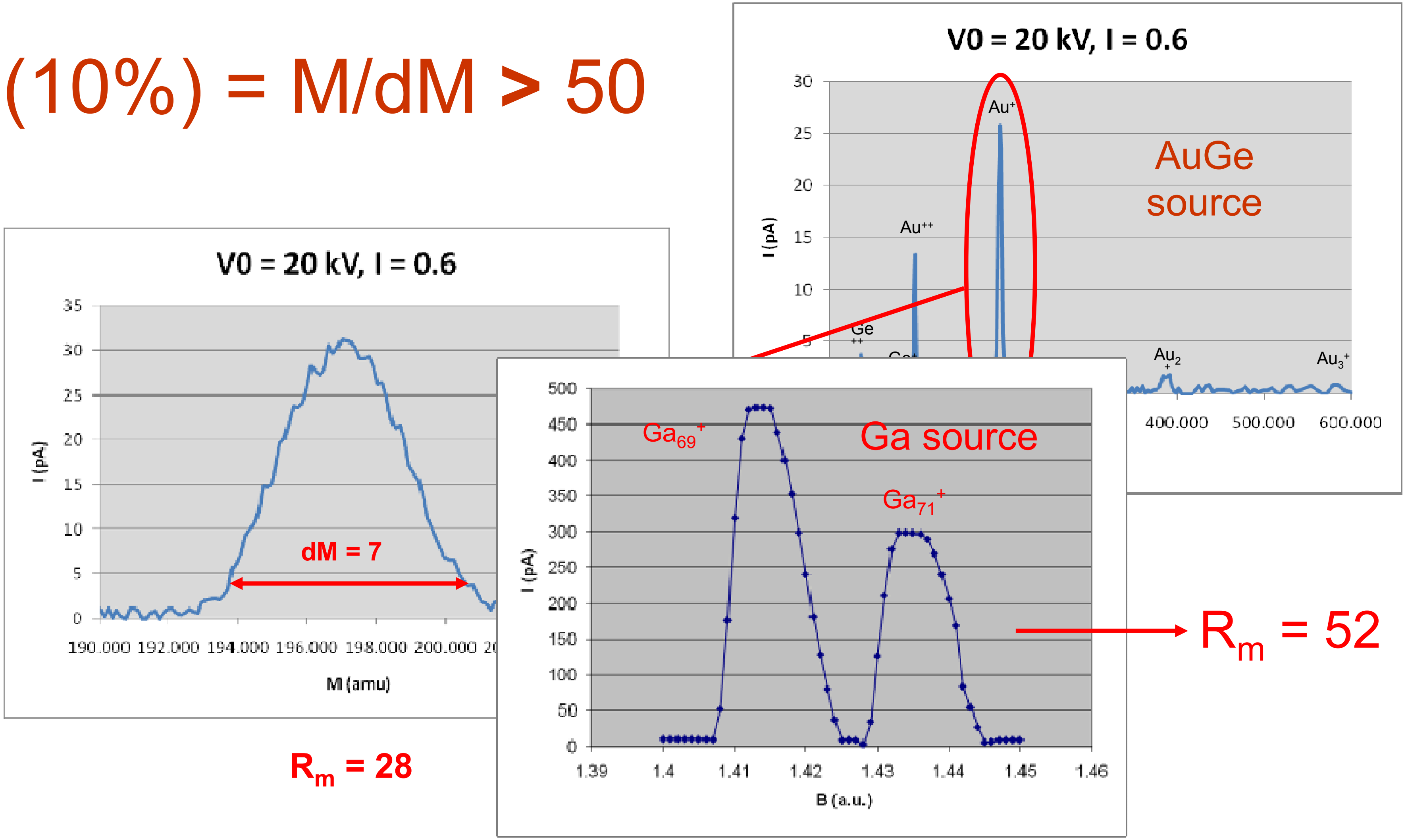


performances: mass range



performances: mass resolution

R_m (10%) = M/dM > 50



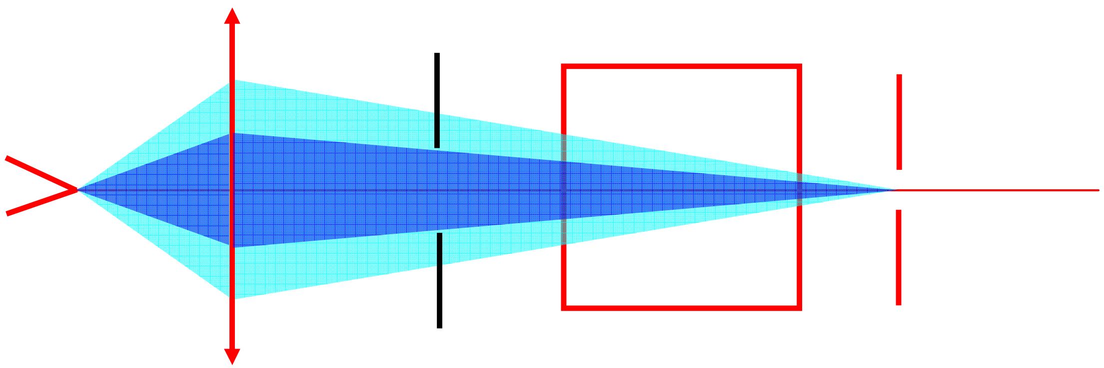
R_m = 52

R_m = 28

performances: current range

from 6 pA to 40 nA

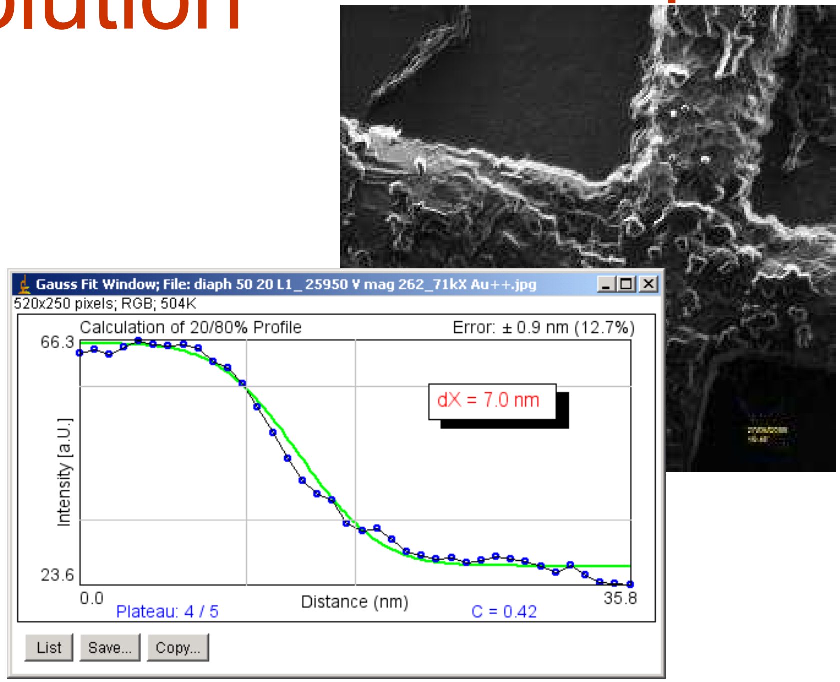
(Ga 30 kV)



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

FOV : 26 µm



➪ resolution with mass filtered COBRA-FIB for AuSi source

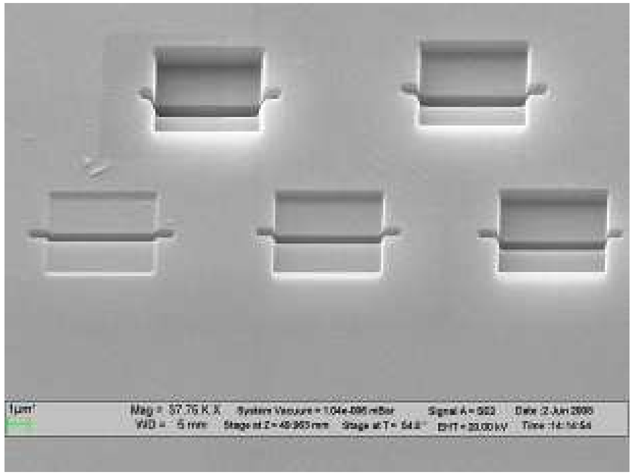
Si beam < 10 nm at I > 10 pA (20-80 %)
Au beam < 10 nm at I > 10pA (20-80 %)

➪ *Filter OFF Ga^+ source*

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

⇨ Sputtering rate :

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

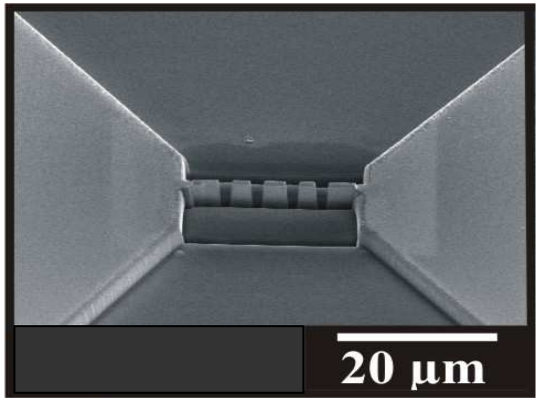


⇨ Au^{+} : 5.2 atoms/ion (0.63 μm^3/nA.s)
⇨ Au^{++} : 5.6 atoms/ion (0.70 μm^3/nA.s)
⇨ Au_2^{+} : 9.5 atoms/ion (1.19 μm^3/nA.s)

For comparison :
Ga^{+} 30 kV : 2.2 atoms/ion (0.26 μm^3/nA.s)

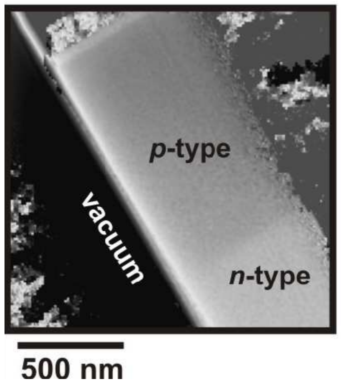
MASS FILTERED FIB Applications

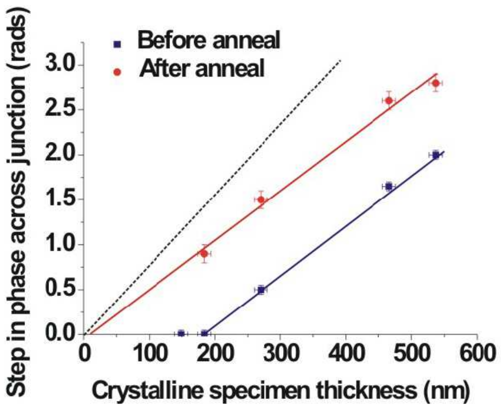
⇨ preparation of samples for off-axis electron holography (mapping of dopant concentration) G. BenAssayag et al., MNE 2009



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

MASS FILTERED FIB Applications

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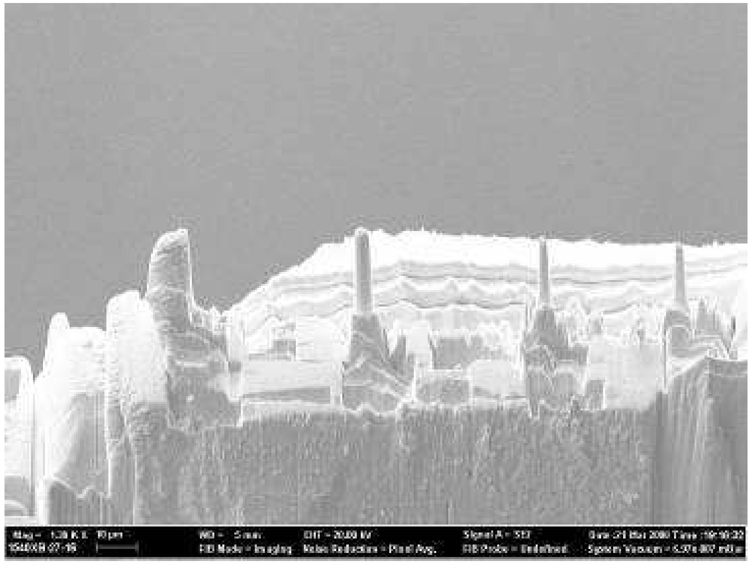
⇨ Micro-compression tests of Gold single crystal micropillars

- pillars oriented along their <123> 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).

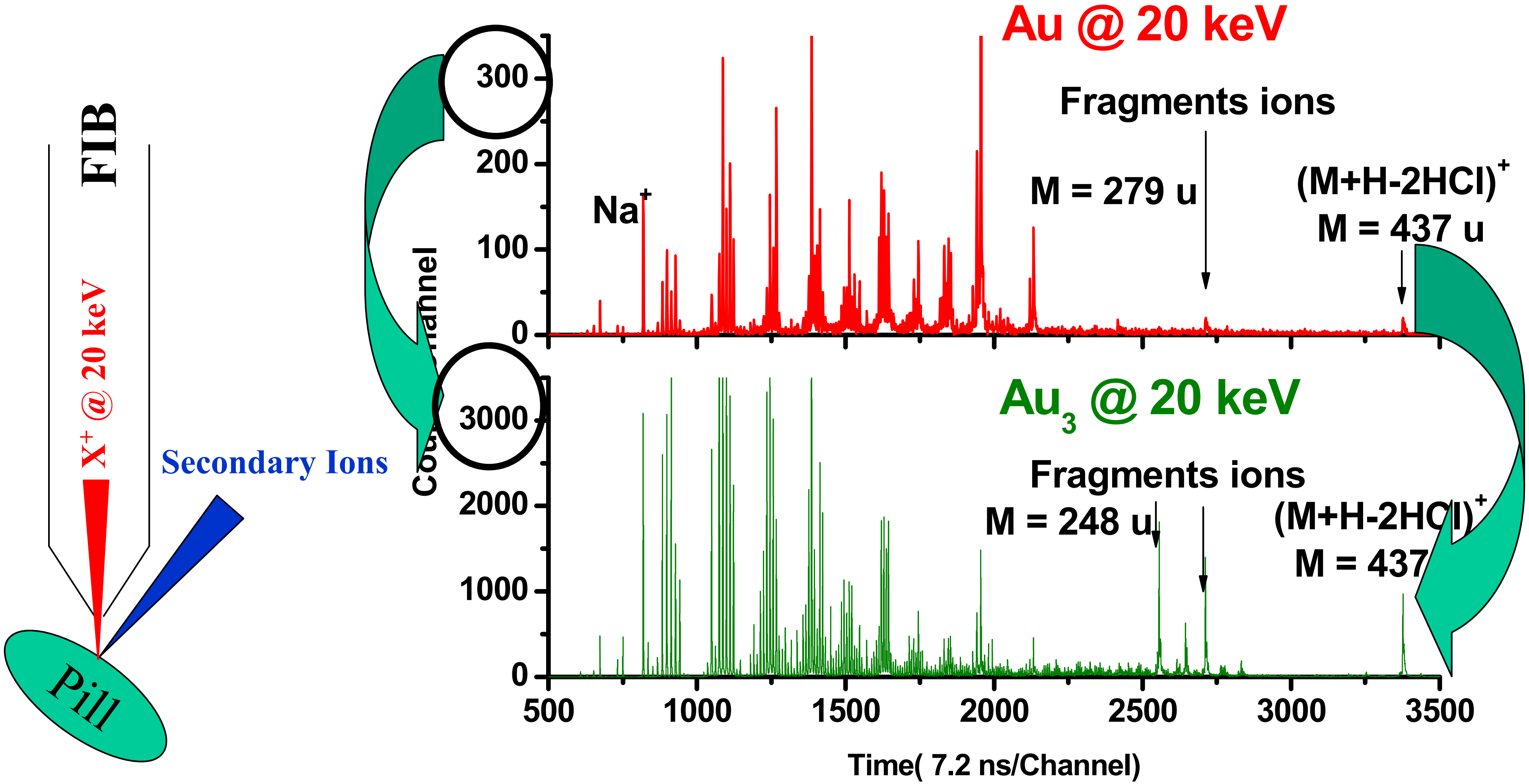
=> Experiment (under study) of **Gold FIB Milling**

MASS FILTERED FIB Applications

NANOSOLUTIONS by ORSAYPHYSICS

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 FIB conclusions

⇨ 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