

Other Ion Sources

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Other Ion Sources ???

Not : *ECR, EBIS, RF,
Fusion, Laser, MEVVA,
Radioactive , Breeders,
Medical, Multi-beam ...*

What to do ???

Ions for the industry

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Ions for the industry

Ion Sources : the accelerators versus the industry

- Accelerators :

Emittance, Intensity, Efficiency

- Industry :

Throughput, Tunability, Cost

Other Ion Sources - Ions for the industry

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Ion Sources for Industry : *the fields of use*

- 1 - Focused Ion Beams :

Focused Ion Beam for the nanotechnologies (FIB)

Ion beam figuring for optical components (IBF)

- 2 - High Intensity Beams for *MicroElectronics*

Ion Sources for implanters

- 3 - Broad Beam & "Ionic Machine" for *the Industrial Coating*

Ion Source for Sputtering

Magnetron discharge & End Hall ion source

Other ion sources - Ions for the industry

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Ion sources for the industry: *the orders of magnitude*

1 - High brightness ~ 1 nm-1 μ m beam (FIB)

2 - High current ~ 1 cm-30 cm beam (Implanter)

3 - Broad beam ~ 30 cm- 10 m beam/treatment (Coating)

Other ion sources - Ions for the industry

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The good Units for the industrial purpose :

1 - Focused Ion Beam : $\mu\text{m}^3/\text{s}$

2 - Implanter : Wafers/h

3 - Coating : $\mu\text{m}/\text{m}^2/\text{h}$

Other ion sources - Ions for the industry

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Popular Ion Sources for the industry :

1 - Focused Ion Beams

LMIS, RF, Microwave

2 - Implanters

Freeman, Bernas

3 - Coatings

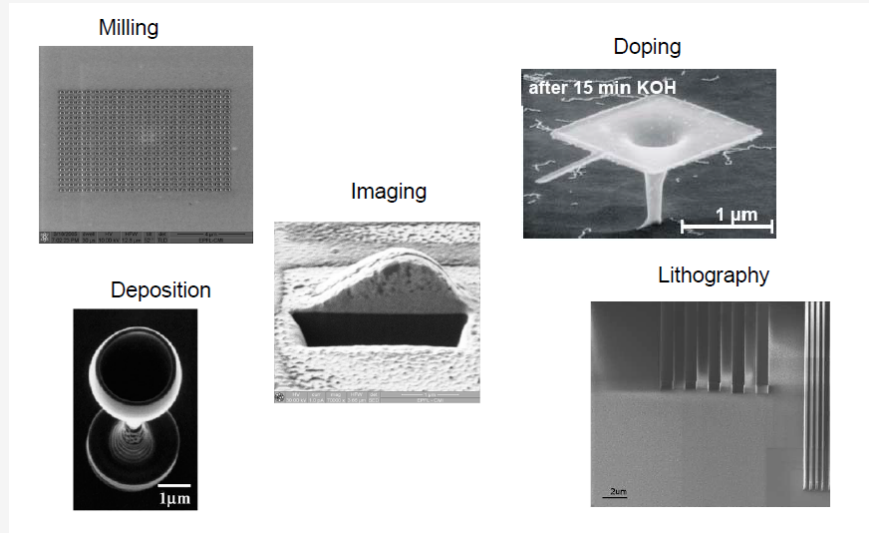
Broad beam, Magnetron, Gridless

Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

The purpose of the Focused Ion Beam systems:

**1 μm
to 1 nm
beam**

**1 μA
to 1 nA
beam**



Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

The process with the Focused Ion Beam :

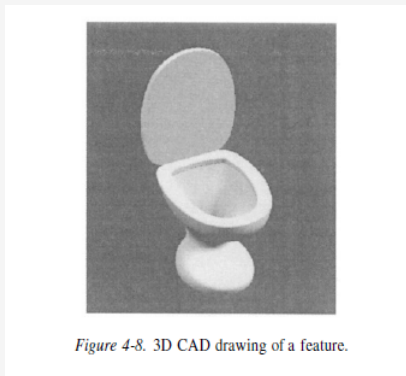


Figure 4-8. 3D CAD drawing of a feature.

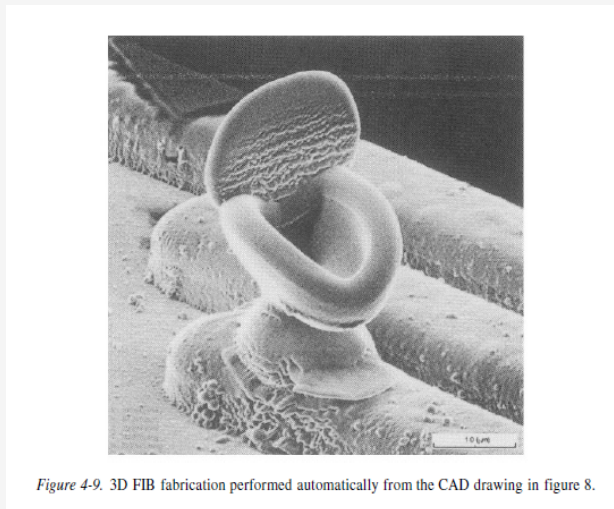


Figure 4-9. 3D FIB fabrication performed automatically from the CAD drawing in figure 8.

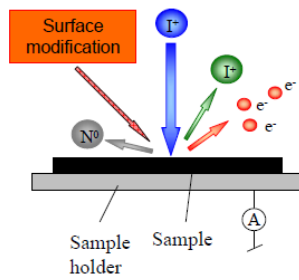
Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

The process with the Focused Ion Beam :

Introduction

Principle



• Surface modification due to Interaction of impinging ions with the surface

• Elastic interaction

⇒ displacement, sputtering, defects, ion-implantation

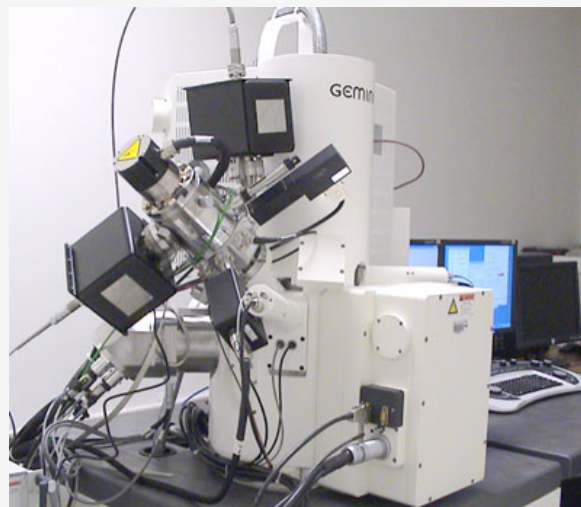
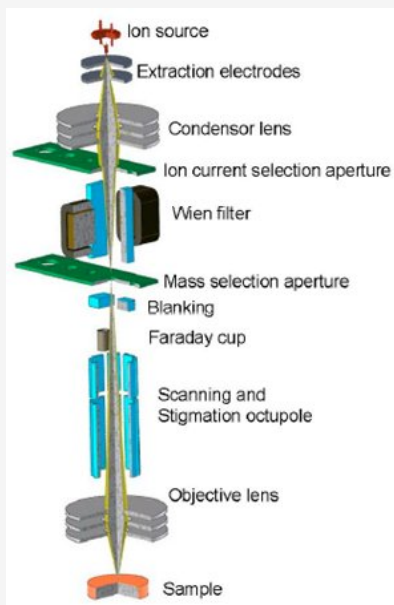
• Inelastic interaction

⇒ secondary e⁻, secondary ions, X-ray, photons γ

Moving the beam ⇒ Surface patterning

Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies



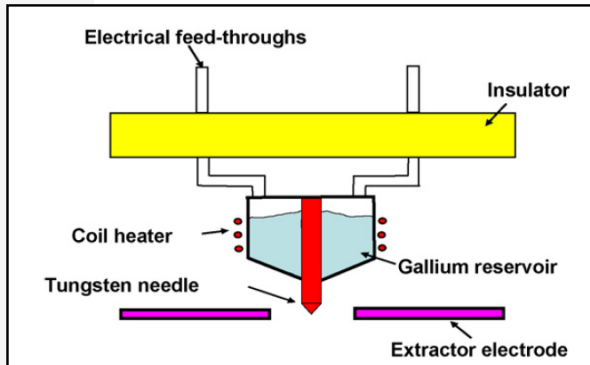
Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

Ion Source

Liquid Metal Field Ionization Source (LMIS)

- High electrical fields at the apex of a rod leads to detachment of ions
- Liquid metal film is drawn into conical shape of the rod (W or Rh)
- Wide variety of ion species including Al, As, Au, B, Be, Cs, Cu, Ga, Ge, Fe, In, Li, Pb, Si, Sn, U, and Zn



Ga⁺ source from FEI

Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

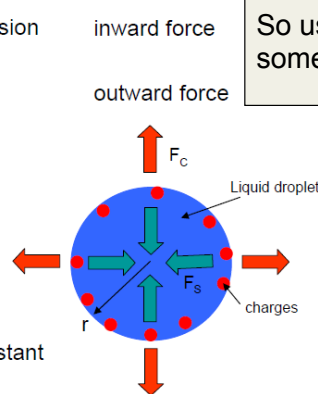
Ion Source

Liquid Metal Field Ionization Source (LMIS)

- **Surface force** $F_s = 2\frac{\gamma}{r}$, γ : surface tension
- **Coulomb force** $F_c = \frac{\epsilon_0 E^2}{2}$, $E = \frac{q}{4\pi\epsilon_0 r^2}$
- Maximum charge may be placed on the surface
 \Rightarrow Rayleigh limit:

$$q_{Rh} = 8\pi\sqrt{\epsilon_0\gamma}r^3$$

$$\epsilon_0 = 8.85 \cdot 10^{-12} \text{ C}^2/\text{J m dielectric constant}$$
- Formation of Taylor Cone



$\sim 20 \mu\text{A}\cdot\text{sr}^{-1}$

So useful current :
some tens of nA max

Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

Ion Source

Liquid Metal Field Ionization Source (LMIS)

Properties of metals used in LMIS

	Properties	Reason
1	Low melting point	Minimise reaction between liquid and substrate
2	Low volatility at melting point	Conserves supply of metal; promotes long source life
3	Low surface free energy	Promotes flow of liquid and wetting of substrate
4	Low solubility in substrate	Dissolution of substrate alters the alloy composition

Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

Ion Source

Liquid Metal Field Ionization Source (LMIS)

	Melting point T_m [K]	Boiling point T_B [K]	Vapor pressure p at T_m [Torr]	T at which $p = 10^{-6}$ mbar [K]
Bi	544	1832	$< 10^{-8}$	672
Ga	310	2510	$< 10^{-8}$	961
In	429	2364	$< 10^{-8}$	877
Sn	505	2952	$< 10^{-8}$	1070
Au	1336	2982	$\approx 10^{-4}$	1180
As	1090	886	< 1000	423

Orloff J, M. Utlaut, L. Swanson: *High Resolution Ion Beams*, Kluwer Academic (2003)

Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

Ion Source

Gas Field Ionisation Source (GFIS)

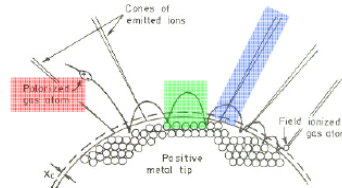
Low temperature (cryogenic)
« LMIS » : 10-300 K

- atoms (molecules) are trapped by polarizations forces
 - Trapped atoms hop on the surface until they are ionised
- Ionisation: tunneling process with probability D:

$$D \propto e^{\frac{-c(I-\Phi)}{V}}$$

I : Ionisation potential
 Φ : Work function of emitter
 V : El. Potential
 c : constant

- Ions are ejected from the surface



Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

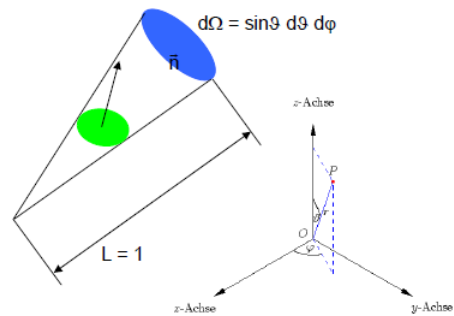
Ion Source

Gas Field Ionisation Source (GFIS)

- Cooling the tip \Rightarrow higher residence time τ_r leads higher ionisation rate

- Ions: $H^+, He^+, Ne^+, \text{etc}$

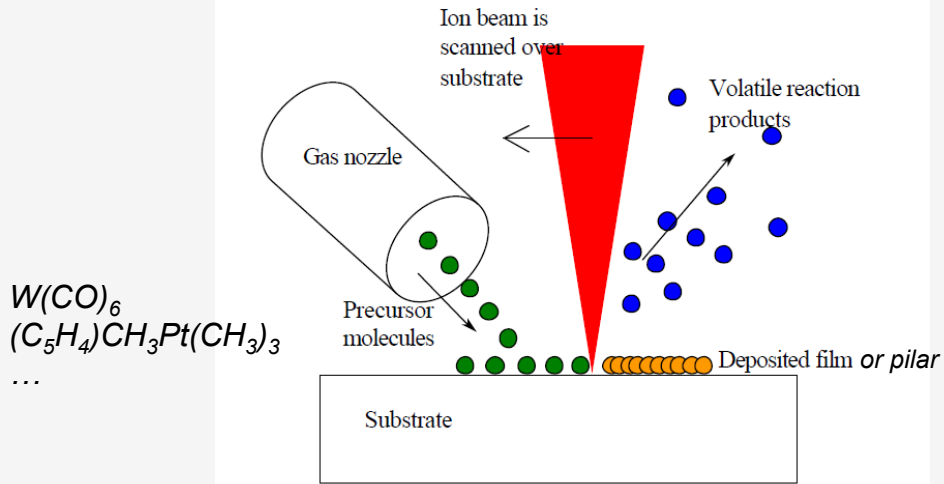
- low current $\frac{dI}{d\Omega} = 1 \mu A \text{ sr}^{-1}$ ^{a)}



^{a)} largest reported value (J. Oriloff: High Resolution Focused Ion Beams, Kluwer Academic, 2003)

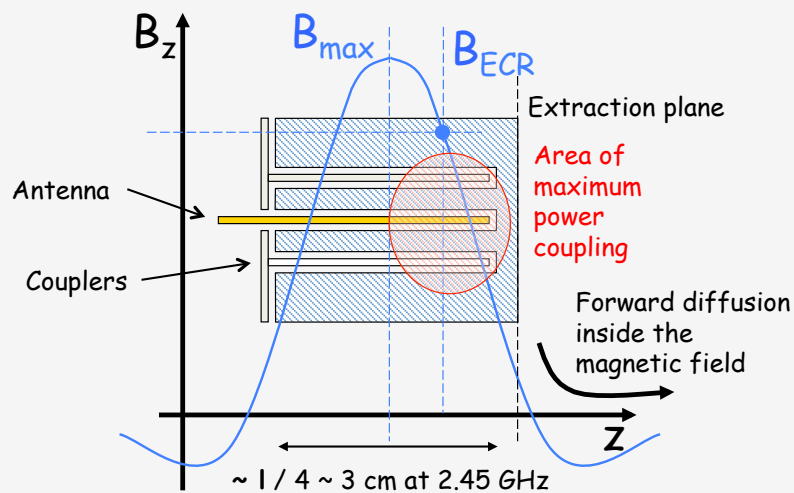
Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

Deposited films induced by focused ion beam

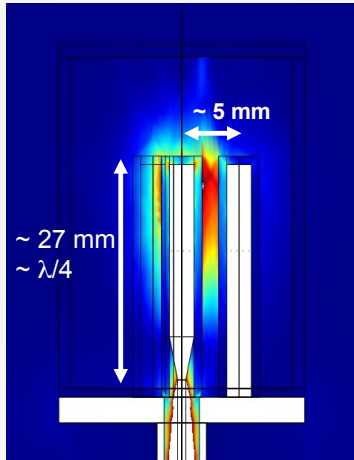


Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

**Microwave source with "high brightness & high current" (μA):
 The COMIC concept**



Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies



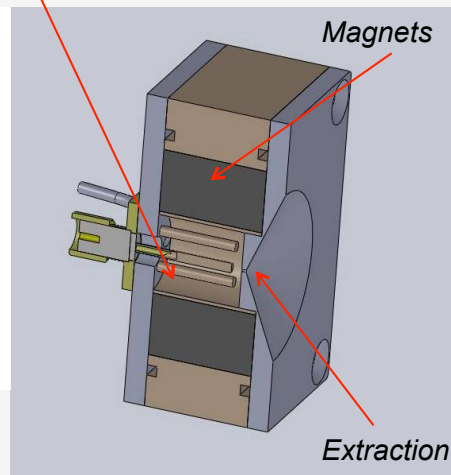
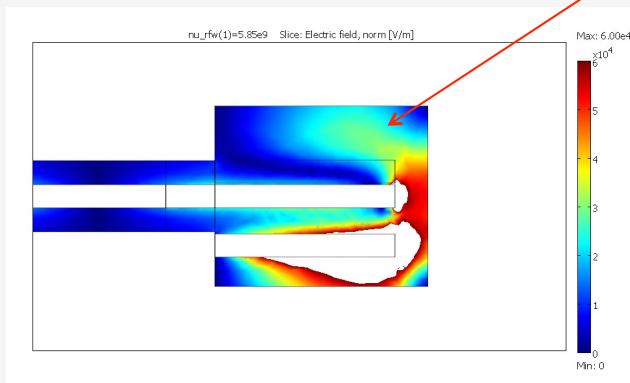
Electric field amplitude distribution between the central antenna and couplers with quasi-coaxial geometry (COMSOL Calculation)
 $f_{hf} = 2.45 \text{ GHz}$ Red $> 10^4 \text{ V/m}$



Distribution of light in a Xenon discharge (2 W) between the central antenna and the coupler with quasi-coaxial geometry
 $p \sim 10^{-2} \text{ mbar}$

Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

Electric field amplitude inside a closed cavity

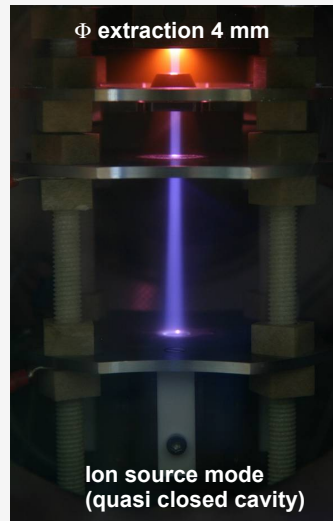


Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies



Plasma source mode
(semi closed cavity)

Argon 10^{-2} mbar / 5 W

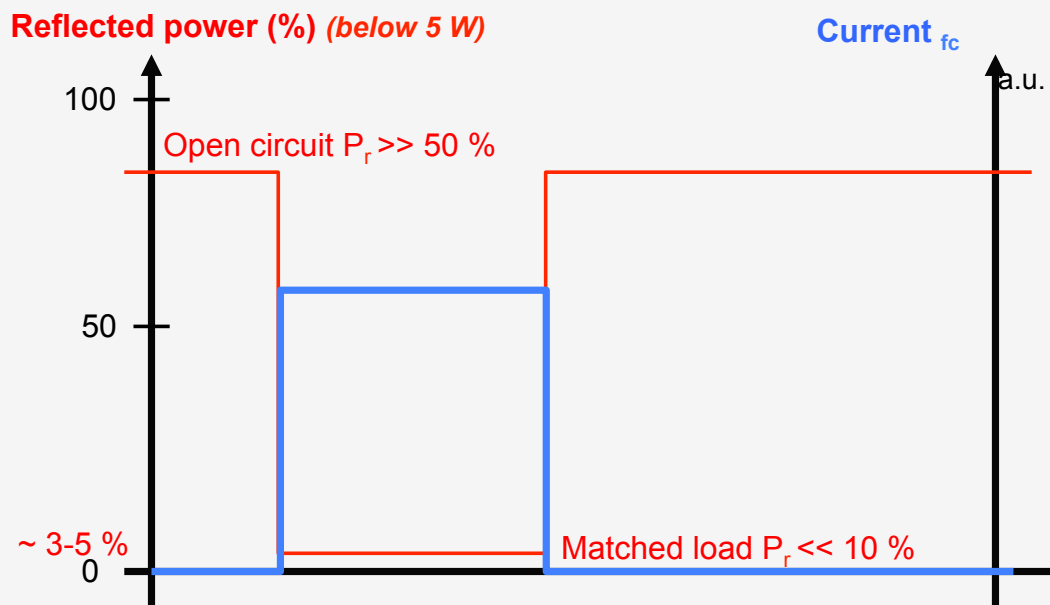


Ion source mode
(quasi closed cavity)

Nitrogen $5 \cdot 10^{-5}$ mbar / 5 W
 $\sim 500 \mu\text{A} \sim 4 \text{ mA/cm}^2$

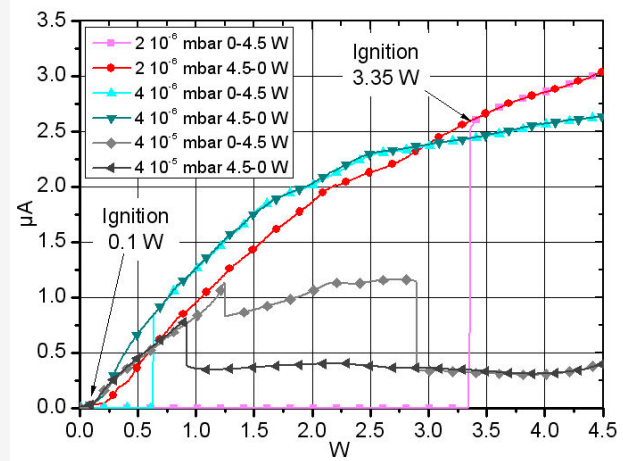
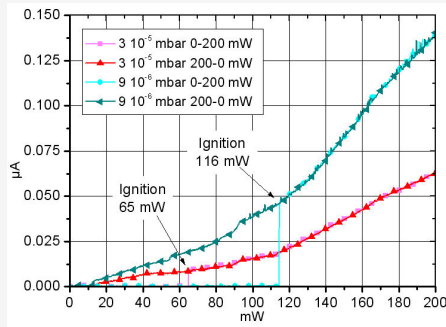
Source
20 KV
 1st elect.
16 KV
 Grounded electrode
0 KV

Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies



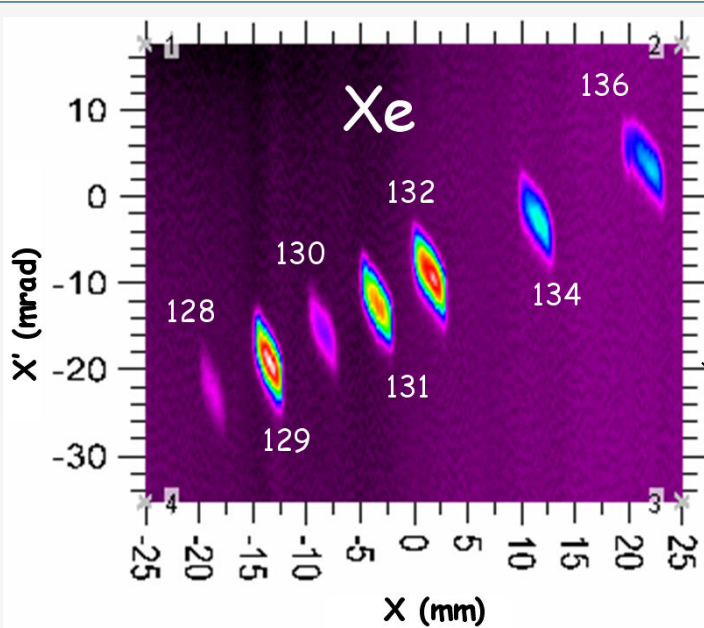
Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

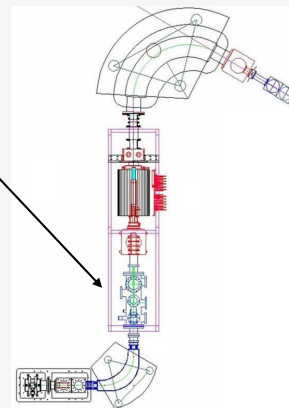


Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies

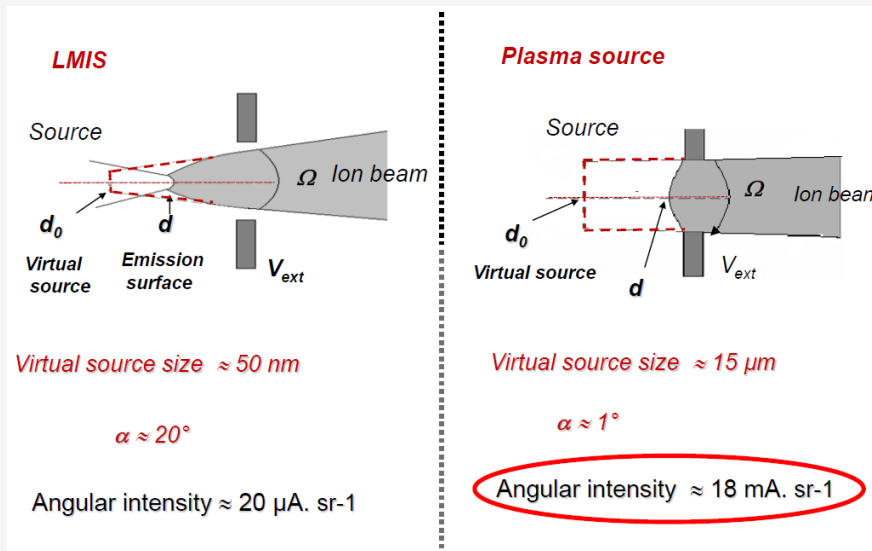


1σ
 $1.2 \pi \cdot \text{mm} \cdot \text{mrad}$
 15 KV
 3/10 mm ext.
 1.8 μAe total / 3 W / ext. 0.3 mm / 15 KV
 (12.5 kV élect. intermédiaire)



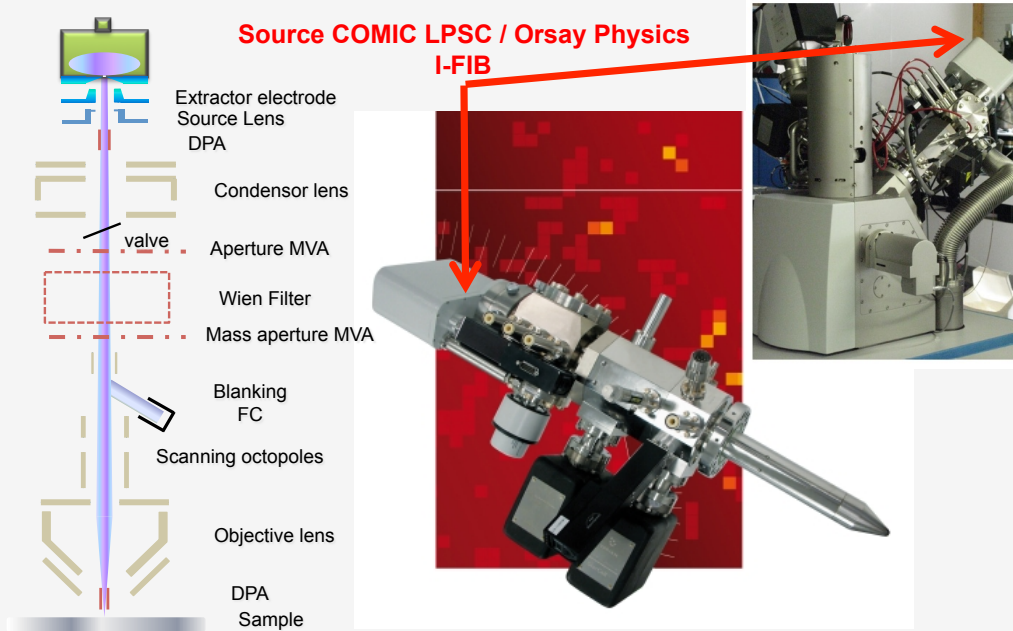
Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies



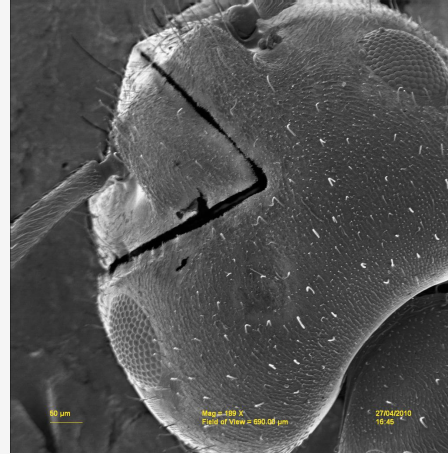
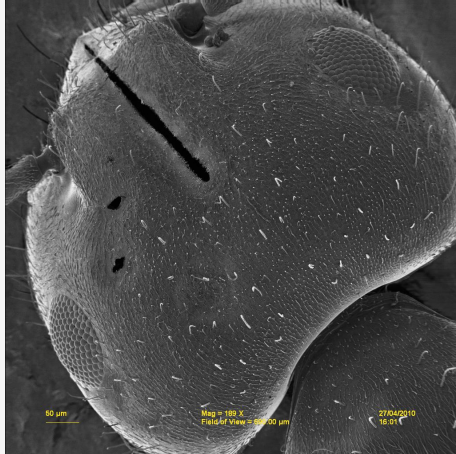
Other ion sources - Ions for the industry

1 - Focused Ion Beam for the Nanotechnologies



Other ion sources - Ions for the industry
1 - Focused Ion Beam for the Nanotechnologies

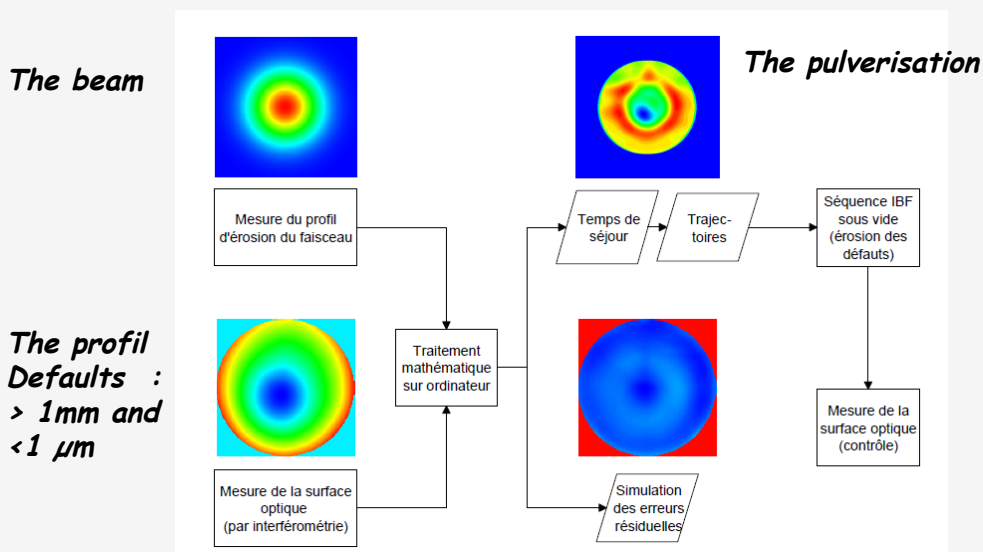
Microsurgery of a ant head with the COMIC source



100 x 100 x 100 µm³
 15 hours with Ga (65 nA) = 40 minutes with Xe (1µA)

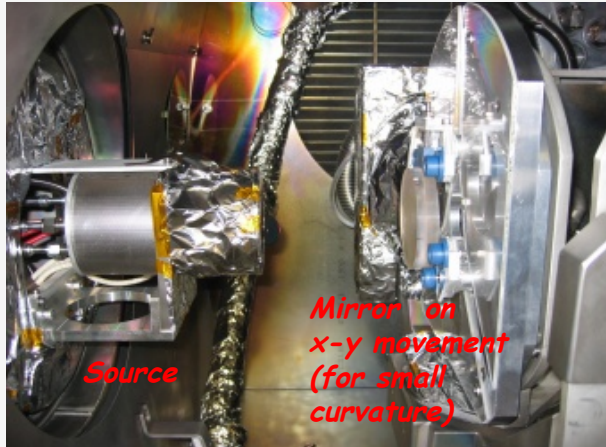
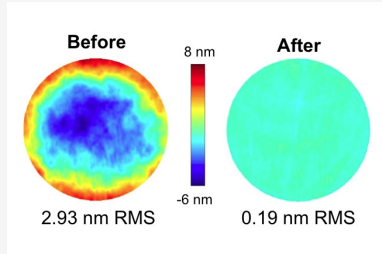
Other ion sources - Ions for the industry
1 - Ion Beam Figuring of the Optic Industry

The purpose of the Ion Beam Figuring :



Other ion sources - Ions for the industry
 1 - Ion Beam Figuring of the Optic Industry

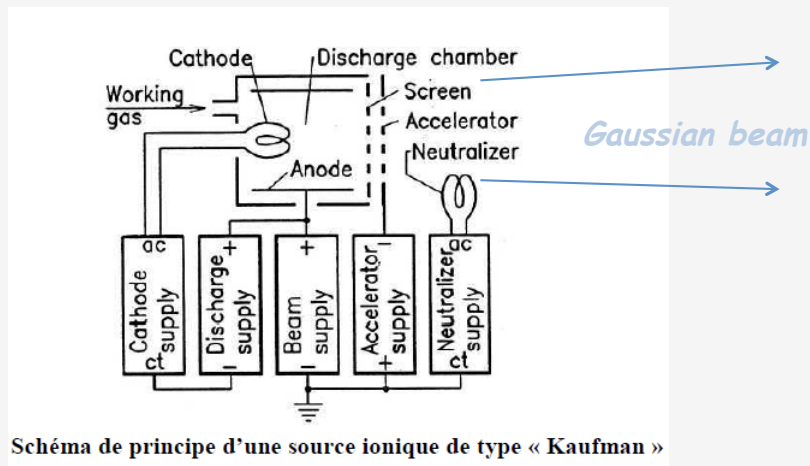
Ion Beam Figuring machine:



- + No pressure : very thin optics
- + Determinist
- Under vacuum (heating)
- Rugosity modification

Other ion sources - Ions for the industry
 1 - Ion Beam Figuring of the Optic Industry

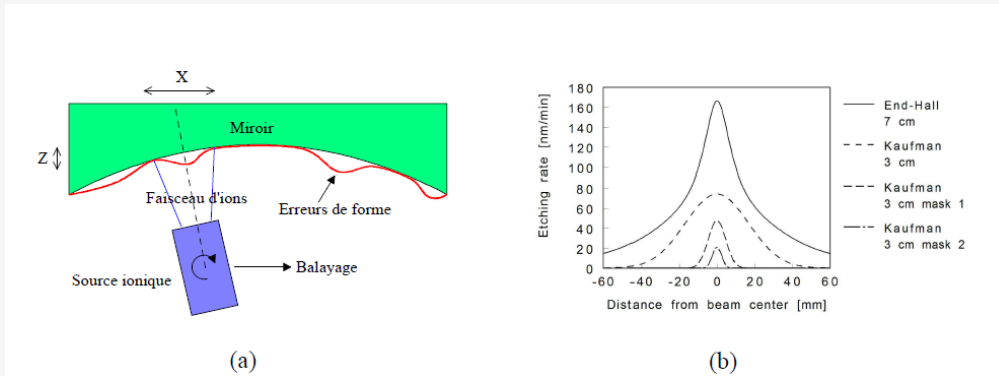
Broad beam (20-40 mm) Kaufman filament source with grid extractor



Other ion sources - Ions for the industry

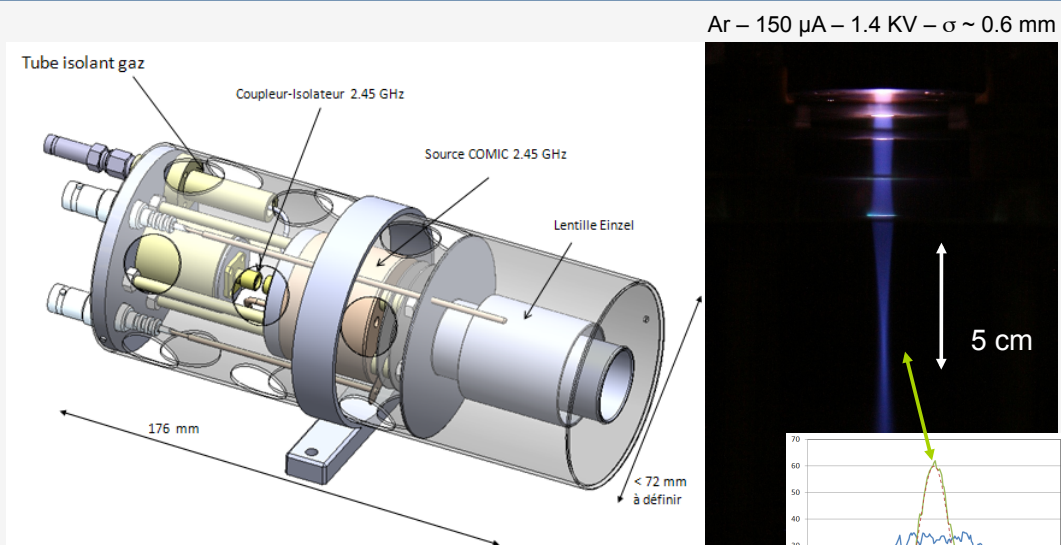
1 - Ion Beam Figuring of the Optic Industry

Matching of the beam size to a characteristic length of the defaults:



Other ion sources - Ions for the industry

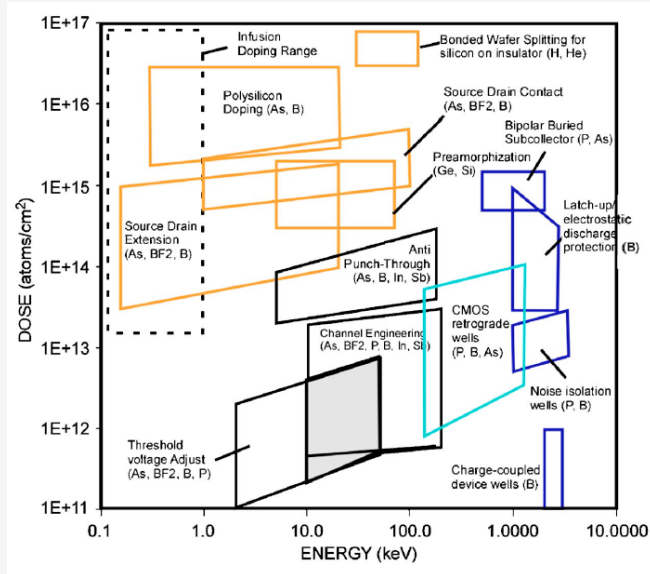
1 - Ion Beam Figuring of the Optic Industry



High brightness gaussian millimeter beam size with COMIC

Other ion sources - Ions for the industry 2 - High Intensity Beams for MicroElectronics

The purpose of the Implantation Technology:



Other ion sources - Ions for the industry 2 - High Intensity Beams for MicroElectronics

The demand for the Implantation Technology:

Boron : BF_3 , B_2H_6

Phosphorus : P (solid) , PF_3 , PH_3

Arsenic : AsH_3

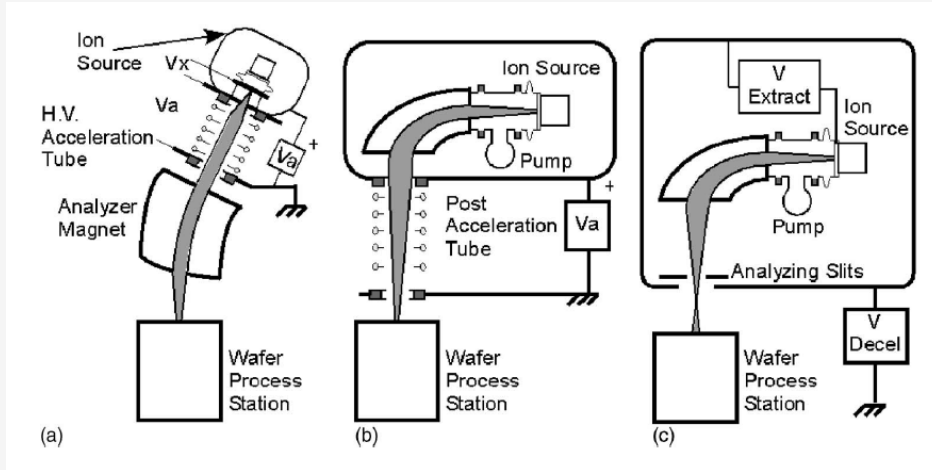
TABLE 1

TYPICAL ION SOURCE OPERATING LIFE
ON HIGH CURRENT (BATCH) IMPLANTERS

SOURCE TYPE	PRIMARY SPECIES	AVERAGE ION BEAM CURRENT	SOURCE OPERATING HOURS
ENHANCED BERNAS	MIXED (As^+ , P^+ , B^+)	2-5mA	140-160 hrs.
	MIXED (As^+ , P^+ , B^+)	5-10mA	80-120 hrs.
	B^+	~5mA	~80 hrs.
	B^+	~10mA	~40 hrs.
	As^+ , P^+	~5mA	~140 hrs.
	As^+ , P^+	~10mA	~100 hrs.
	Sb^+	5-10mA	40-50 hrs.
STANDARD FREEMAN	MIXED (As^+ , P^+ , B^+)	2-5mA	60-80 hrs.
	MIXED (As^+ , P^+ , B^+)	5-10mA	30-50 hrs.
	B^+	~5mA	30-40 hrs.
	B^+	~10mA	15-25 hrs.
	As^+ , P^+	~5mA	40-60 hrs.
	As^+ , P^+	~10mA	30-40 hrs.
	Sb^+	5-10mA	20-40 hrs.

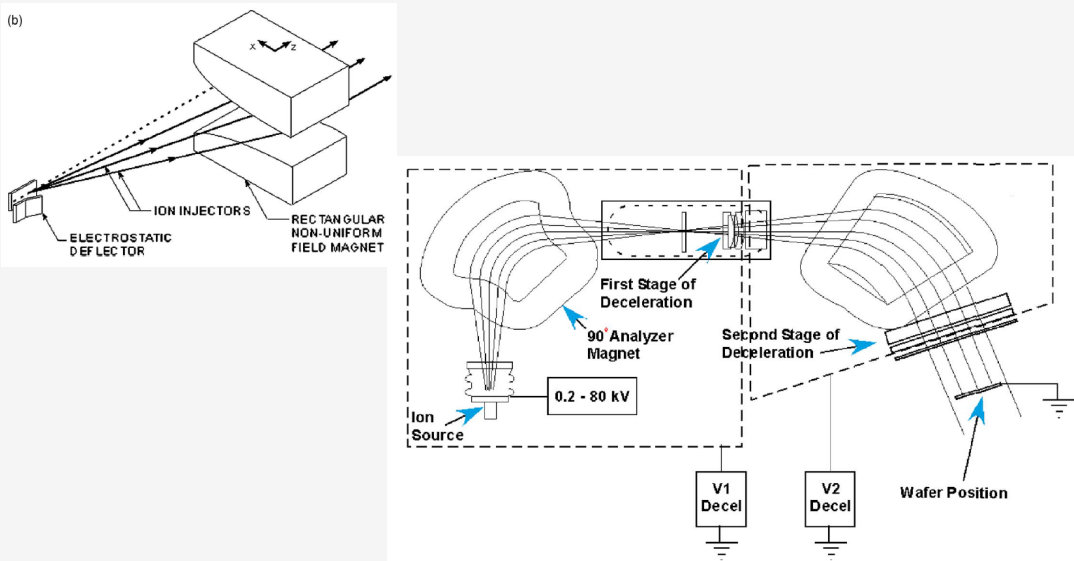
Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

The purpose of the Implantation Technology:



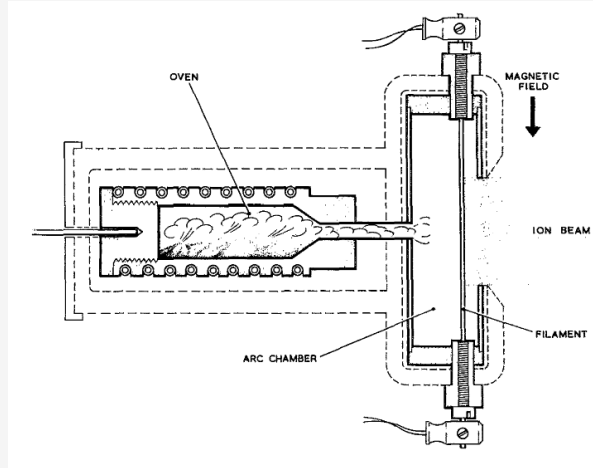
Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

The purpose of the Implantation Technology: Ribbon beam generation



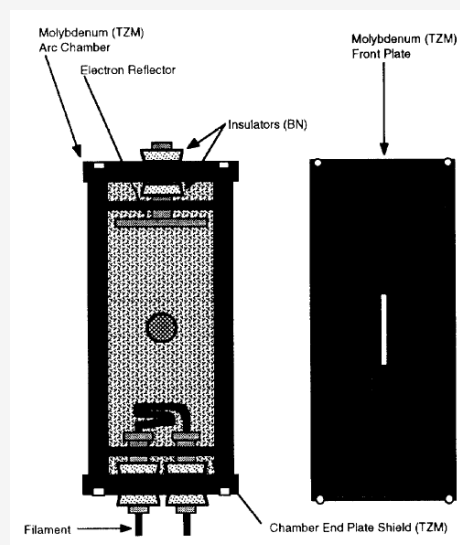
Other ion sources - Ions for the industry 2 - High Intensity Beams for MicroElectronics

The Freeman Ion Source:



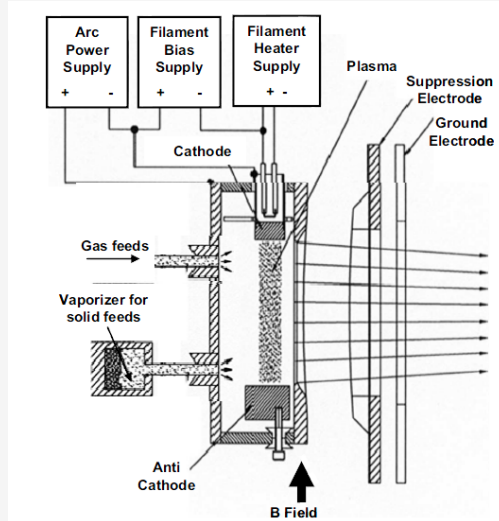
Other ion sources - Ions for the industry 2 - High Intensity Beams for MicroElectronics

The Bernas Ion Source:



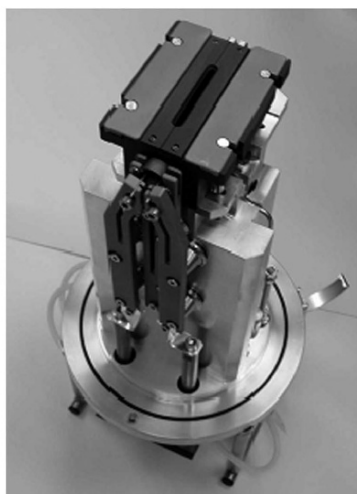
Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

The Indirectly Heated Cathode Ion Source (IHC):

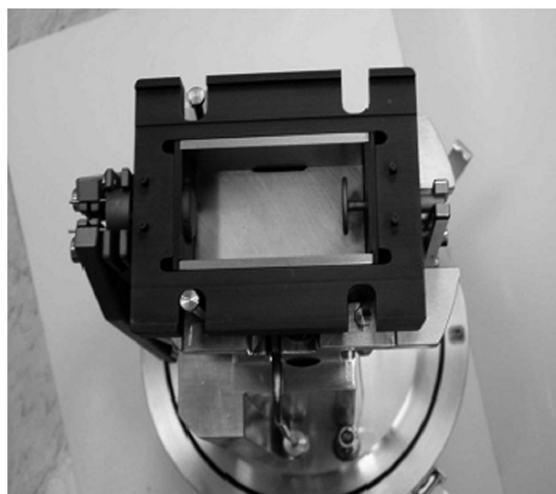


Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

The Indirectly Heated Cathode Ion Source (IHC):



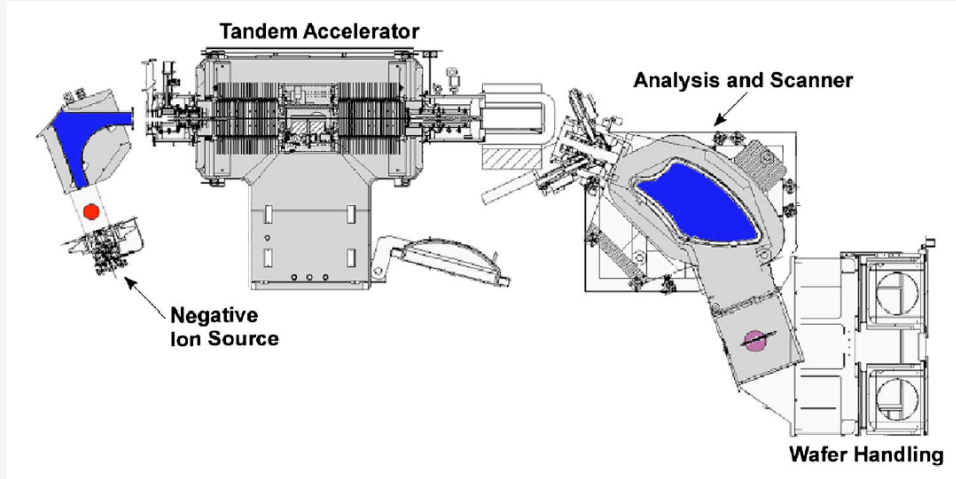
(b)



(c)

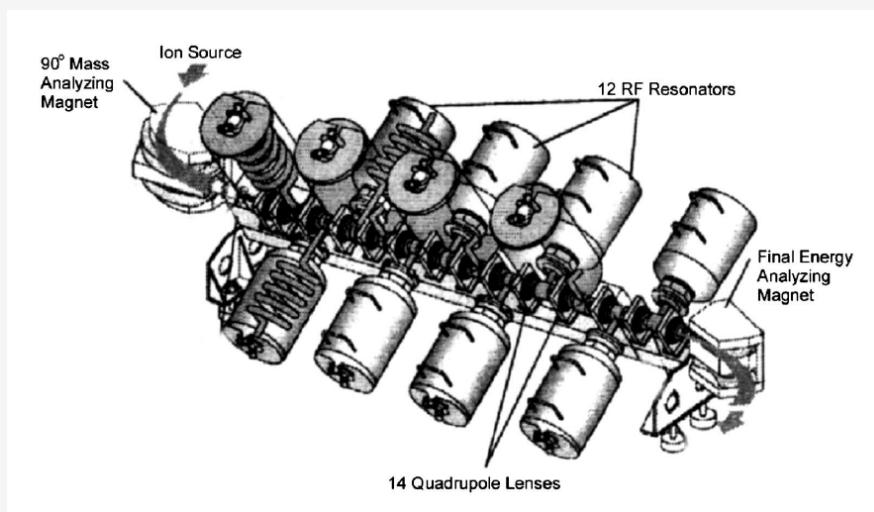
Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

High energy implantation : Negative ion source and Tandem



Other ion sources - Ions for the industry
2 - High Intensity Beams for MicroElectronics

High energy implantation : Positive ion source and Linac

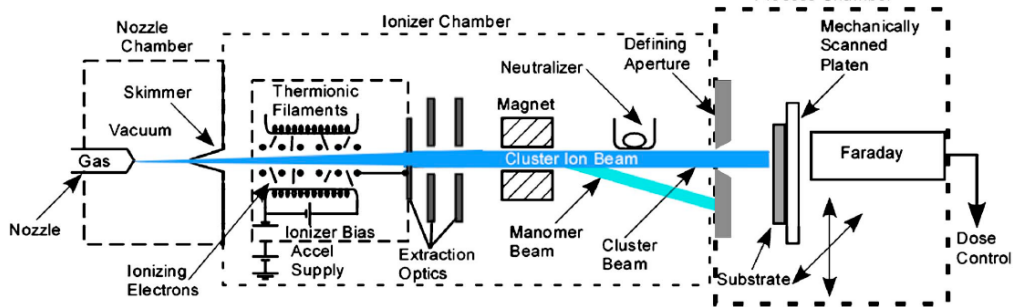
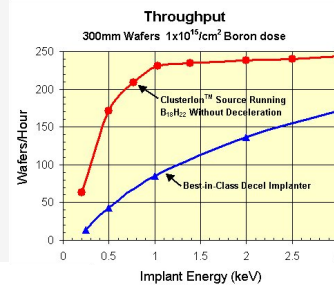


Other ion sources - Ions for the industry

2 - High Intensity Beams for MicroElectronics

Low energy implantation :
Complex Molecular ion and Cluster

$B_{18}H_{22}$, $C_{16}H_{10}$
 followed by annealing ($\sim 1000^{\circ}C$)



Other ion sources - Ions for the industry

2 - High Intensity Beams for MicroElectronics

Problems already open in the implantation technology :

(from A. Renau, Varian Semiconductor Equipment Associates
 35 Dory Rd, Gloucester, Massachusetts 01930, USA, RSI, 81, 02B907, 8 February 2010)

- 1 - > 5 mA CW of 1^+ , 2^+ & 3^+ compact, low cost and upgradable
- 2 - > 5 mA CW of B^- , P^- , As^- with lifetime > 168 h
- 3 - Large area implantation : < 1% over Φ 500 mm
- 4 - Low maintenance ion source
 (without any modification inside the beam line optics)

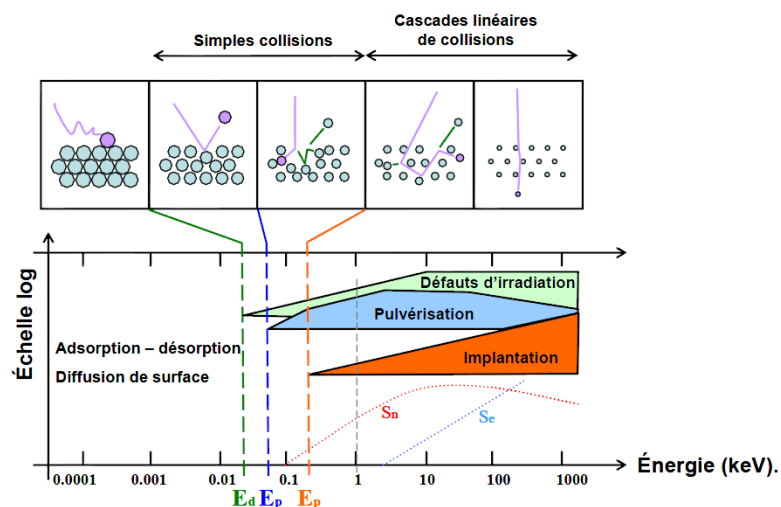
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The industrial field of use : the PVD coating
(Physical Vapor Deposition)

- Hardness modification (cutting tools, tribology)
- Solar (large area deposition)
- Optic component (laser and large optical mirror)
- Decorative coating (watchmaking,...)

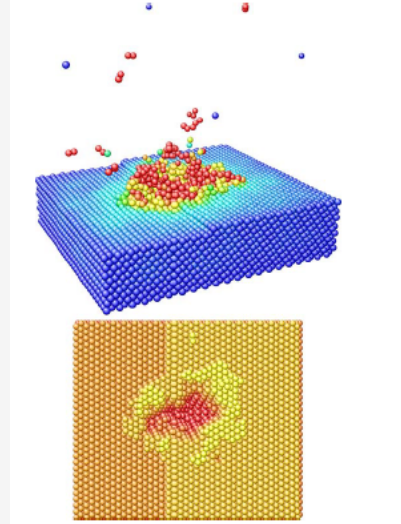
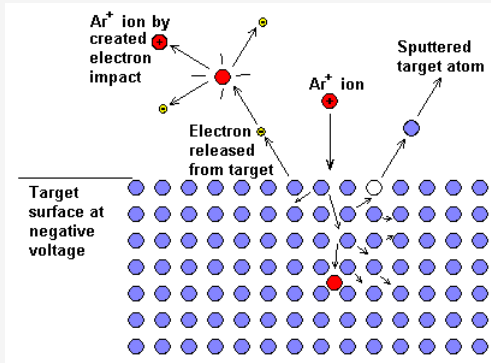
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

Ionic modification of matériel :

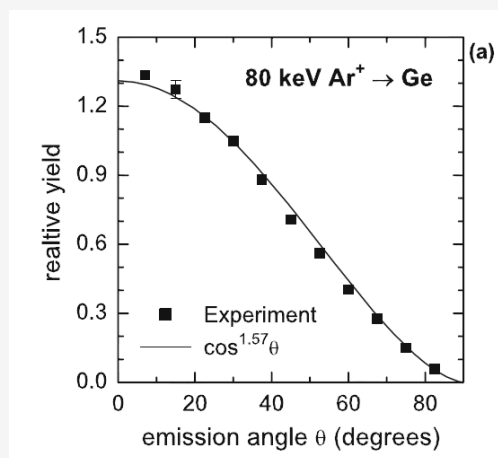
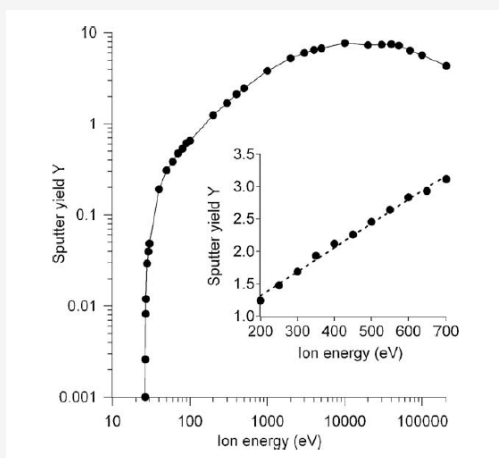


Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The sputtering process : (Ar^+ , 5 kV at 83° / surf., 2.5 ps)

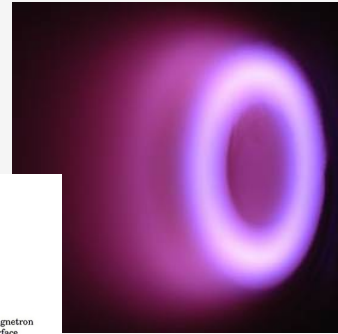
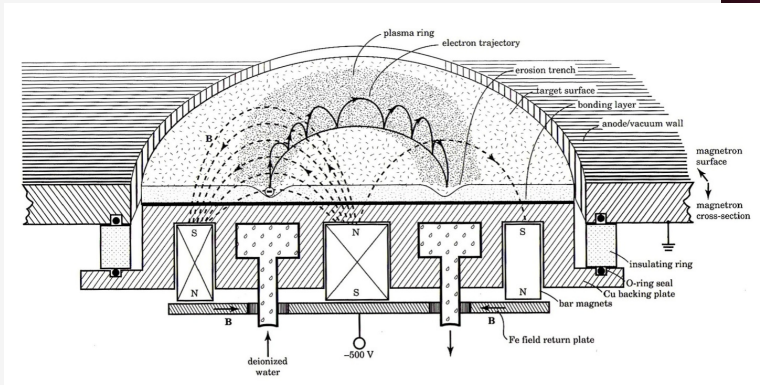


Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating



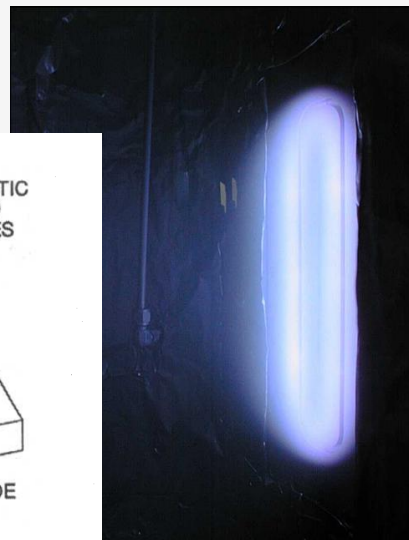
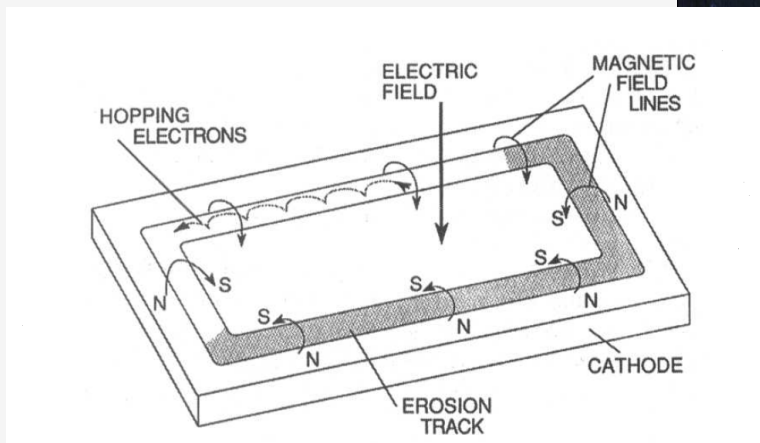
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Magnetron Sputtering (MS) :



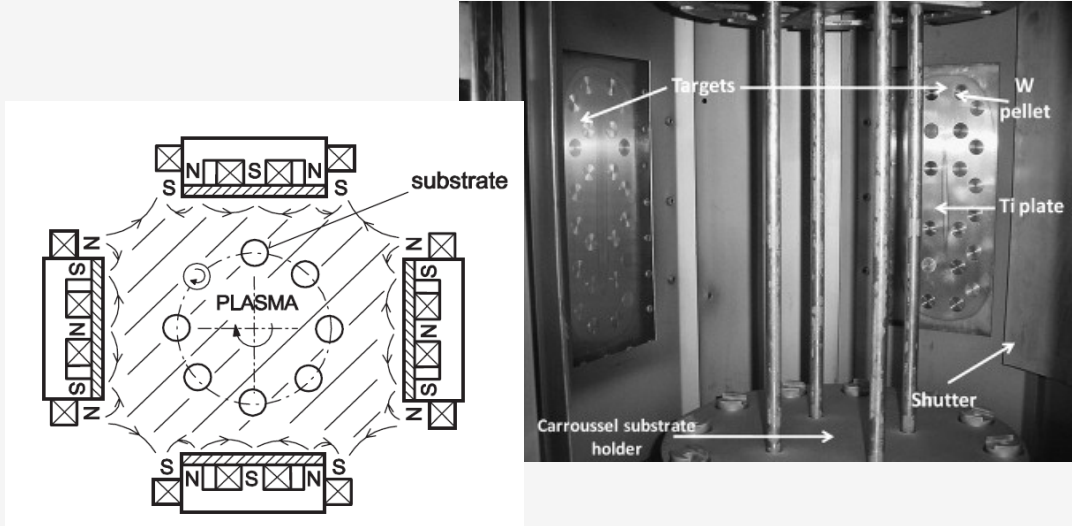
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Magnetron Sputtering (MS) :



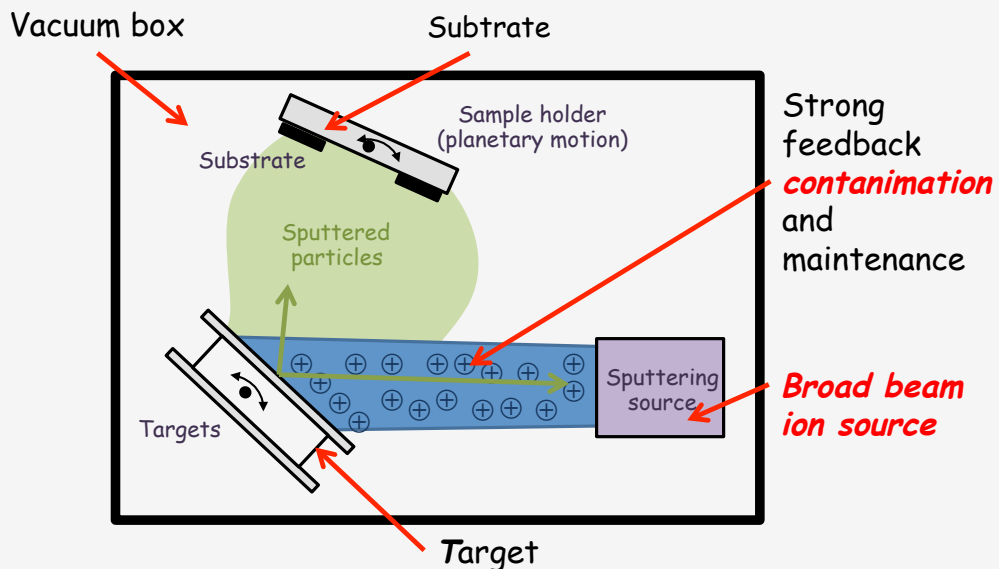
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Magnetron Sputtering (MS) :



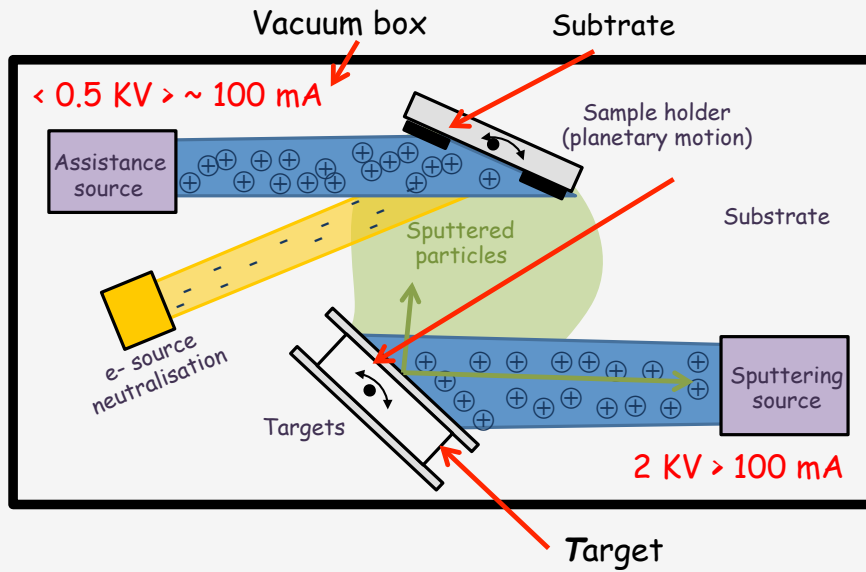
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Ion Beam Sputtering (IBS) :



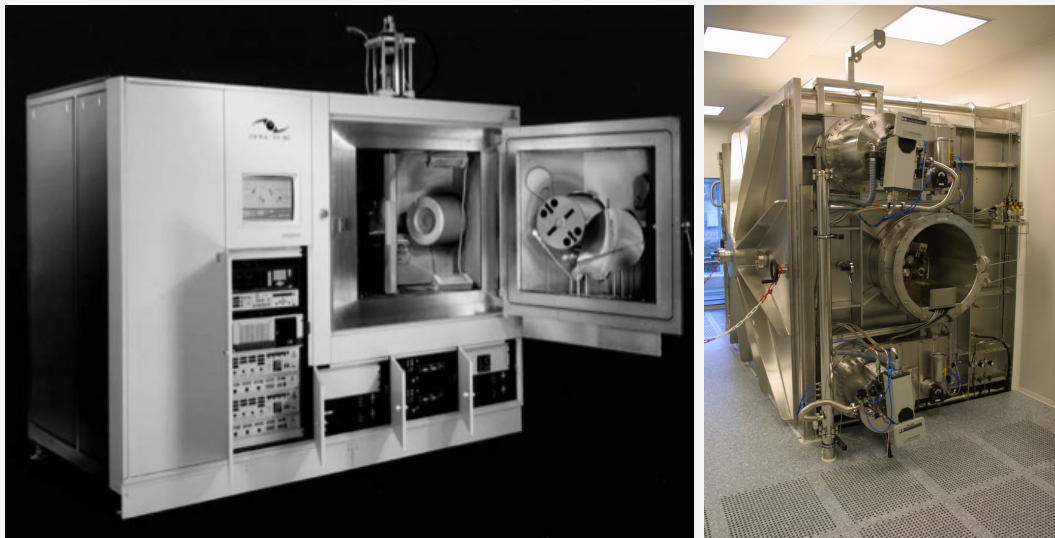
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Double Ion Beam Sputtering (DIBS) and assistance ion source :



Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Double Ion Beam Sputtering (DIBS) and assistance ion source :



Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The RF broad beam "gridded":

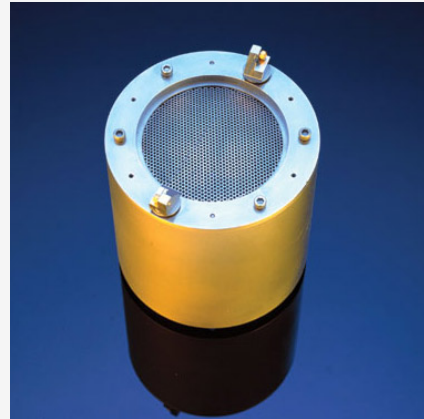
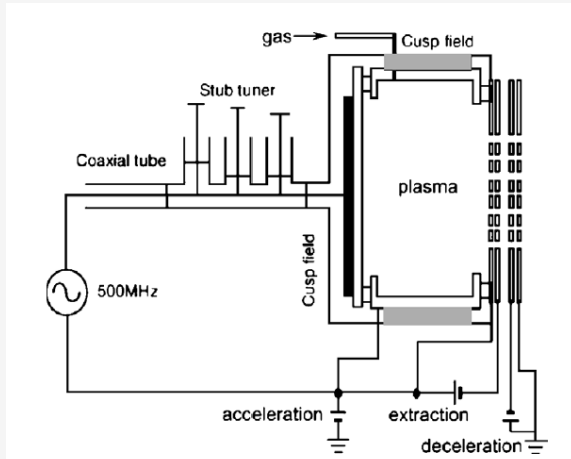
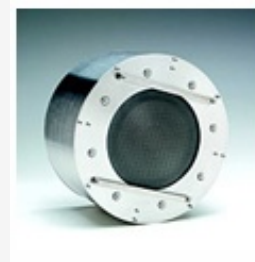
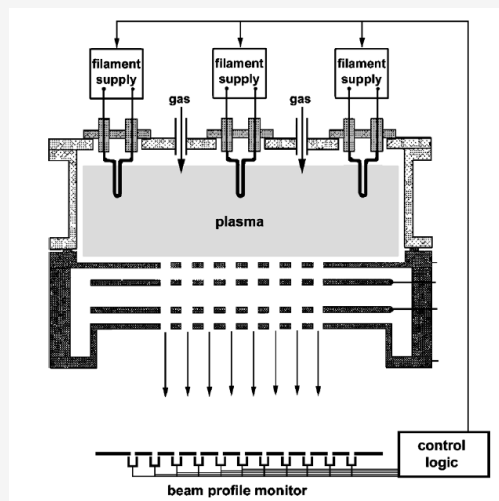


Fig. 3. Example of RF ion source, operating at 500 MHz, with four-grid ion extraction from a 600 × 300-mm plasma chamber (adapted from [40]).

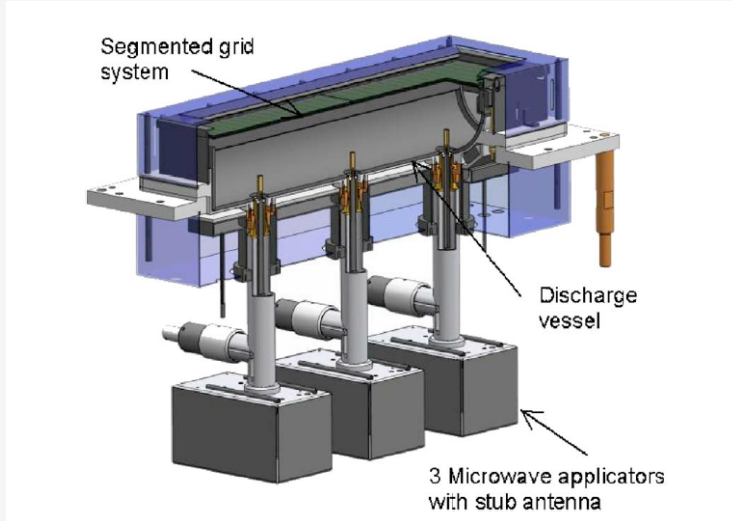
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The DC broad beam "gridded":



Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The Microwave Linear ECR (2.45 GHz) :



Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The industrial broad beam "gridless":

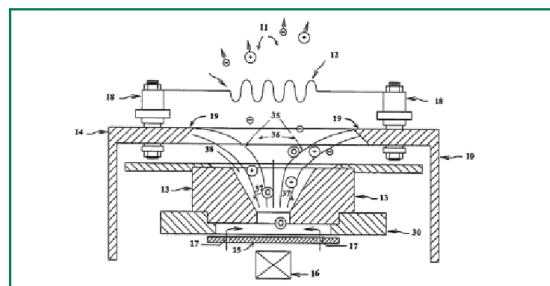
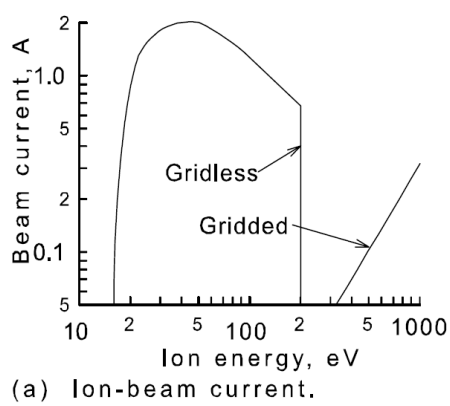


Figure 2. End-Hall ion source schematic: 10 - ion source; 11 - ion beam; 12 - Hot Filament cathode; 13 - anode; 14 - magnetic system; 15 - gas distributor - reflector; 16 - magnet; 17 - holes for working gas supply; 18 - cathode supports; 19 - magnetic pole; 30 - dielectric separating plate; 35 - magnetic field lines; 36-37 - discharge channel.

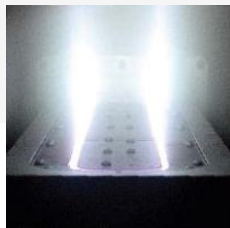
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The industrial broad beam "gridless":

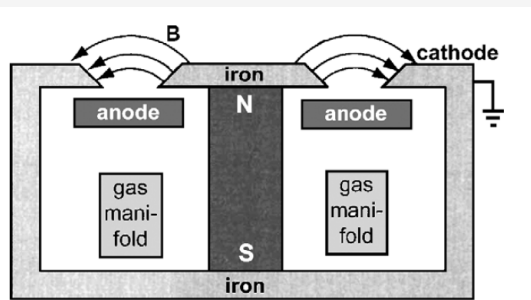


Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

The industrial broad beam "gridless ion source" :
 Anode layer ion source / the reverse of the magnetron

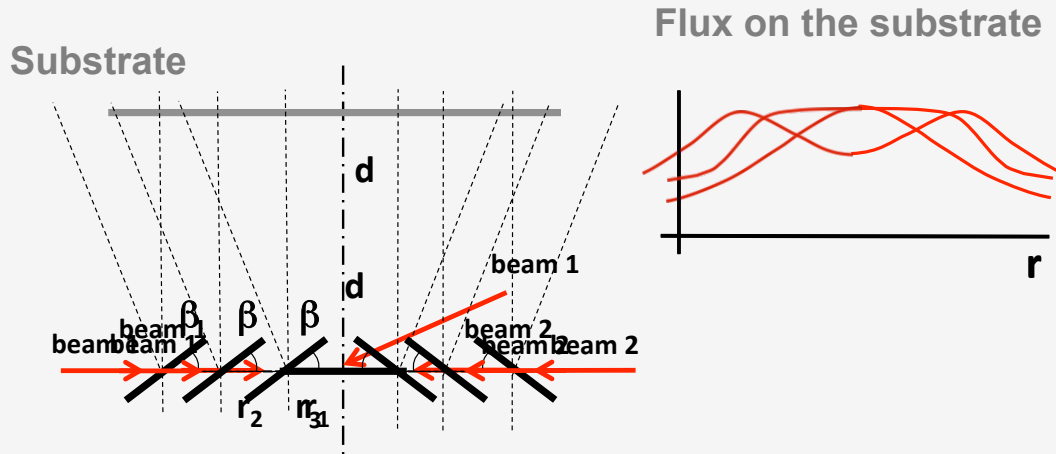


For cleaning
 Surface preparation
 Etching

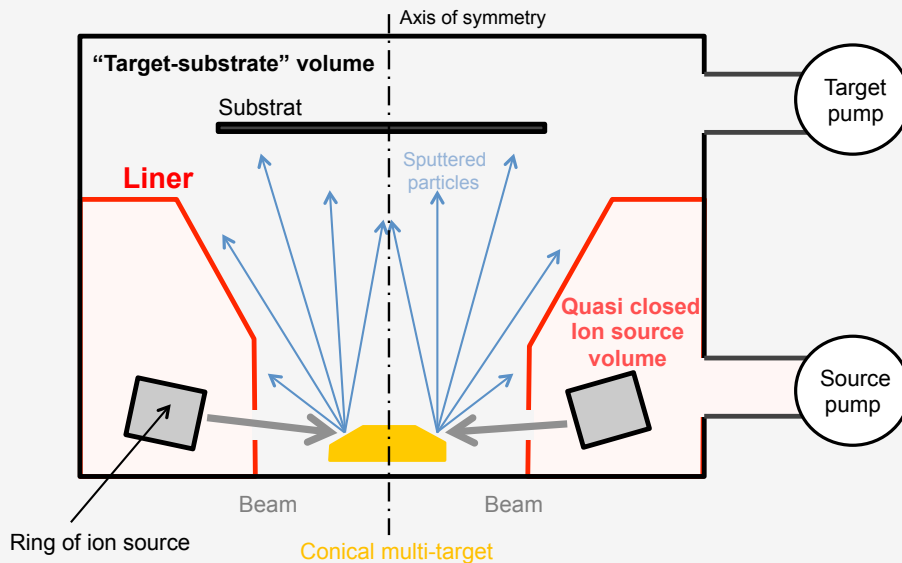


Other ion sources - Ions for the industry
 3 - Broad Beam & "Ionic Machine" for the Industrial Coating

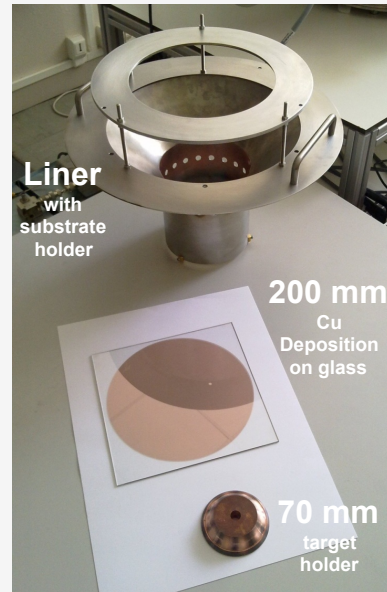
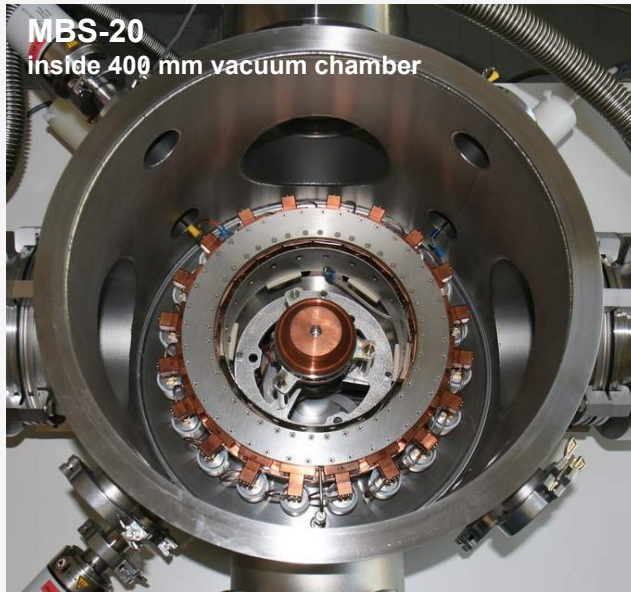
The Principle of multi beam devices :



Other ion sources - Ions for the industry
 3 - Broad Beam & "Ionic Machine" for the Industrial Coating



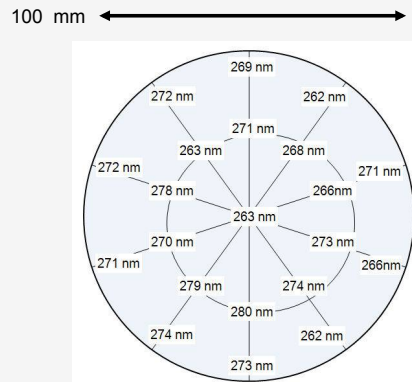
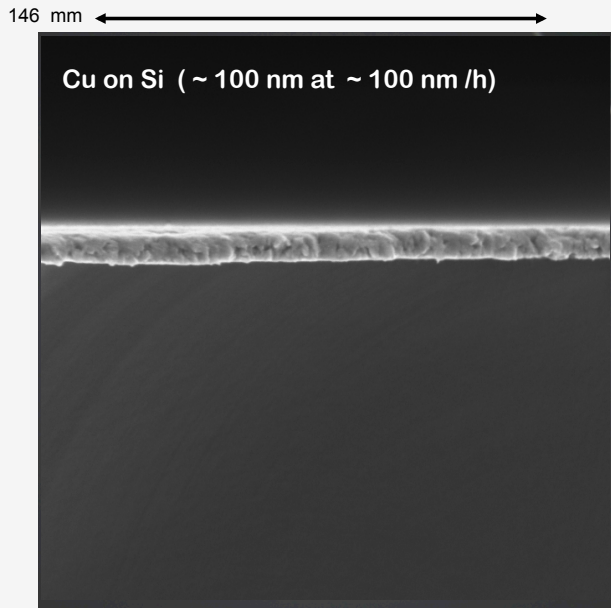
Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating



Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating

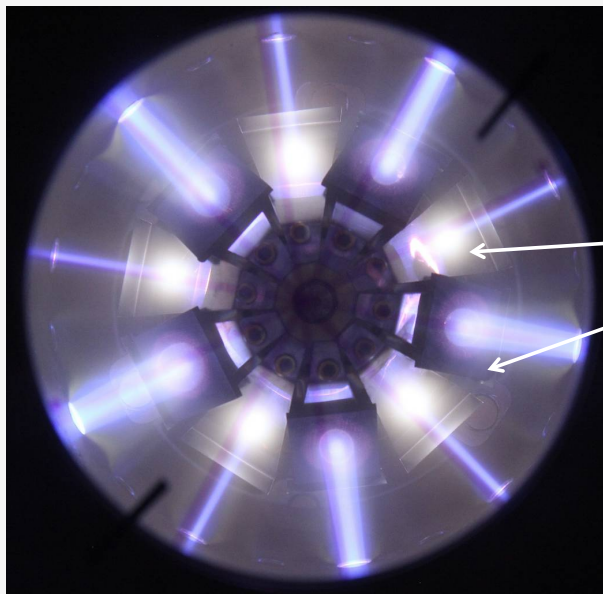


Other ion sources - Ions for industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating



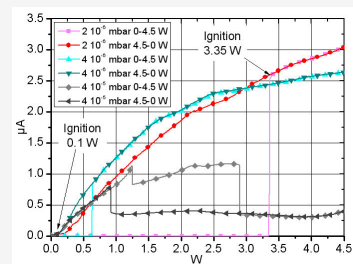
263 +/- 7 nm
 Profilometer measurements
 Static substrate
 Ta_2O_5 on Silicon
 (Ta target under O_2)

Other ion sources - Ions for the industry
3 - Broad Beam & "Ionic Machine" for the Industrial Coating



Multi beam (10)
 Multi target (Ta and C)
 Multi current (25 and 500 μ Ae)

Simultaneous Argon beams on Ta and C targets



Other ion sources - Ions for the industry
Conclusion

Ion Source for Industry : possible bridges between industry and accelerator technology

- 1 - Focused Ion Beams :

High quality beam for AMS, radioactive ions, electrostatic acc. cyclotron injection, ...

- 2 - High Intensity Beams for MicroElectronics

*Knowhow for high intensity transportation
Ion source for molecular ions ...*

- 3 - Broad Beam & "Ionic Machine" for the Industrial Coating

Multi beam machine for beam merging, superconducting material deposition, ...