

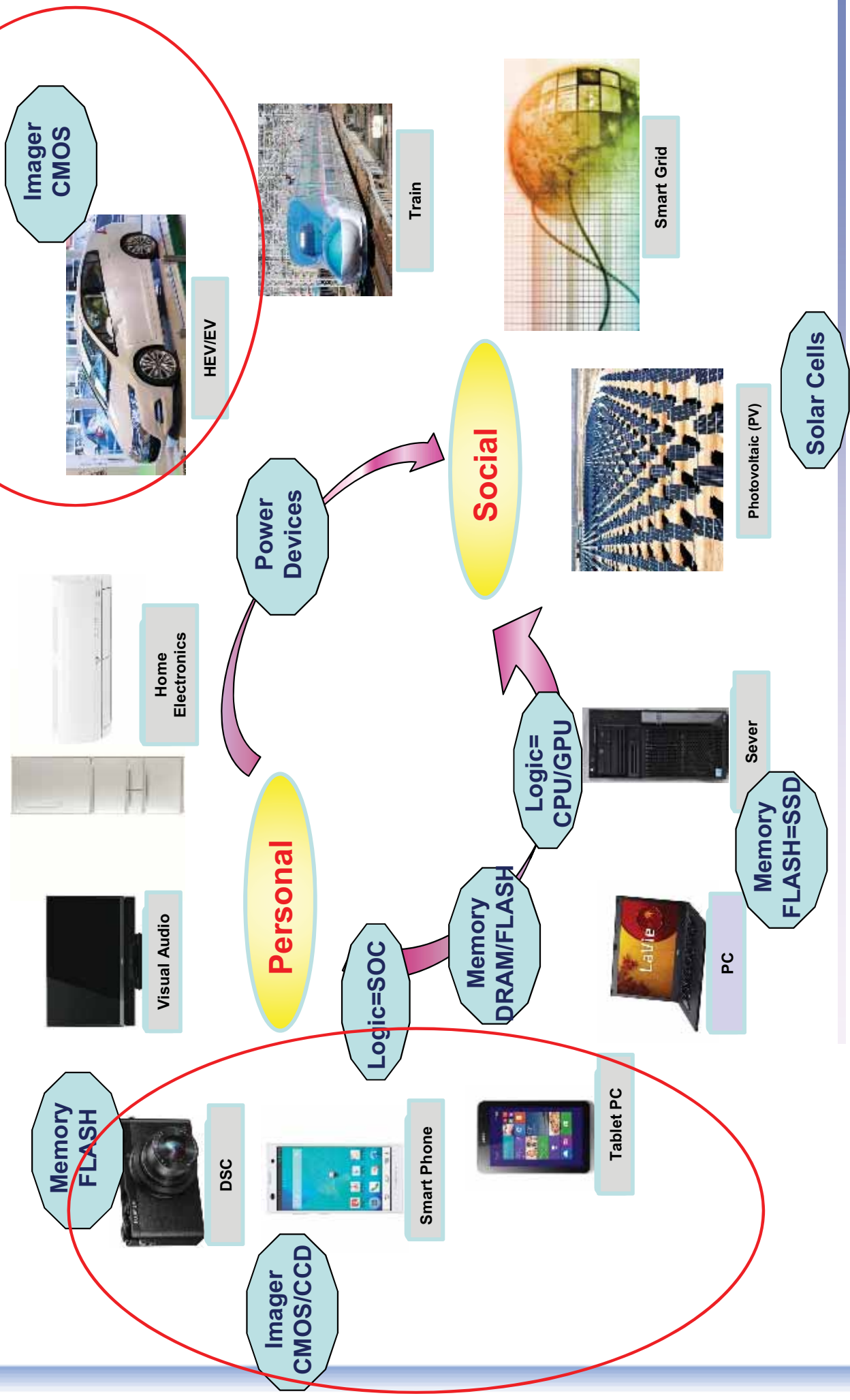
Ion Implantation Technology for Semiconductor Fabrication

Michiro Sugitani

SEN Corporation

Productivity with Precision

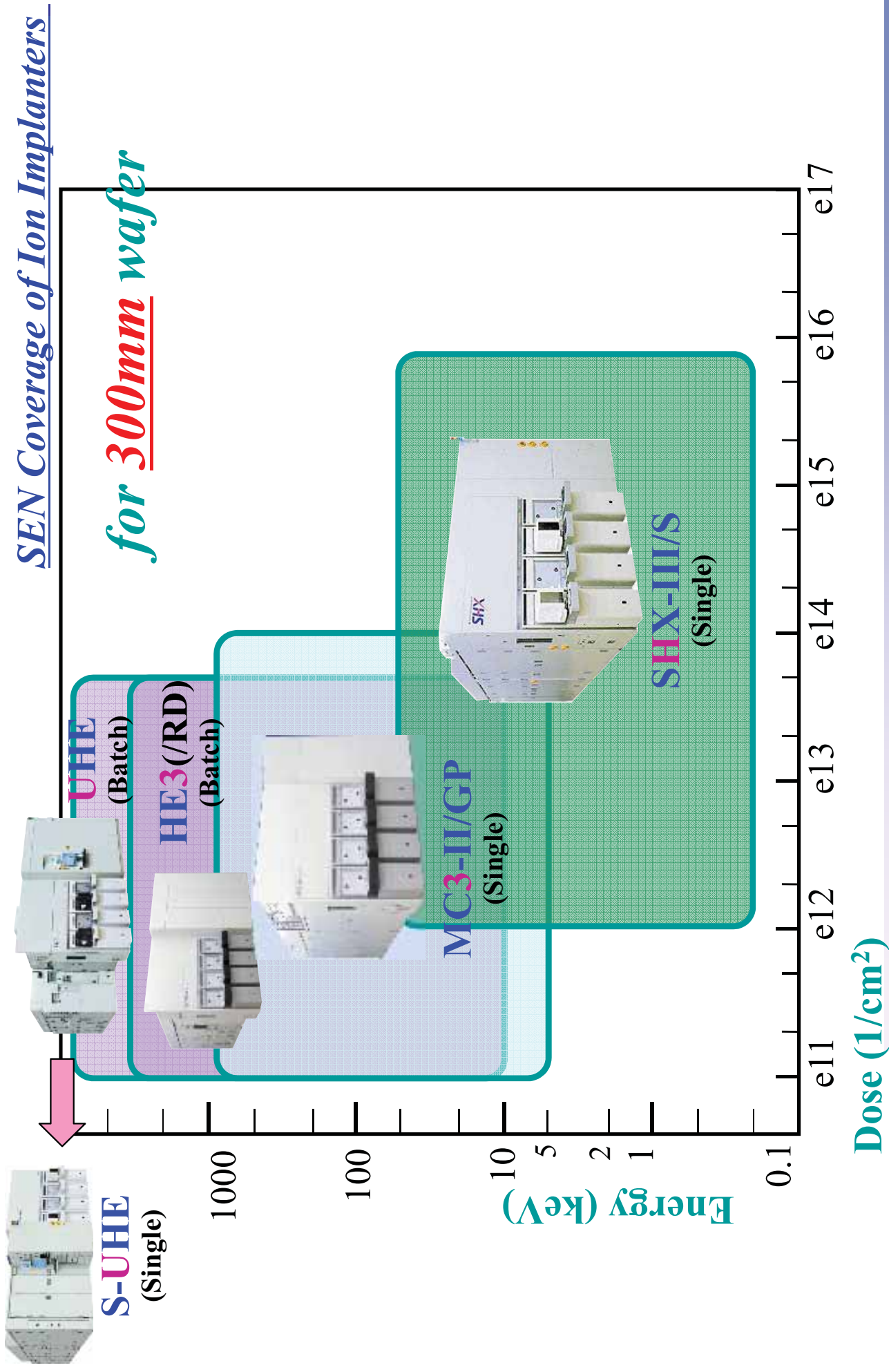
Variety of Semiconductor Consumer



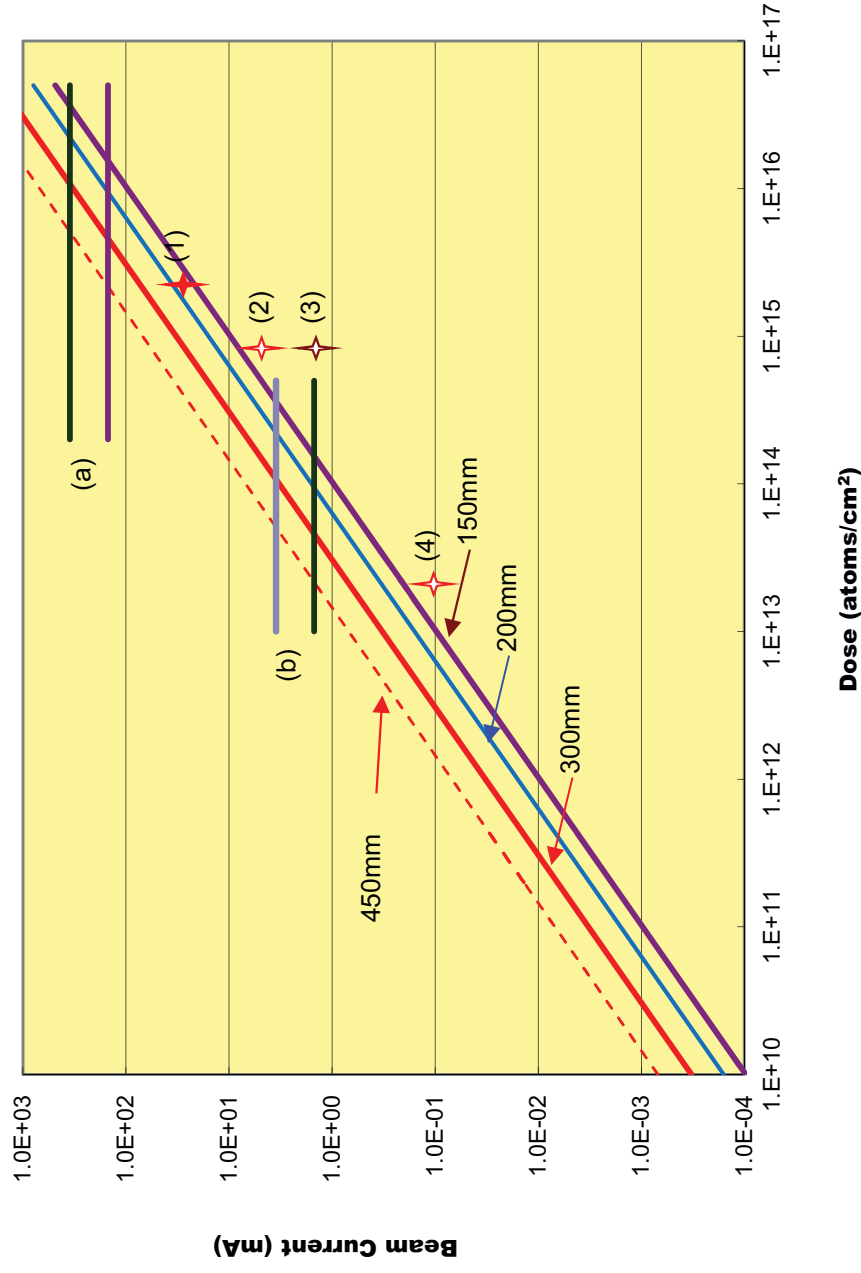
Contents

- **Implantation Energy, Dose and Species**
- **Typical beam line and endstation of Ion Implanters**
- **C/S issues**
 - Benefits or advantages of I/I
- **Fundamental knowledge of I/I technology**
 - Implant damage
 - Recrystallization by thermal annealing
- **C/S issues**
 - Metal contamination
 - Implant damage

Skip item



Required Beam Current for 500 wph



Four slope lines represent required beam current to obtain 500 wph for 150mm (brown), 200mm (blue), 300mm (red), and 450mm wafers (Orange), respectively, assuming a circle beam shape and beam size of 3 cm in diameter in 3.5-second implant time.

Dagger marks indicate actual maximum beam current for (1) 20-200 keV, (2) 1 keV, (3) 200 eV, and (4) 1 MeV with typical doses.

Horizontal lines show upper limits of beam current for (a) 10 keV and (b) 1 MeV for batch implanters (upper line) and single-wafer implanters (lower line), respectively.

Typical ion species used in ion implantation for VLSI

N-type	H[*], P, As, Sb
P-type	B (BF₂^{**}), Al, Ga, In
Non dopant	H, He, C, N, [O], F, Si, [S], Ar, Ge, [Se], Sn, [Xe]

Atoms in solid angled brackets have not become popular or are not promising.

*) Hydrogen itself is not a donor but it generates phosphorous through a ³⁰Si (p, γ) ³¹P

reaction on natural ³⁰Si in Si substrates.[3]

***) BF₂⁺ is usually used to obtain higher beam current than B⁺ beam, particularly in low energy region.

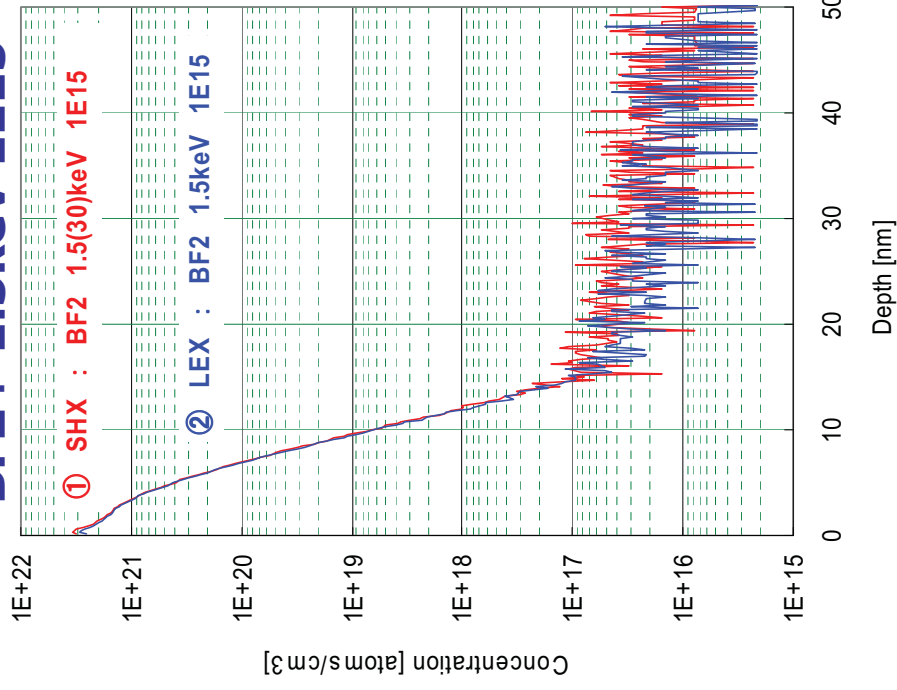
Productivity with Precision

SHX-III/S

Low Energy Implant, SIMS profile

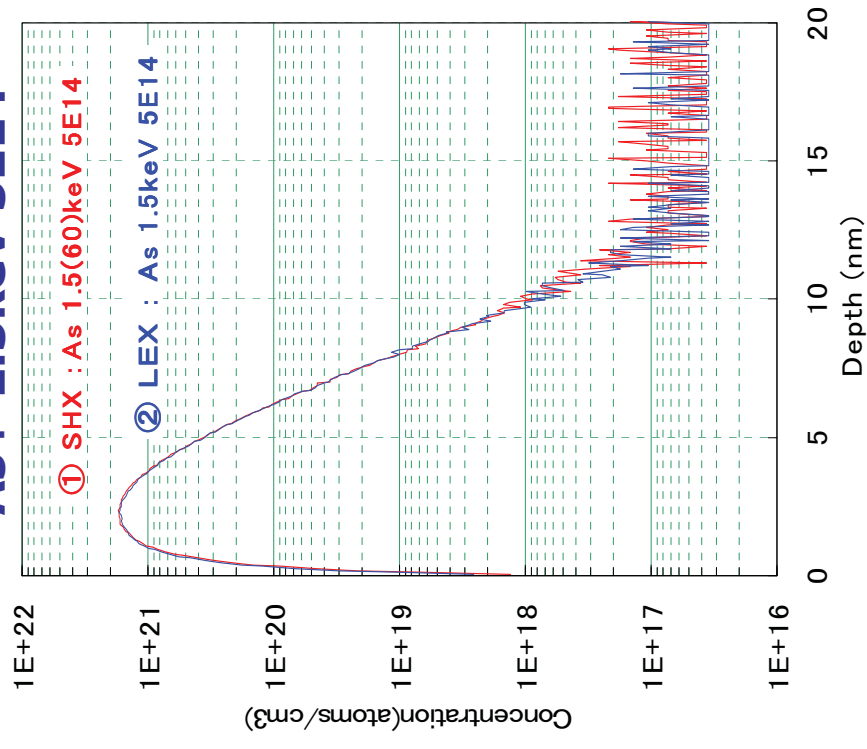
Boron profile with

BF2+ 1.5keV 1E15



Arsenic profile with

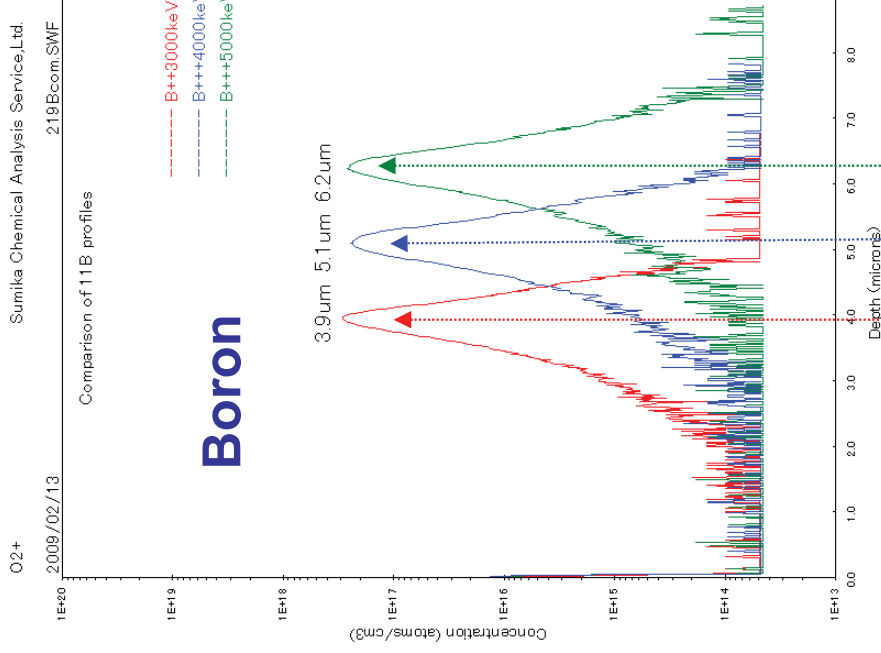
As+ 1.5keV 5E14



Productivity with Precision



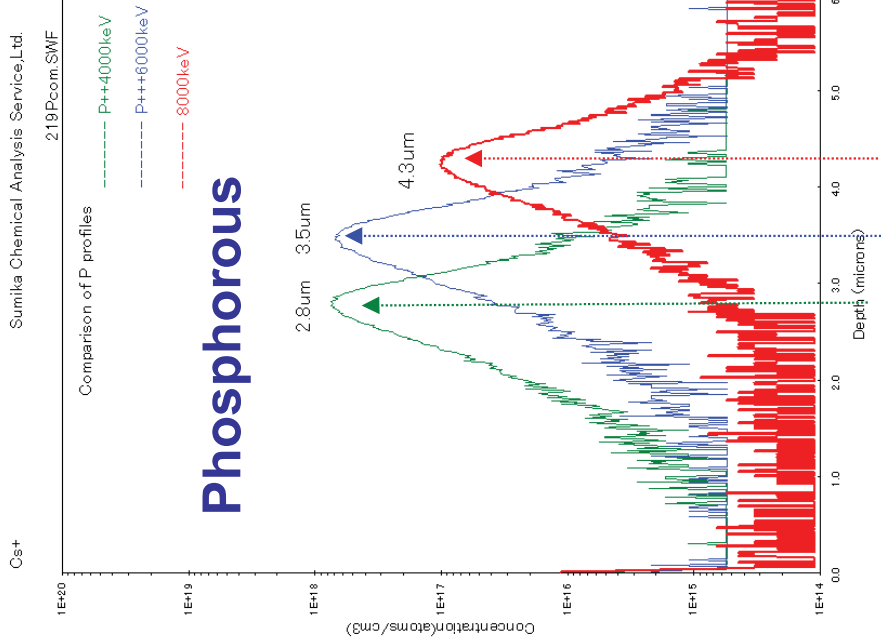
UHE: High Energy implant, SIMS Profiles



3.9 μm @3MeV

6.2 μm @5MeV

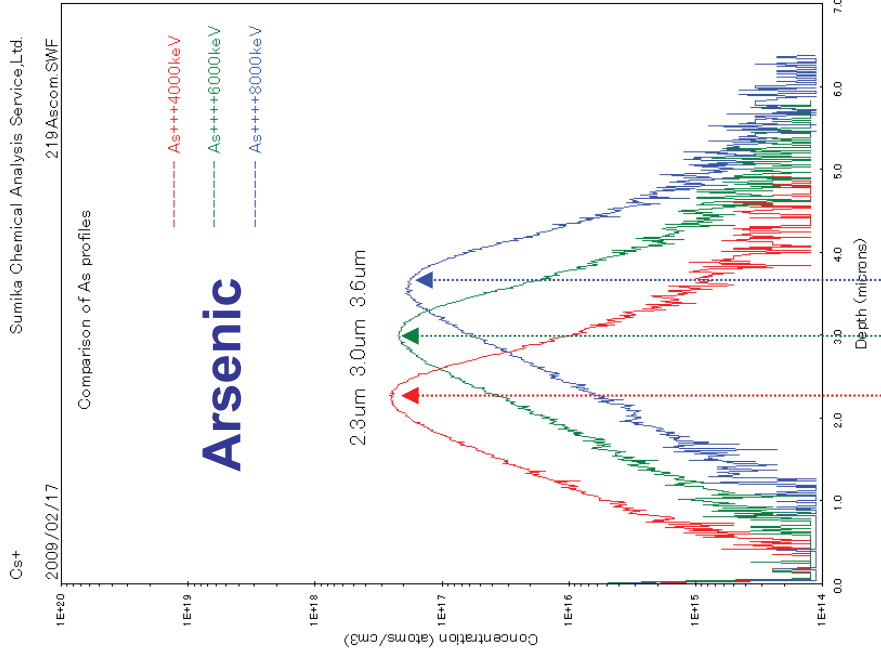
5.1 μm @4MeV



2.8 μm @4MeV

4.3 μm @8MeV

3.5 μm @6MeV



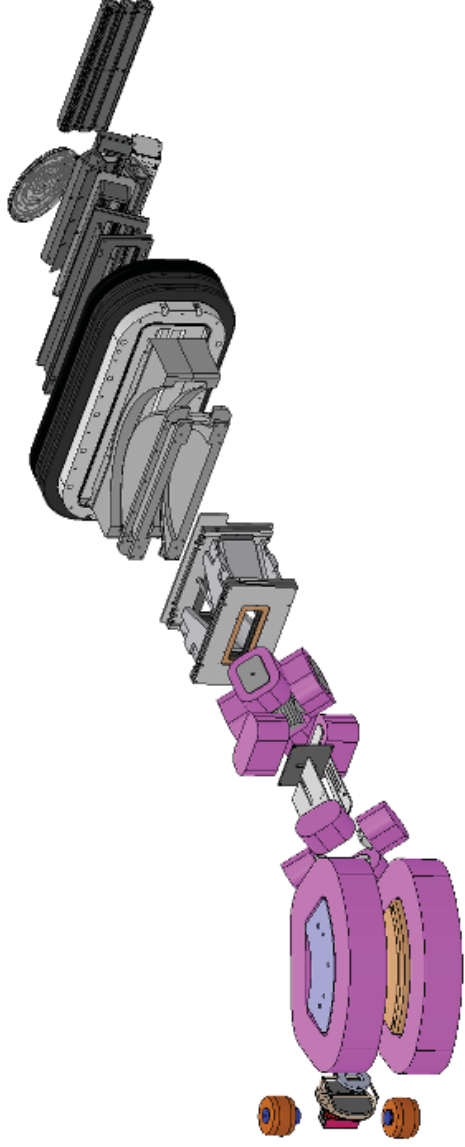
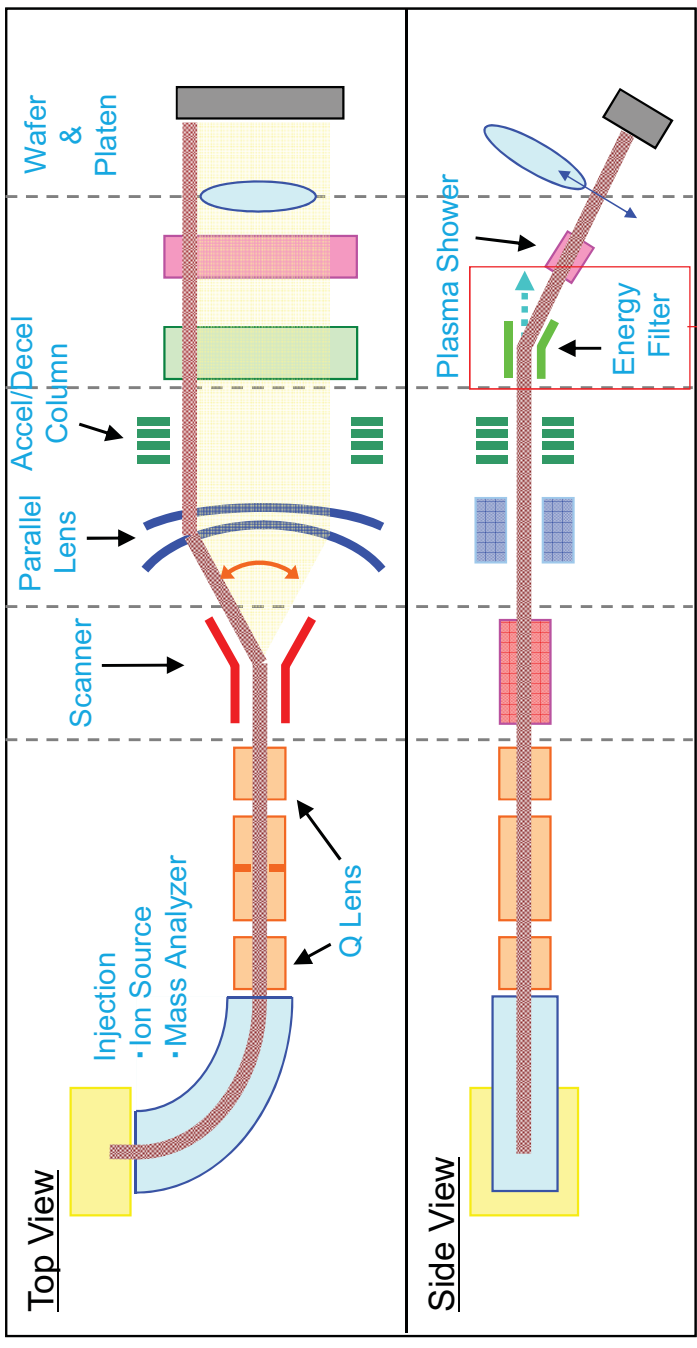
2.3 μm @4MeV

3.6 μm @8MeV

3.0 μm @6MeV

Productivity with Precision

SHX-III/S Layout of Major Components



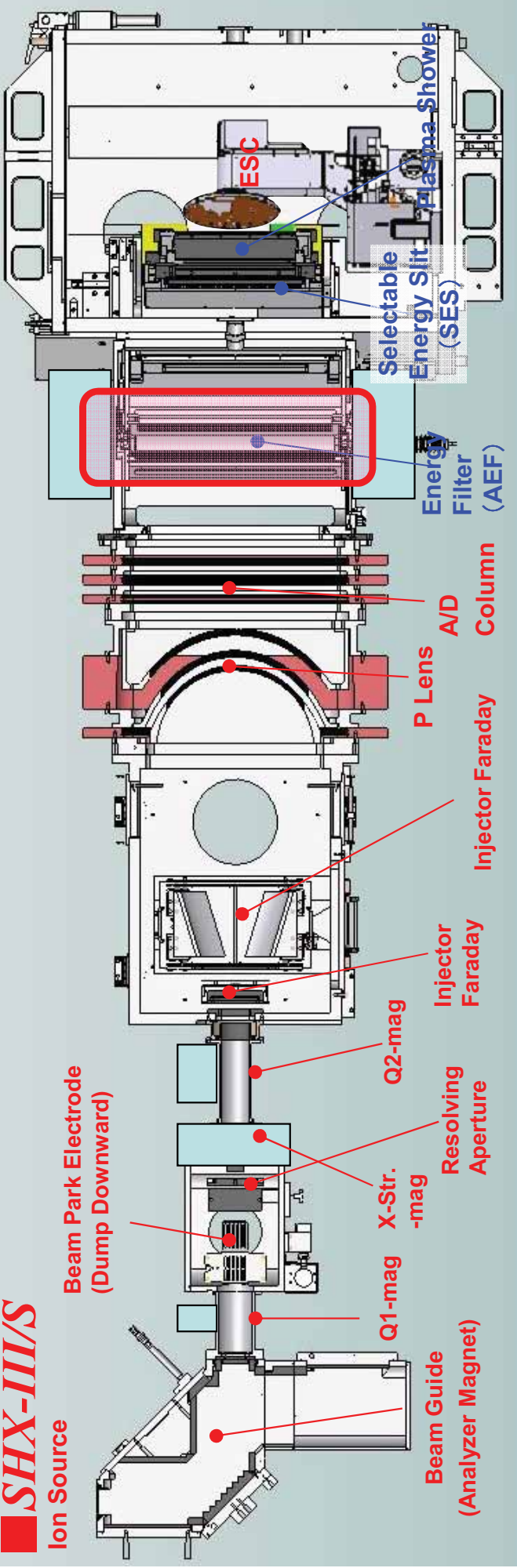
Hybrid type

- Electric
- Magnetic

SHX-III/S

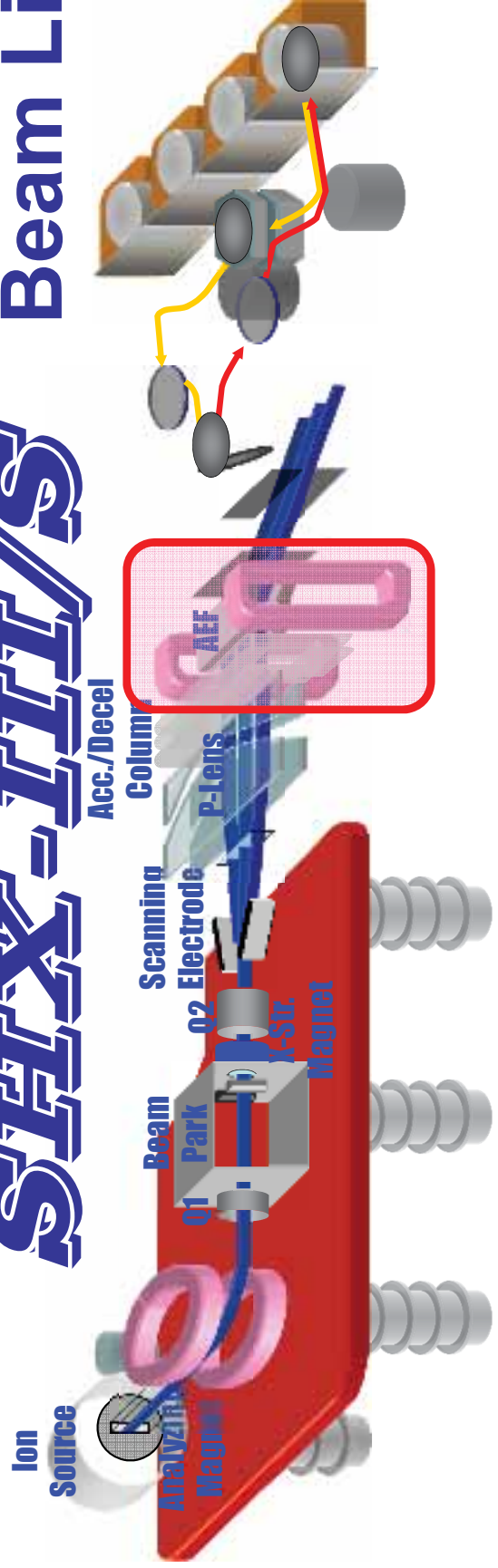
Ion Source

Beam Park Electrode
(Dump Downward)



SHX-III/S

Beam Line



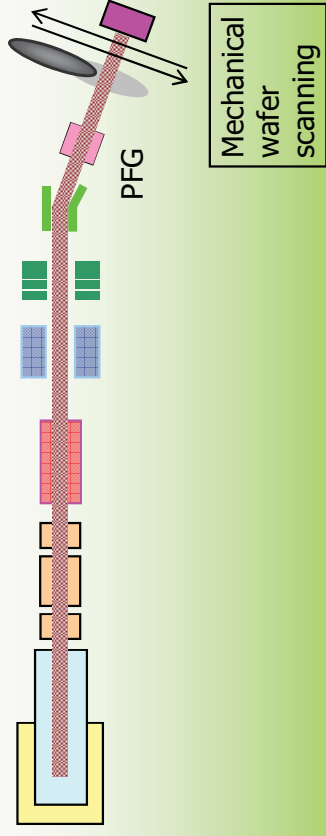
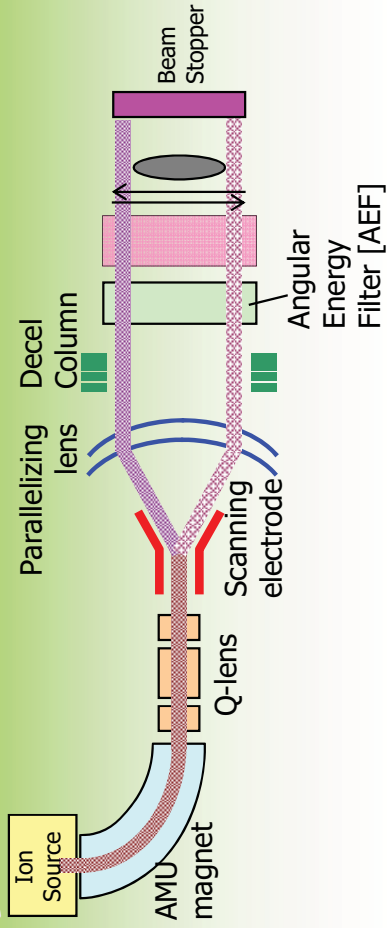
Productivity with Precision

High Current Implanter STHX-III/S

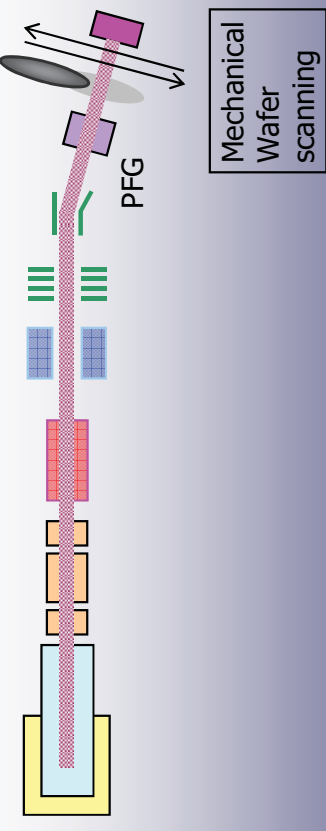
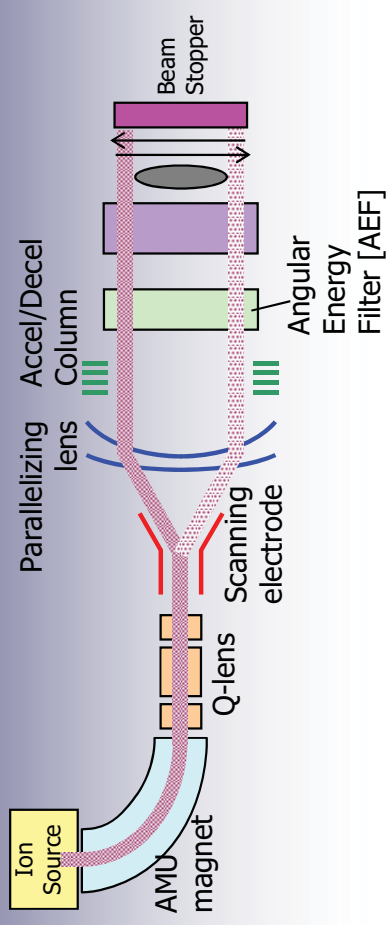
Medium Current Implanter MCC3-II/GP



= Top View =



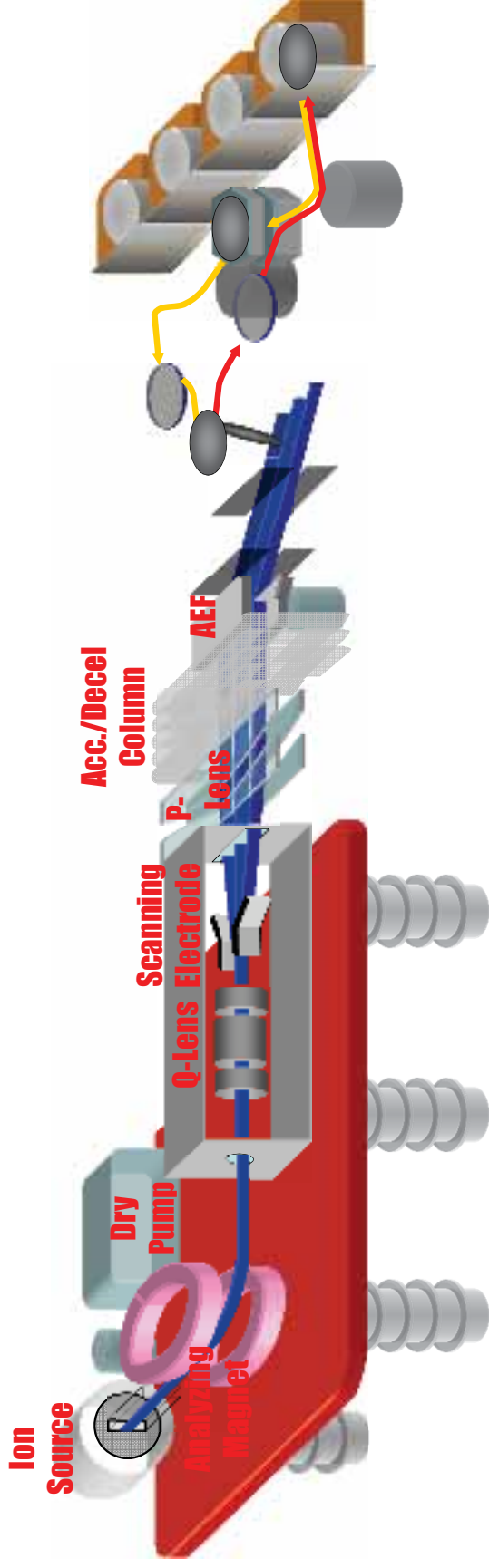
= Side View =



Productivity with Precision

MIC3-II/GP

Beam Line

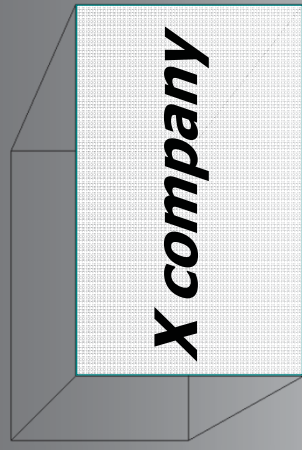
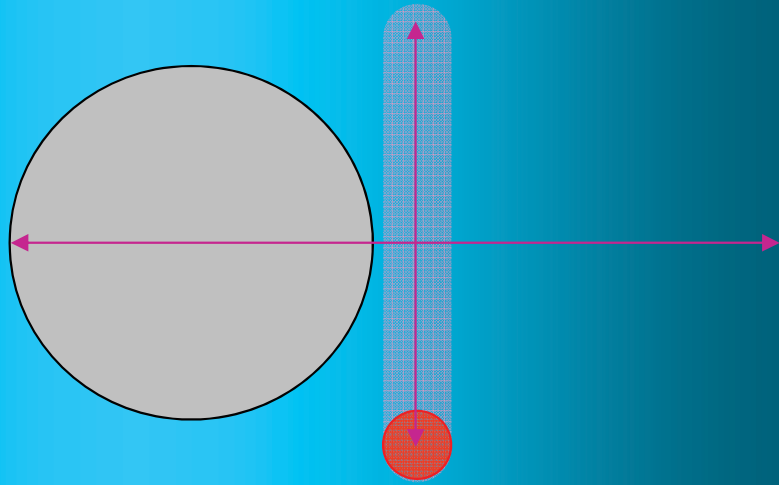


Implant sequence of various types of single-wafer implanters

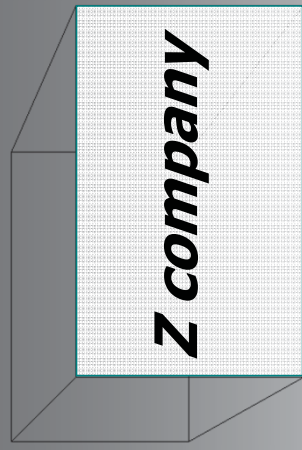
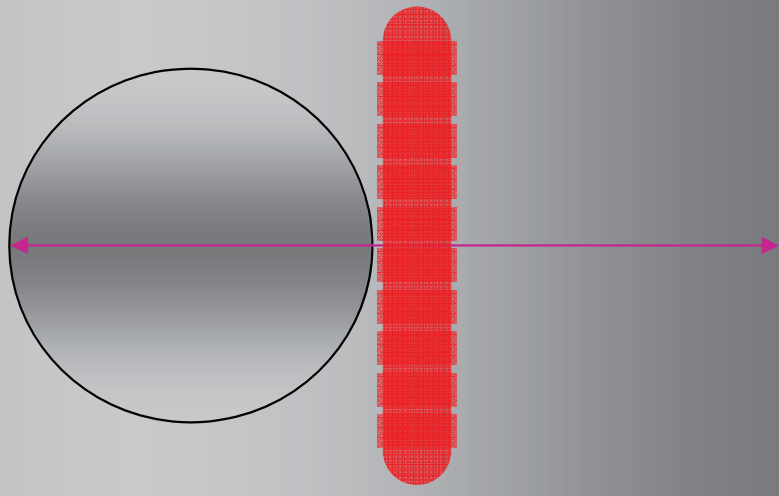
Accuracy with Precision



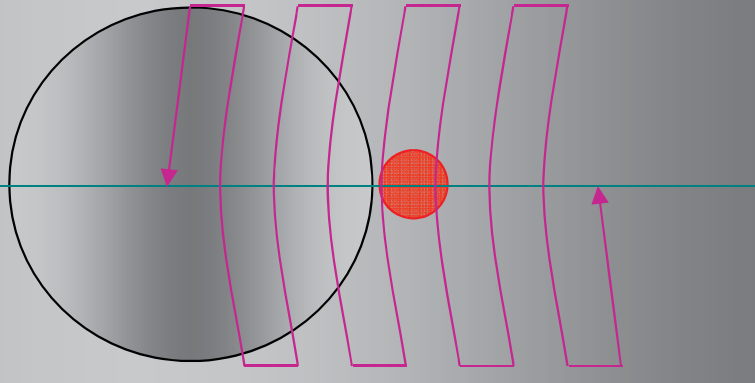
Scanned beam
1D mechanical



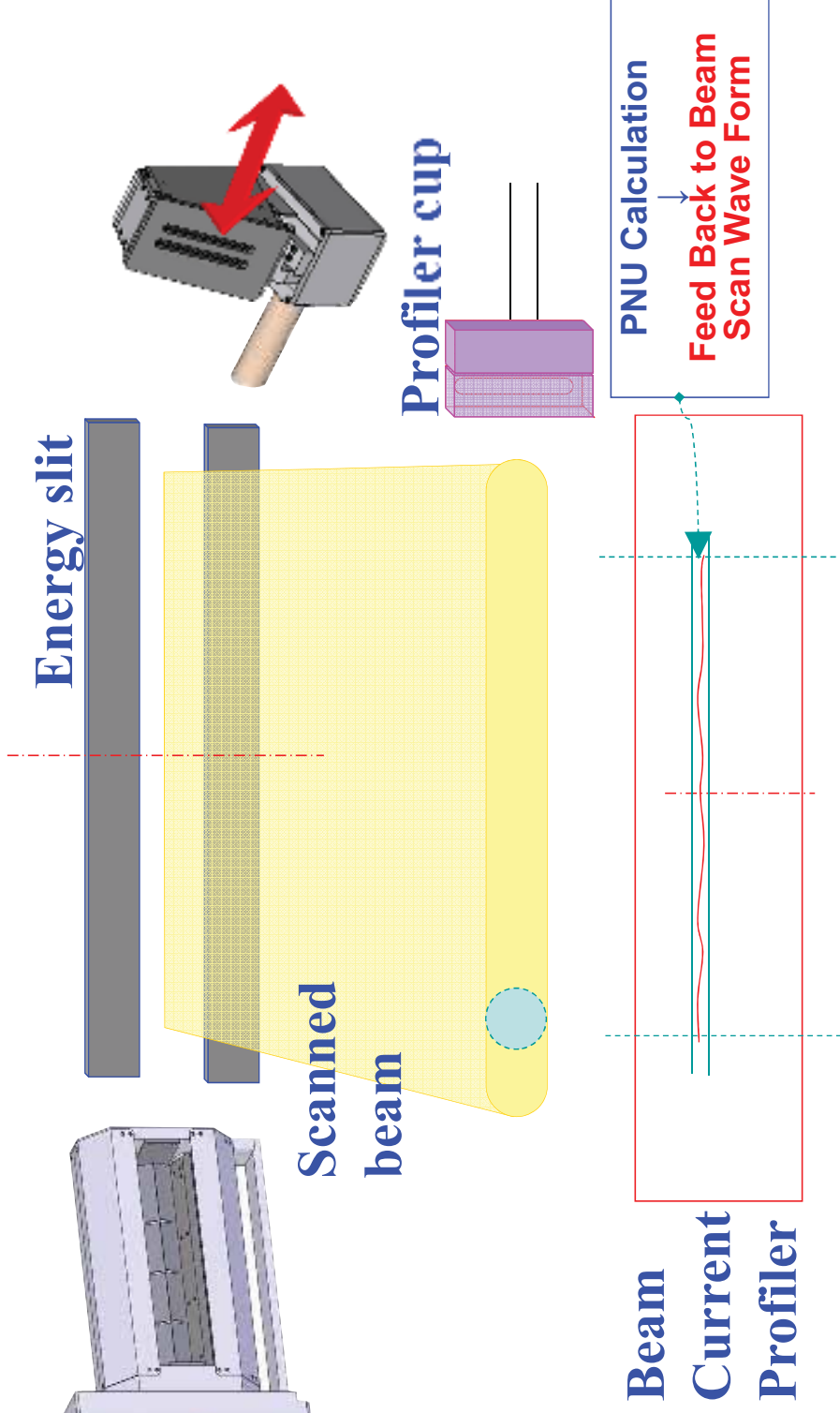
Ribbon beam
1D mechanical



Spot beam
2D mechanical



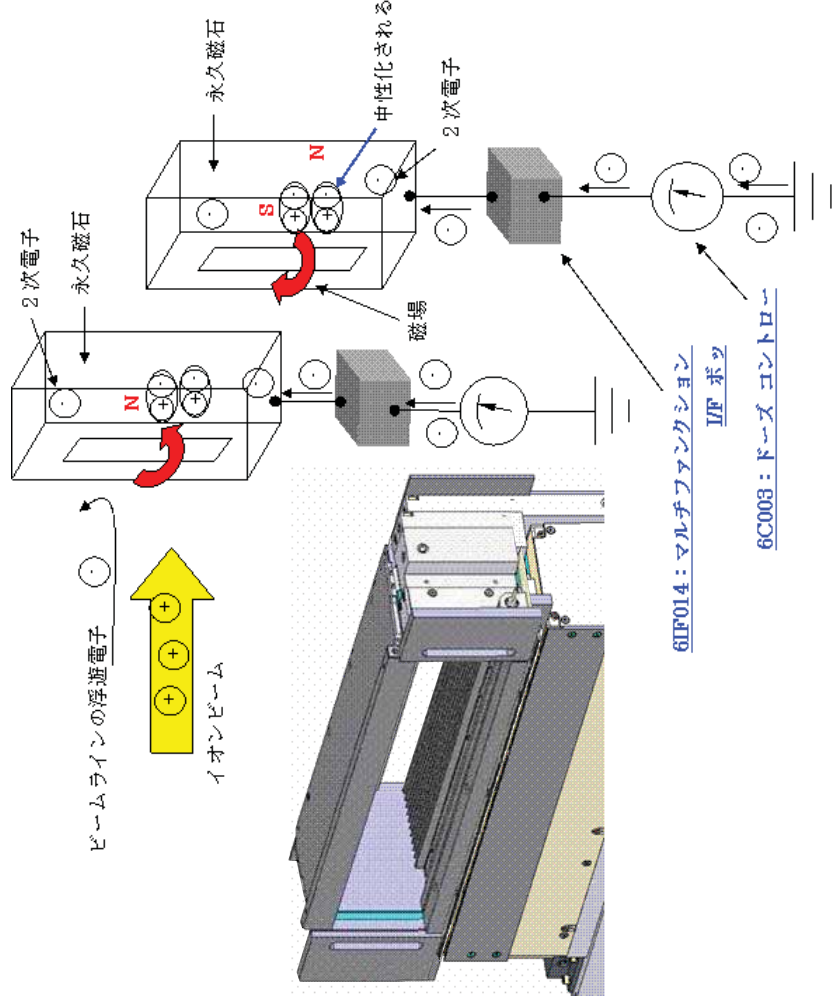
Measurement of Predicted Non-Uniformity (PNU)



- PNU : Predicted Non-Uniformity of the Beam at wafer position
- Profiler cup : Faraday Cup measuring Beam Current Distribution at Wafer Position
- C/F : Correction factor for speed adjustment of Scanned Beam
- C/F Auto : Software for C/F auto-adjustment by measured PNU

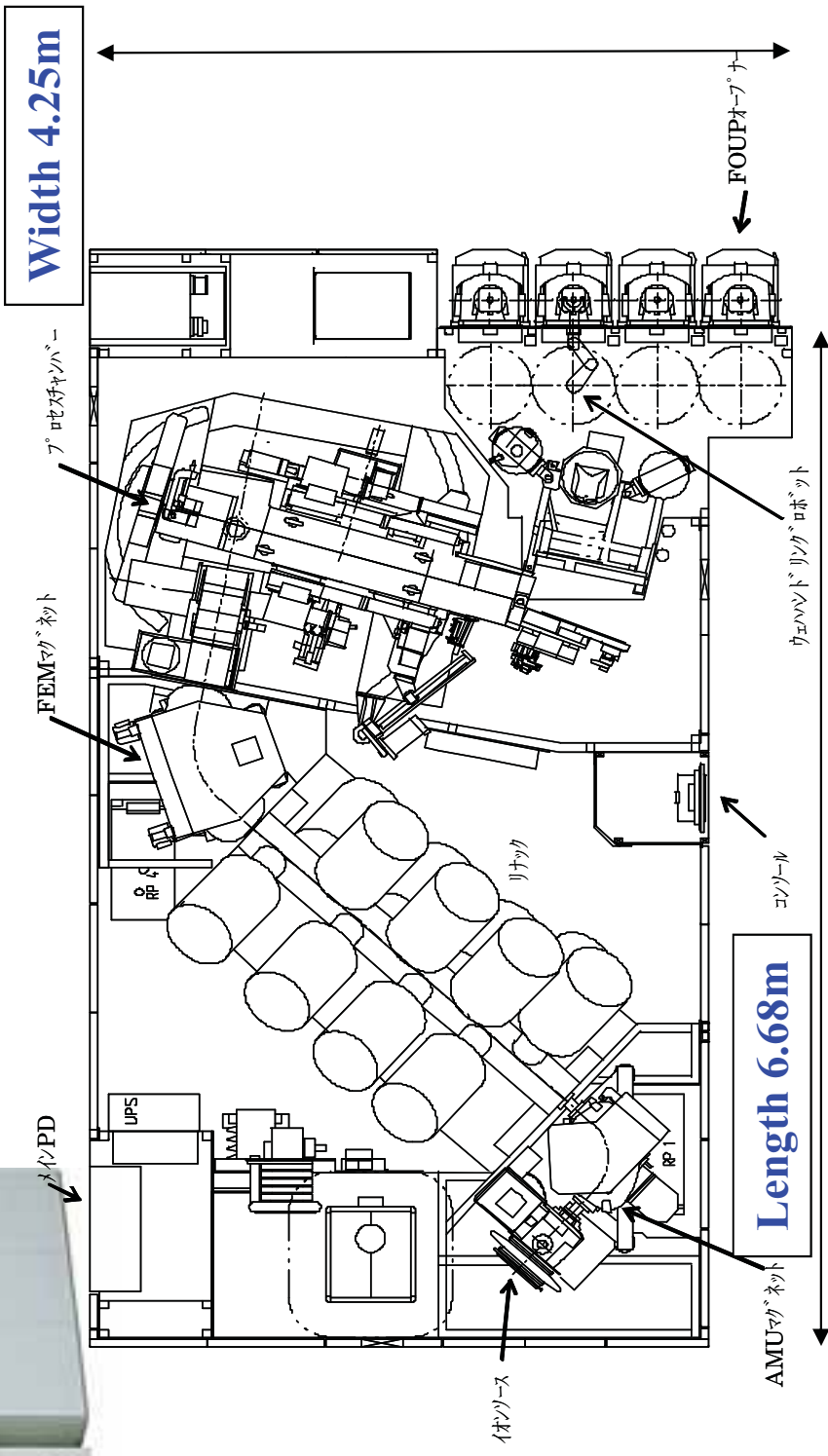
Mechanical Scan control during implant

- During implant, the beam current is measured by Dose Cups located at the both ends of Plasma shower housing in real-time
 - Measured beam current is used for Y-scan speed control

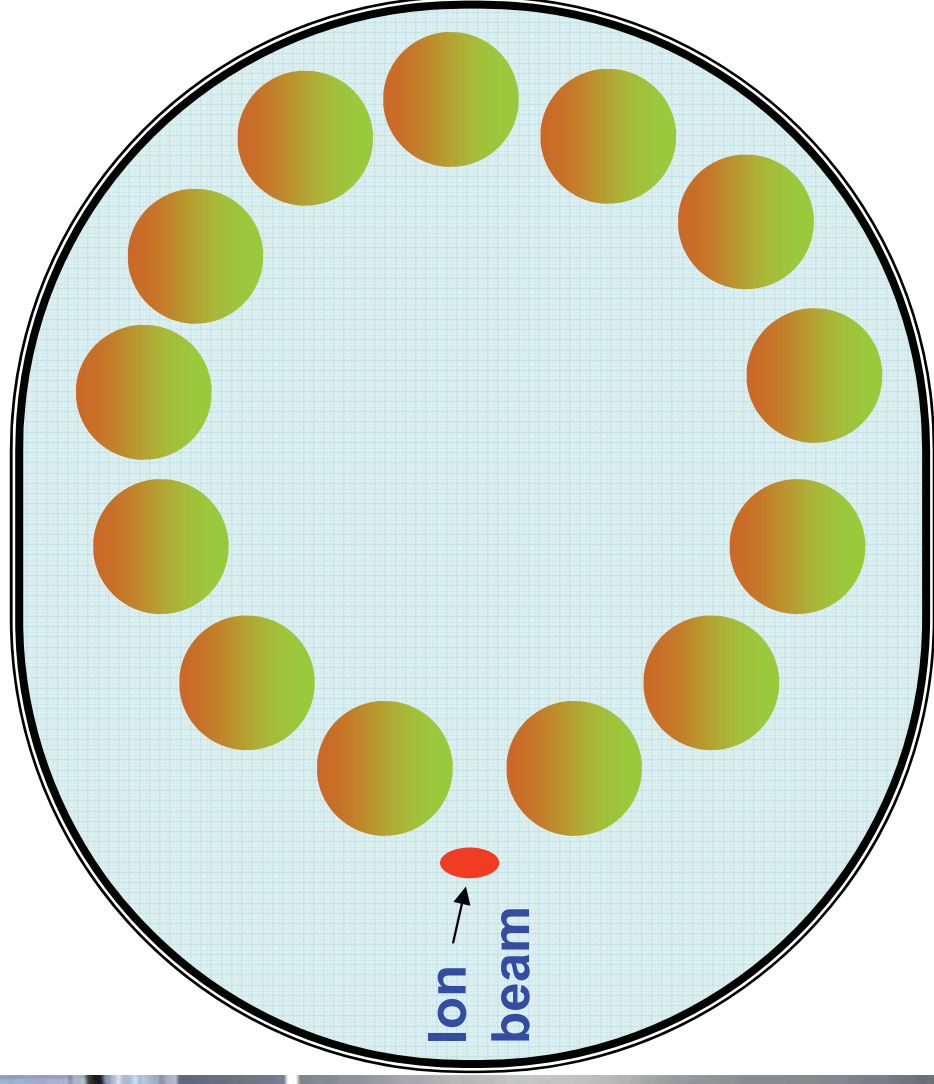


Productivity with Precision

HE3/RD Layout



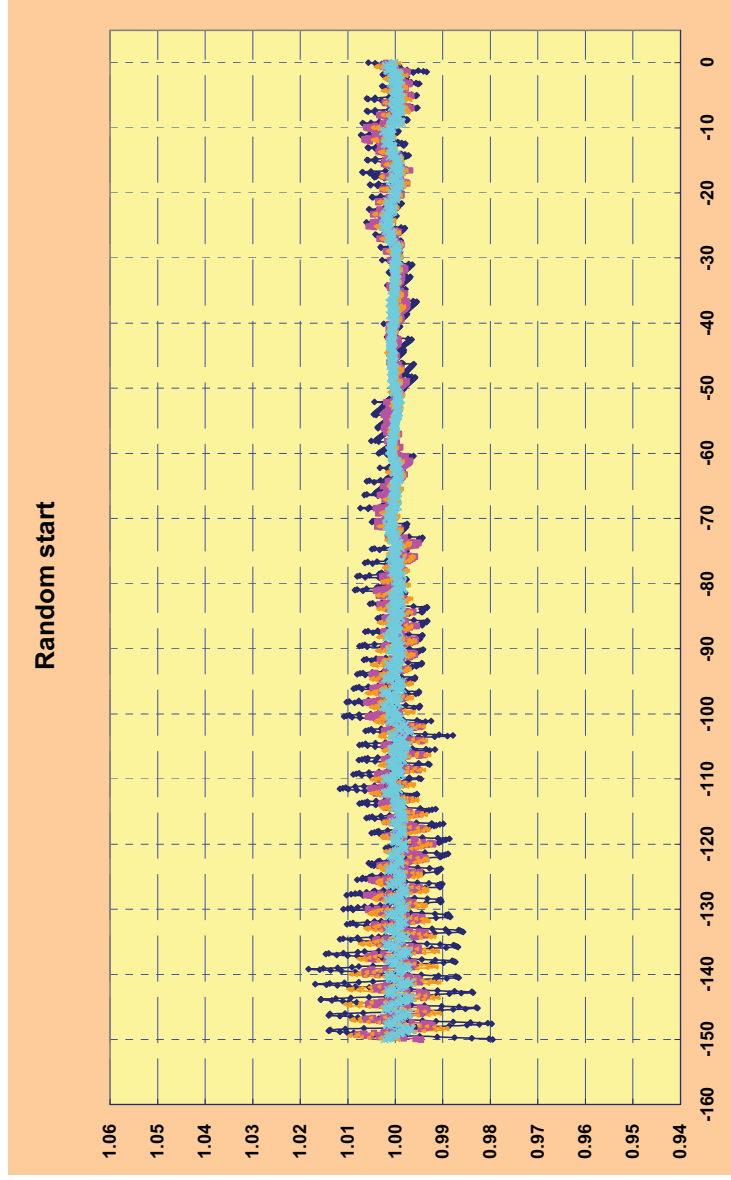
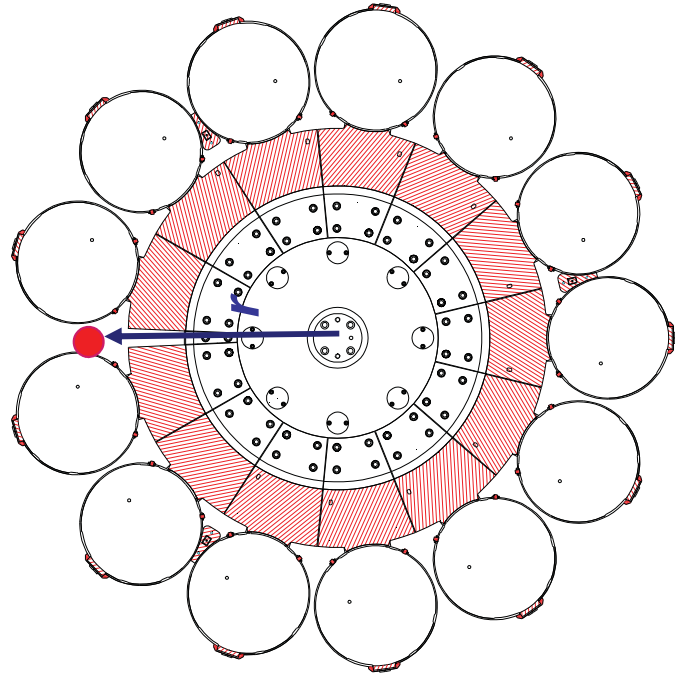
Implant mechanism by Batch-type implanter



Y-scan is controlled by $1/r$ algorithm

VSD (VIRTUAL SLIT DISK)

Si COAT



- How to reduce undulation
- ◆ make pitch shorter
 - faster rotation speed
 - slower Y-scan
 - ◆ more scan number

Comparison between ion implantation and thermal diffusion

Items \ Doping methods	Ion implantation	Vapor phase diffusion	Solid phase diffusion
Doping range (cm ⁻³)	Wide range 10 ¹⁶ ~ 10 ²¹	Narrow range 10 ²⁰ ~ 10 ²¹	Narrow range 10 ¹⁹ ~ 10 ²¹
Temperature	<200°C (photo resist mask)	>900°C (need hard mask)	>900°C (need hard mask)
Process cost	High	Low	Low
Defect injection	High damage	Low damage	Low damage
Lateral spread toward depth	~0.7	1	1
Process steps	Only implant	Deposition Etching Diffusion and Strip	Deposition Etching Diffusion and Strip
Depth profile	Control by energy Retrograde profile	No control Highest concentration at surface	No control Highest concentration at surface

Lower concentration at surface region

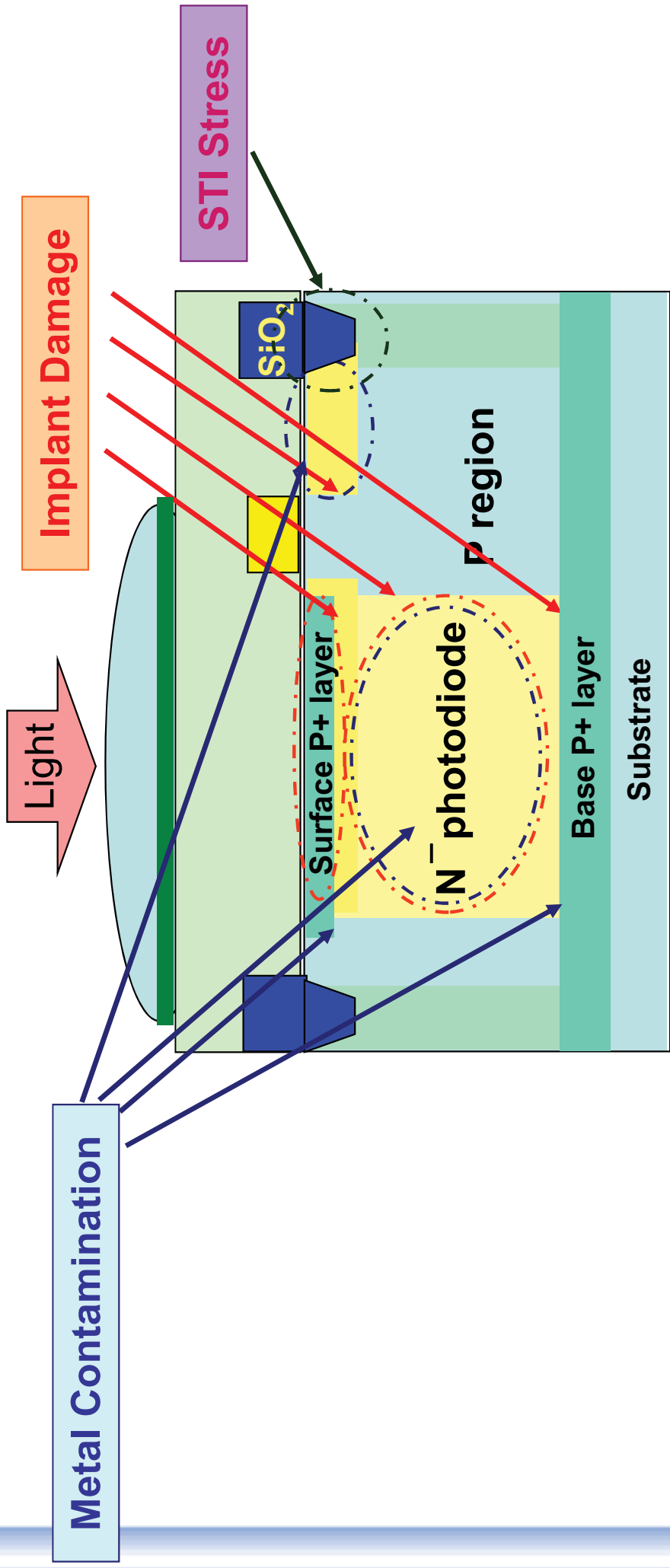
Five superior advantages of ion implantation

1. Dose uniformity: $\sigma < 0.5\%$ within a 300mm wafer
2. Wide dynamic range in dose and depth: **5 orders**
Dose: E10 – E16
Depth: a few nm – several μm
3. Selective doping **only by photo-resist mask**
thanks to room temperature process
(No need of hard mask.)
4. Retrograde profile (buried peak profile)
5. Setting-up energy can accurately control the depth

Key words of basis of implantation

1. Dose and concentration
2. Basically damage induced process
3. Knock-on, vacancy, and interstitial
4. Amorphous and “End of range”
5. Channeling
6. 5 advantages of implantation
7. Annealing must be performed after implantation
temperature, time, vs. diffusion, solid solubility
8. Annealing and Leakage current
9. Halo implantation

CIS standard structure and Total image of CIS issues



4. Metal contamination

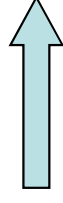
- **Energetic contamination**
- **Surface knock-on contamination**

Energetic implant of metallic atoms

- Metallic atoms ionized in ion source chamber
- Pass through Mass Analyzer Magnet due to inseparable “momentum to charge ratio”
- Typical cases: BF₂
 - Molybdenum (Mo) case
 - Tungsten (W) case

Magnetic: $r = \sqrt{2mE}/qB$

Electrostatic: $r = 2E/qE$



If mE/q^2 is same or close, different two species cannot be separated.

Energetic implant of metallic atoms

Mo case

Same Analyzing Magnet strength

Mo⁺ : 98

Mo⁺⁺ : 49 ↔ [BF₂⁺ = 49]

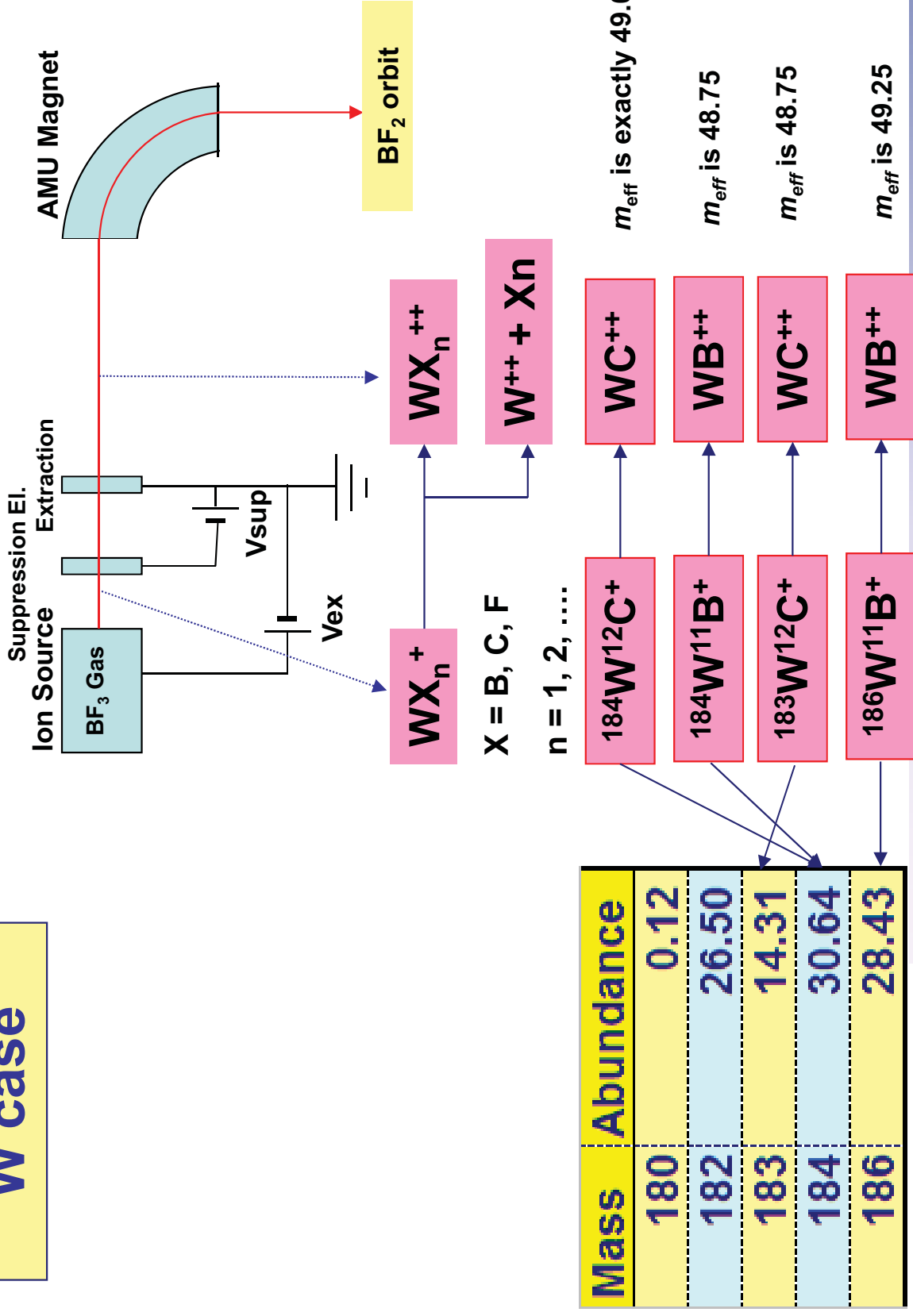
Mass	Abundance
92	14.84
94	9.25
95	15.92
96	16.68
97	9.55
98	24.13
100	9.63

Mo⁺⁺ ions are never separated from BF₂⁺

2-1-1. Energetic implant of metallic atoms

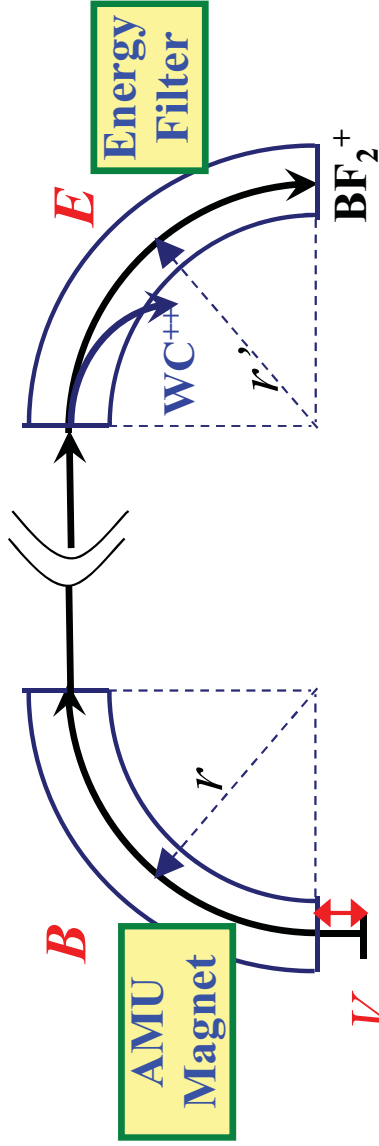
W case

More complicated sequence than Mo case



Actual Ion Implanter

Magnetic: $r = \sqrt{2mE}/qB$
 Electrostatic: $r = 2E/qE$



V: extraction voltage
 r: magnet radius

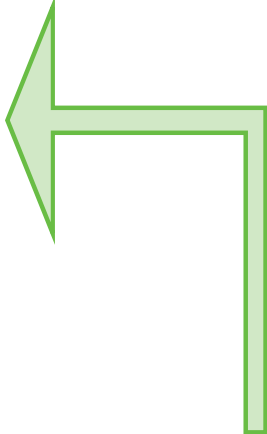
Mo → W

MC3 and SHX series has a combination of magnetic and electro-static filtering

AMU analysis must be done by magnet because electro-static analyzer can not separate the same energy ions; $E = qV$.

Even with an AMU magnet, if mE/q^2 is same, mass **cannot** be separated;
 BF₂⁺ (m=49, E=V, q=1) → Mo⁺⁺ (m=98, E=2V, q=2) or
 WC⁺ (m=196, E=V, q=1) → WC⁺⁺ (m=196, E=V, q=2)

If an additional electric-static analyzer is used, WC⁺⁺ (m=196, E=V, q=2) can be separated from BF₂⁺ (m=49, E=V, q=1)



Surface contamination knocked-on by dopant ions

- Usually, surface contamination can be swept out by following cleaning process
- However, during ion implantation metallic atoms on the surface could be driven into silicon by knock-on process
- Comparison of knock-on effect among ion energy and species
 - Energy range from several 10keV to 1MeV
 - Typical B, P and As cases

Metal Knock-on comparison between HE and MC

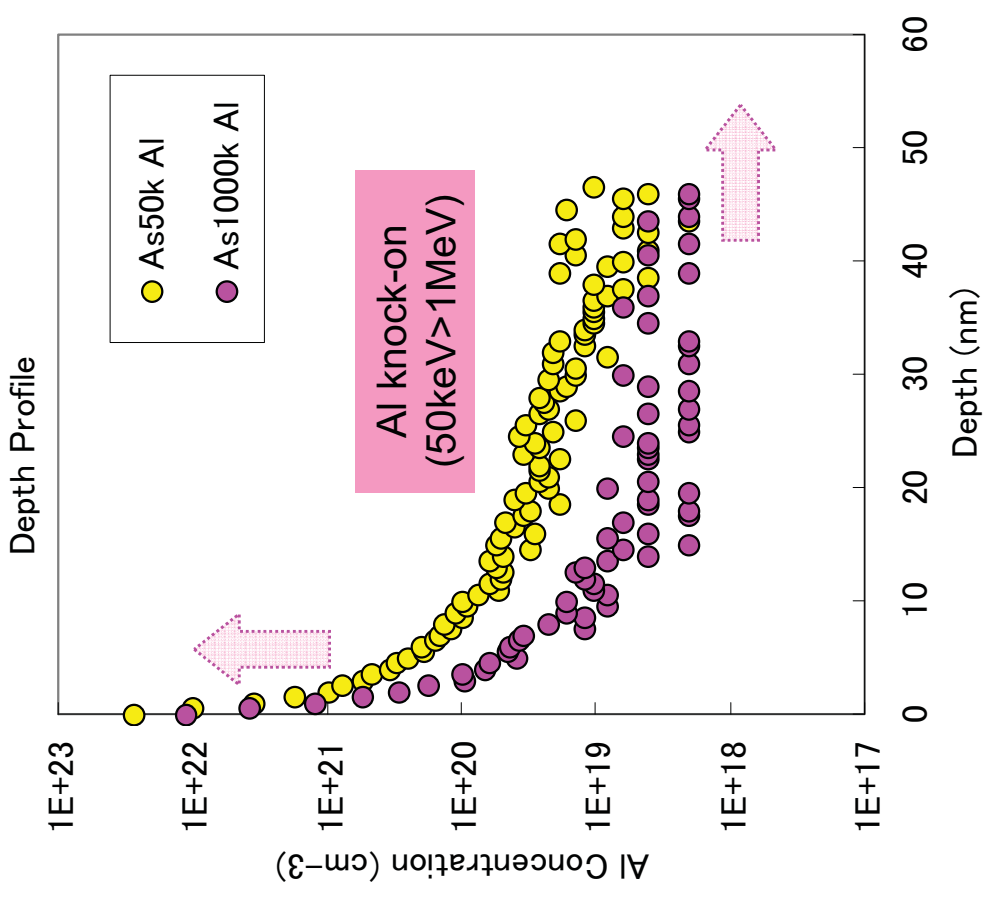
Rutherford Scattering

$$\frac{d\sigma}{d\Omega} = \left(\frac{ZZ'e^2}{4E}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

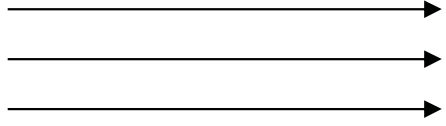
Etched layer : 1nm

As 50keV 1E15cm⁻²
As 1MeV 1E15cm⁻²

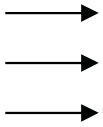
Al/As : 0.412
Al/As : 0.090



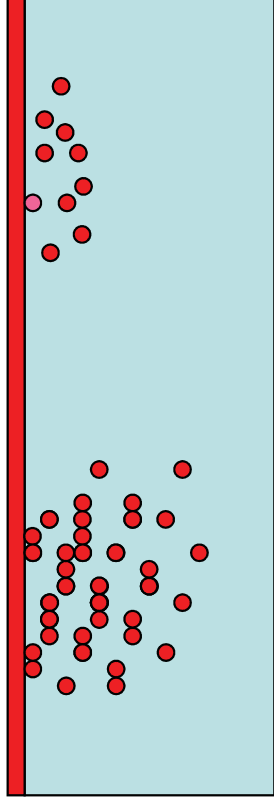
As 1MeV



As 50keV



Al 3nm

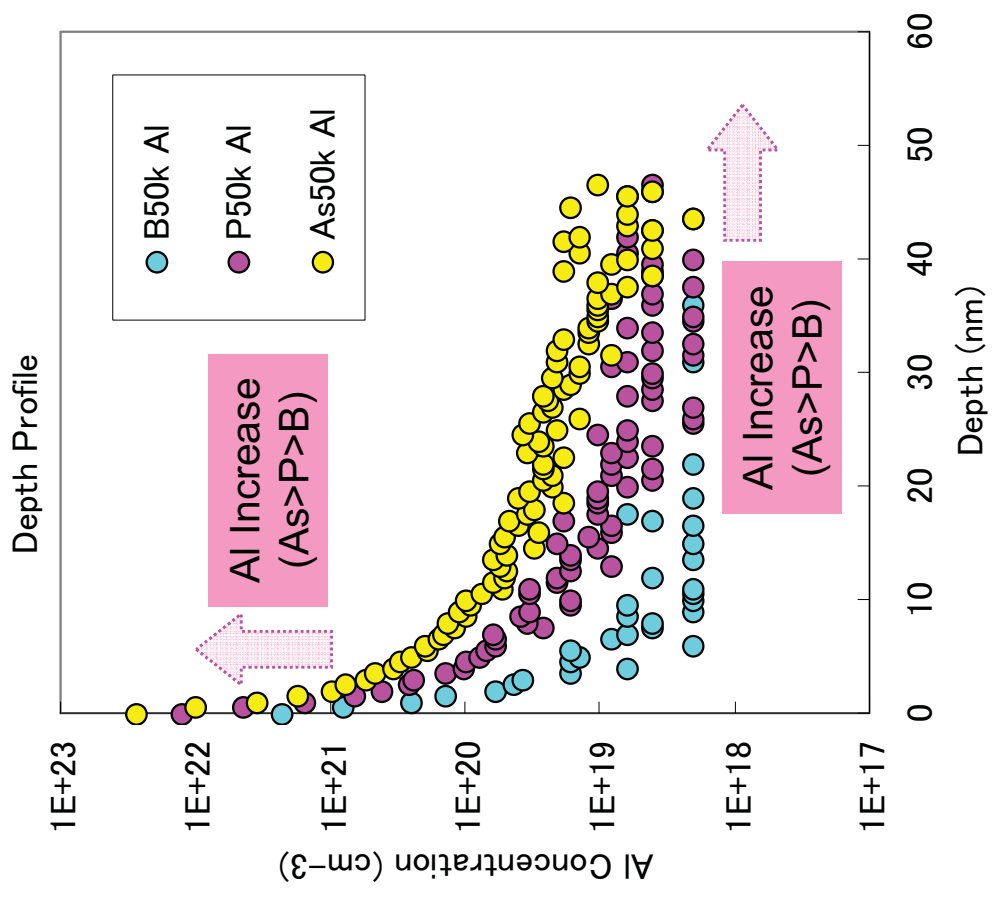
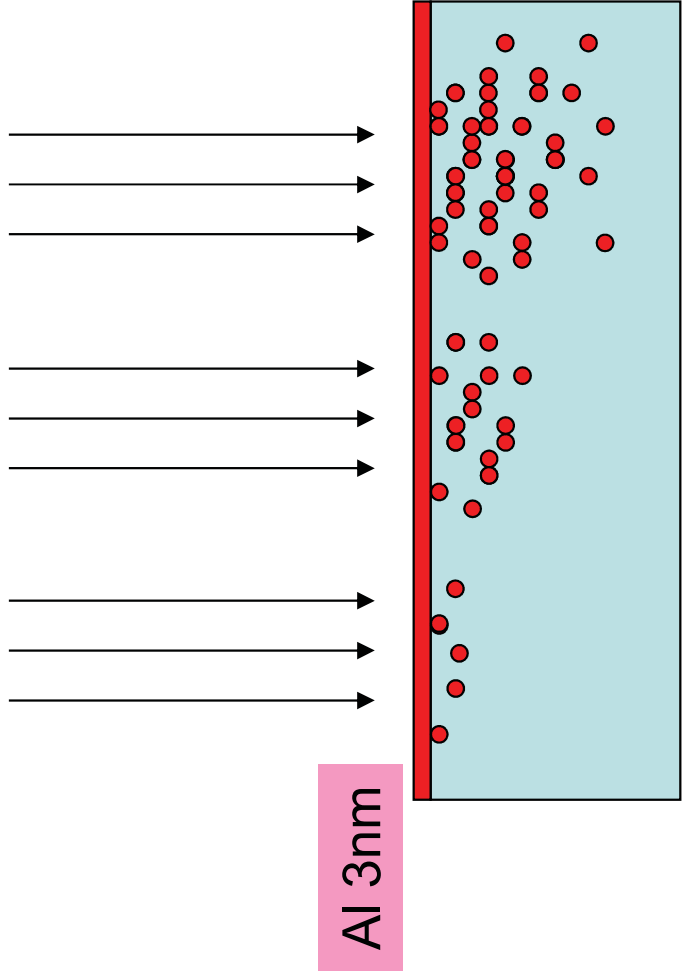


Metal Knock-on comparison between B, P and As

As 50keV 1E15cm⁻²
 P 50keV 1E15cm⁻²
 B 50keV 1E15cm⁻²

Etched layer : 1nm
 Al/As : 0.412
 Al/P : 0.141
 Al/B : 0.021

B 50keV P 50keV As 50keV



Metal Knock-on comparison between B, P and As

Etched layer : 1nm

As 50keV 1E15cm⁻²
 P 27keV 1E15cm⁻²
 B 10keV 1E15cm⁻²

Al/As : 0.412
 Al/P : 0.202
 Al/B : 0.056

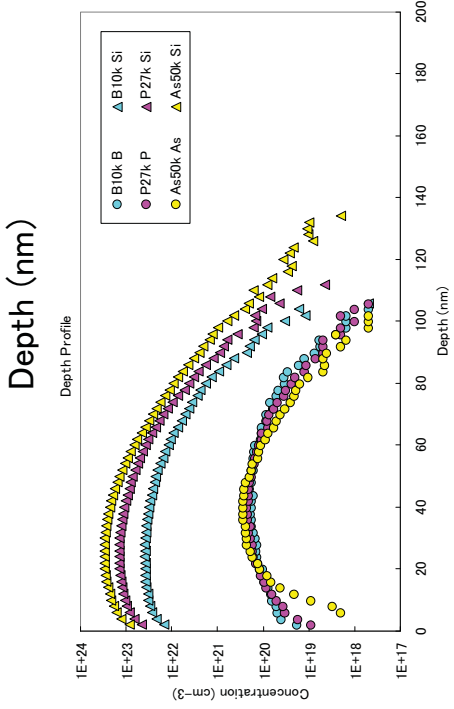
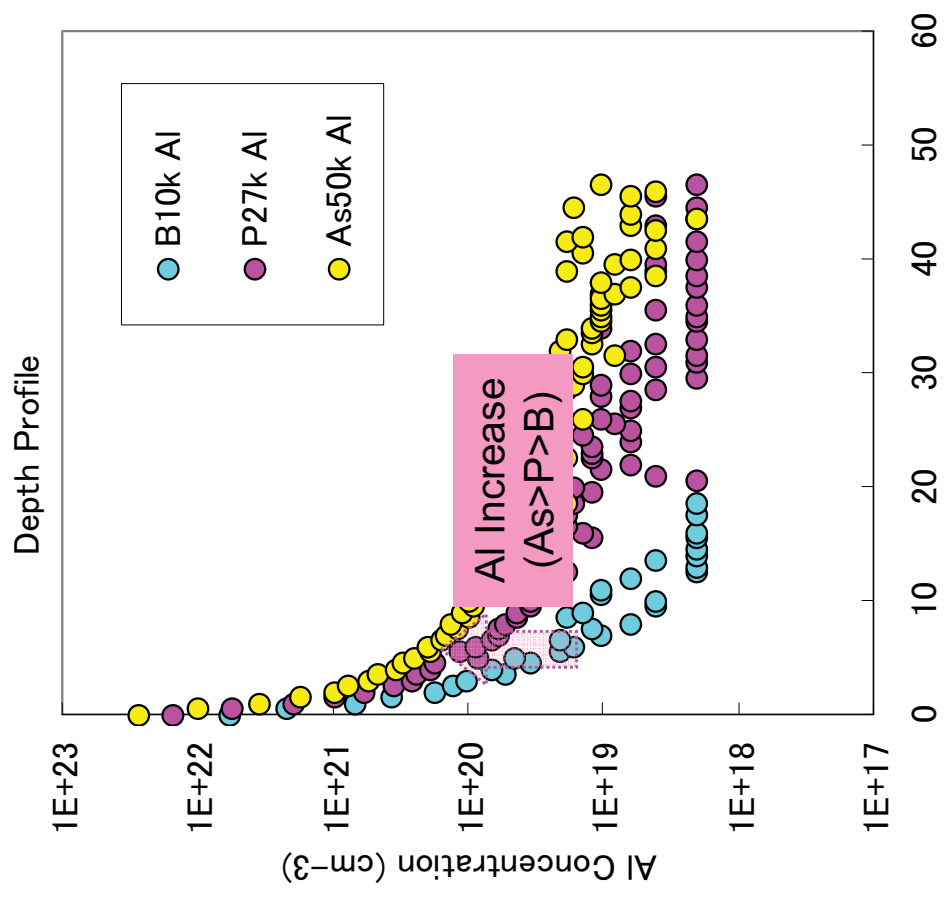
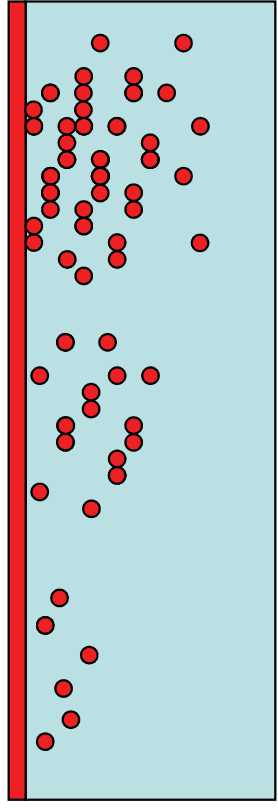
These conditions have similar projection ranges

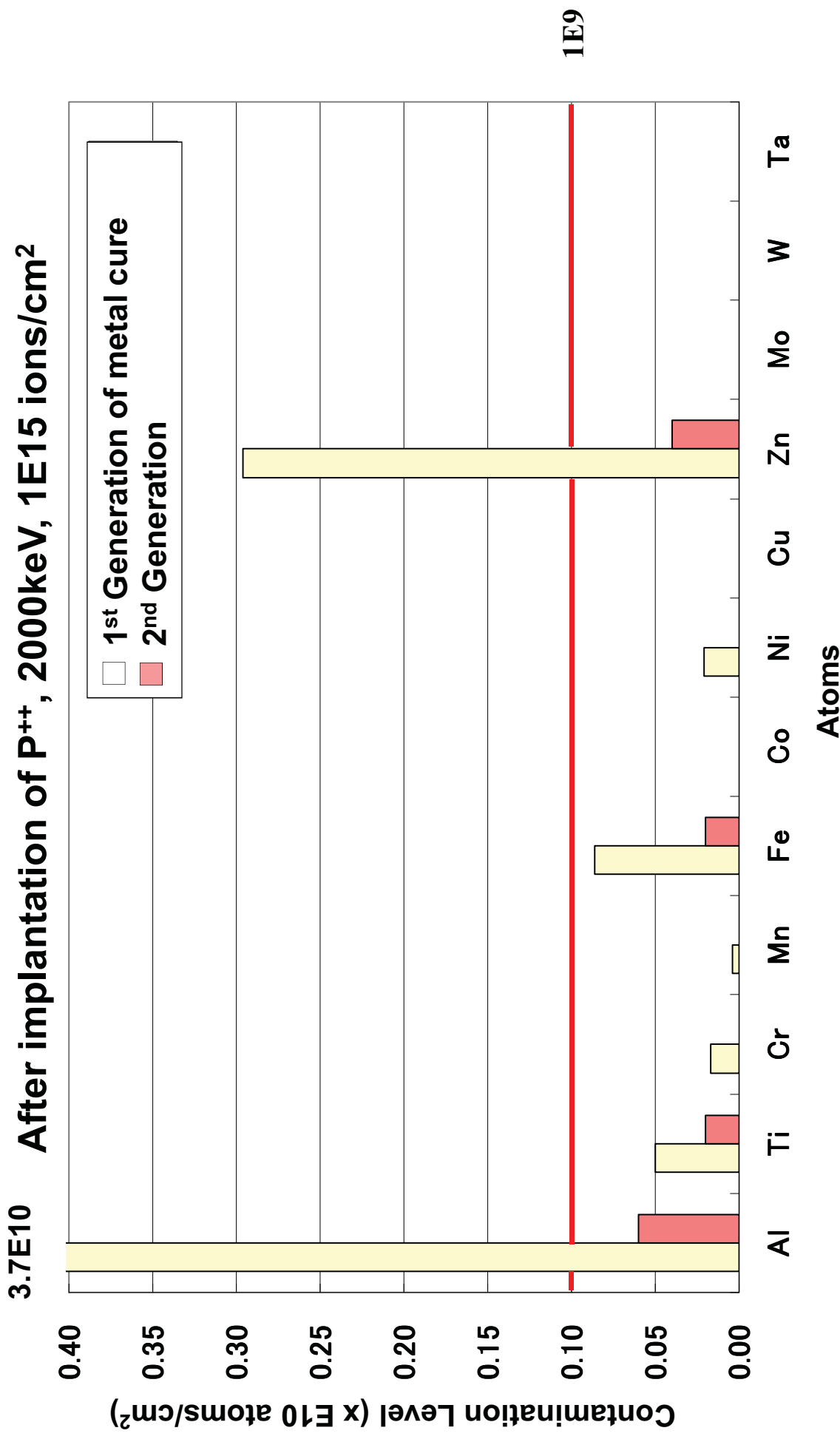
As 50keV

P 27keV

B 10keV

Al 3nm



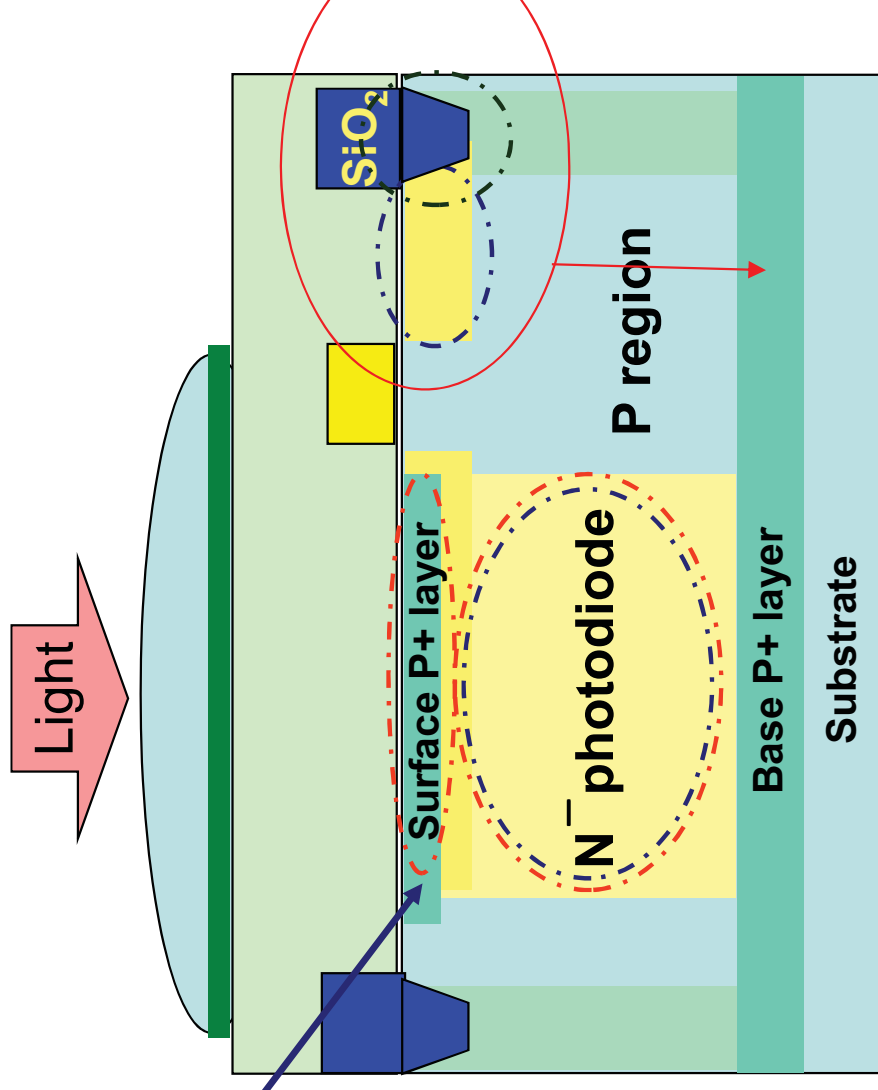


Implant Damage

- **Implant damage would cause dark current enhancement or white blemish generation**
- **Quantitative analysis has not been performed due to complexity of combination of ion implantation and following annealing processes**
- **Some qualitative study was done with very sensitive CCD (Charge Coupled Device) image sensors**

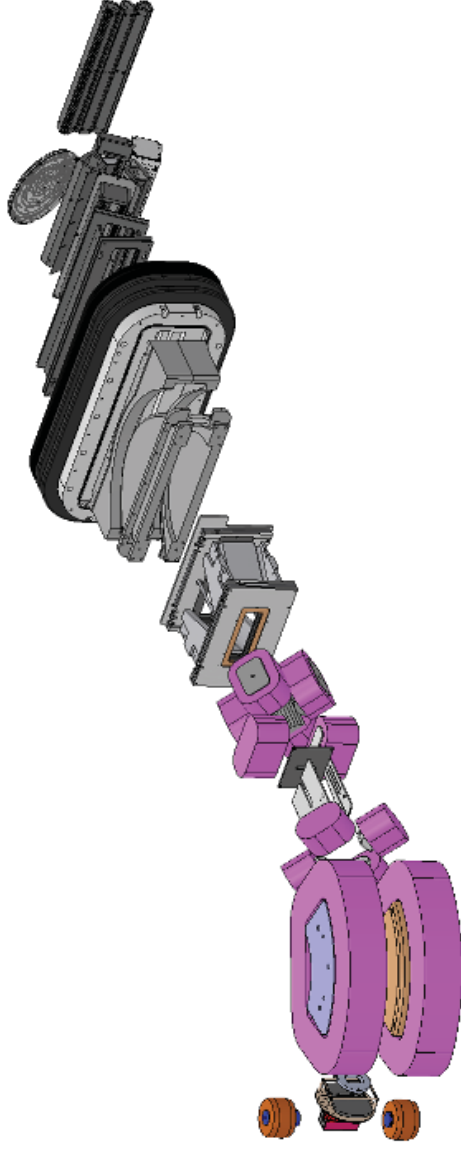
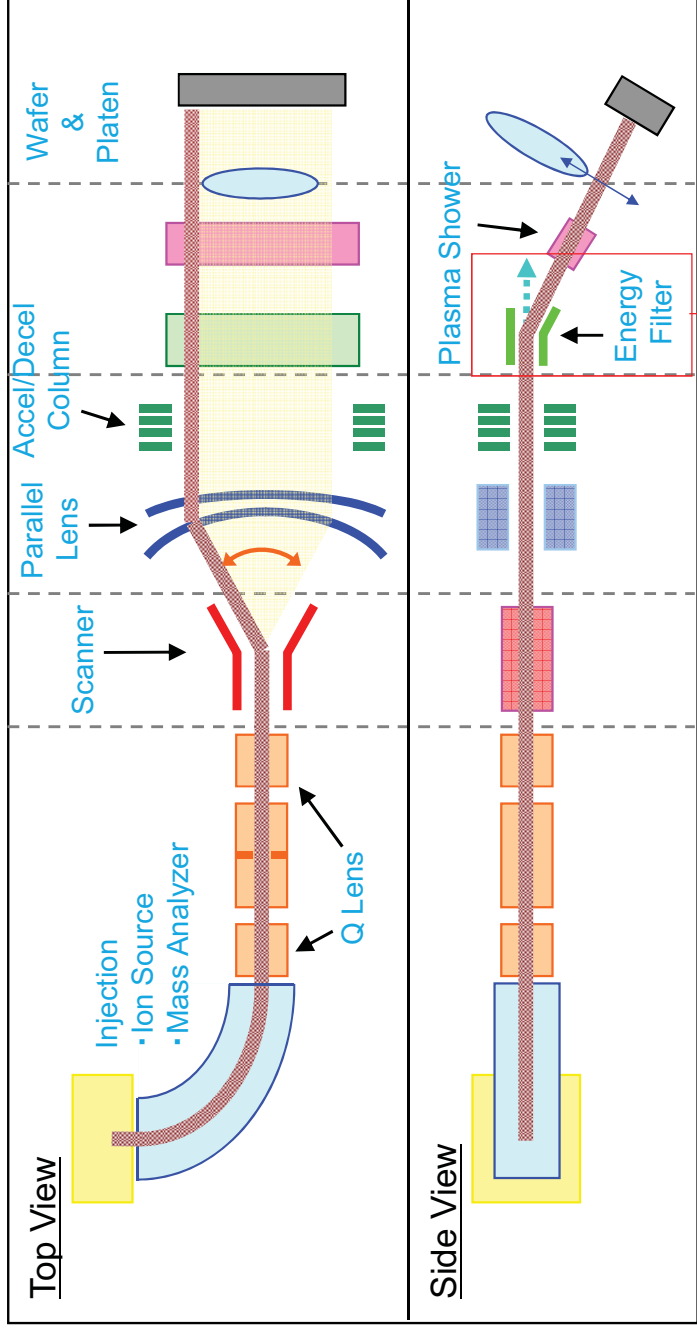
Issues of BSI (Back Side Illumination) CMOSIS

- Usually, Surface P+ layer of BSI CIS is formed after metal layer formation
- Annealing this implant cannot have thermal budget
- Laser annealing is one of the solutions
- This very shallow but mid-dose implant is one of the bottle necks of productivity, because HC tools have enough beam current but very poor uniformity, where MC tools have good uniformity but very poor beam current



Productivity with Precision

SHX-III/S is the answer to solve the issue



Hybrid type

- Electric
- Magnetic

Productivity with Precision

Wide Range Dose Control of SHX-III/S

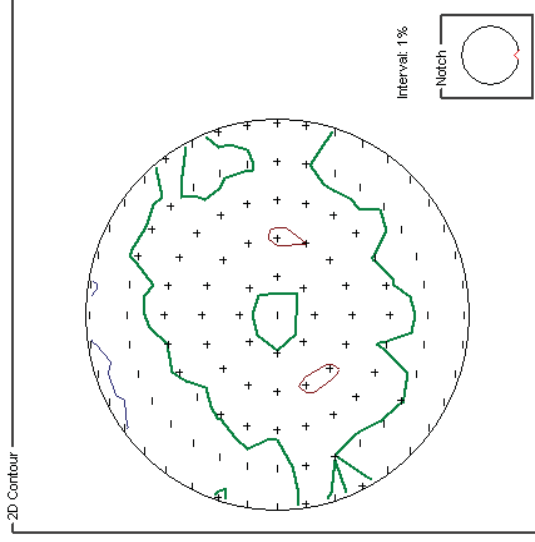
Good Uniformity even in 1 pass(= 1 scan)

B 5keV 2.5E13

Tilt/Twist=25/0

Water Statistics	
Mean:	2297.631
Maximum:	2324.289
Minimum:	2269.207
Std. Dev:	12.8444
Range:	0.56 %
HI/LO Var:	55.0813
Unit:	Ohms/Sq

Water Size	
Wafer Diam:	300.00 mm
Test Diam:	294.00 mm
No. Sites:	121
Style:	Notch



Water Statistics	
Mean:	2297.631
Maximum:	2324.289
Minimum:	2269.207
Std. Dev:	12.8444
Range:	0.56 %
HI/LO Var:	55.0813
Unit:	Ohms/Sq

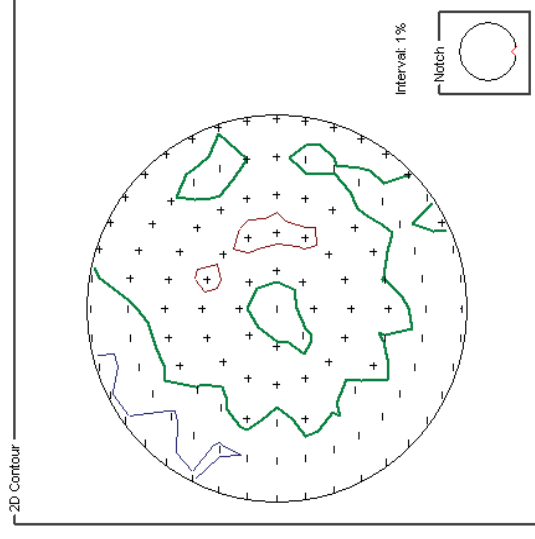
Rs=2297.63
 $\sigma=0.56\%$

B 5keV 2.5E13

Tilt/Twist=25/27

Water Statistics	
Mean:	2368.224
Maximum:	2400.847
Minimum:	2327.19
Std. Dev:	14.6955
Range:	0.62 %
HI/LO Var:	73.6575
Unit:	Ohms/Sq

Water Size	
Wafer Diam:	300.00 mm
Test Diam:	294.00 mm
No. Sites:	120
Style:	Notch



Water Statistics	
Mean:	2368.224
Maximum:	2400.847
Minimum:	2327.19
Std. Dev:	14.6955
Range:	0.62 %
HI/LO Var:	73.6575
Unit:	Ohms/Sq

Rs=2368.22
 $\sigma=0.62\%$

Those good features bring high level implant quality
in wide dose range

High Productivity in Medium Dose Range

SHX-III's wide dose-range coverage with good uniformity brings overwhelming improvement of productivity in some medium recipes

