E-beam lithography

RAITH

JEOL JBX-9300FS 100kV

CRESTEC CABL-9000 Series

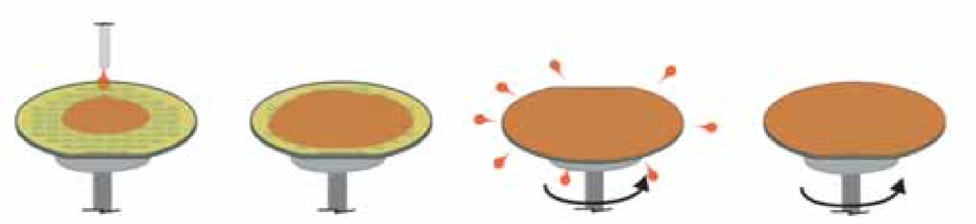
Basic Principles

LEICA SB350 DW

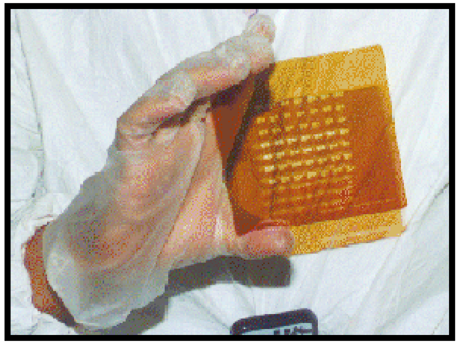
José Luis Prieto

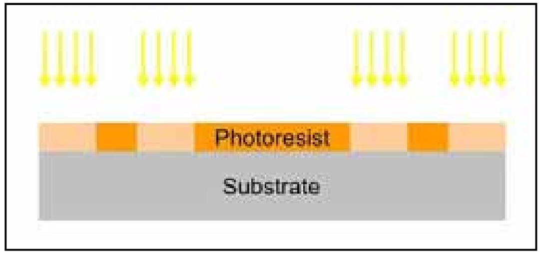
VISTEC VB300

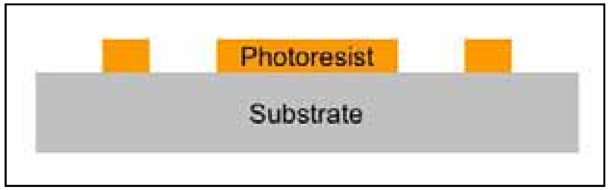
Photolitography

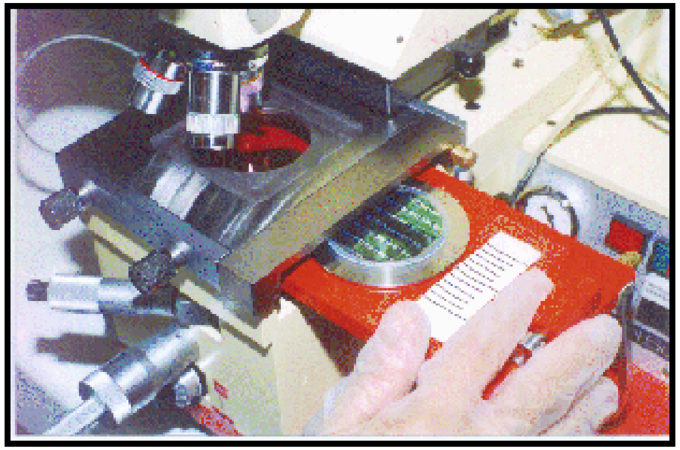


1.- Spinning of a layer of resist

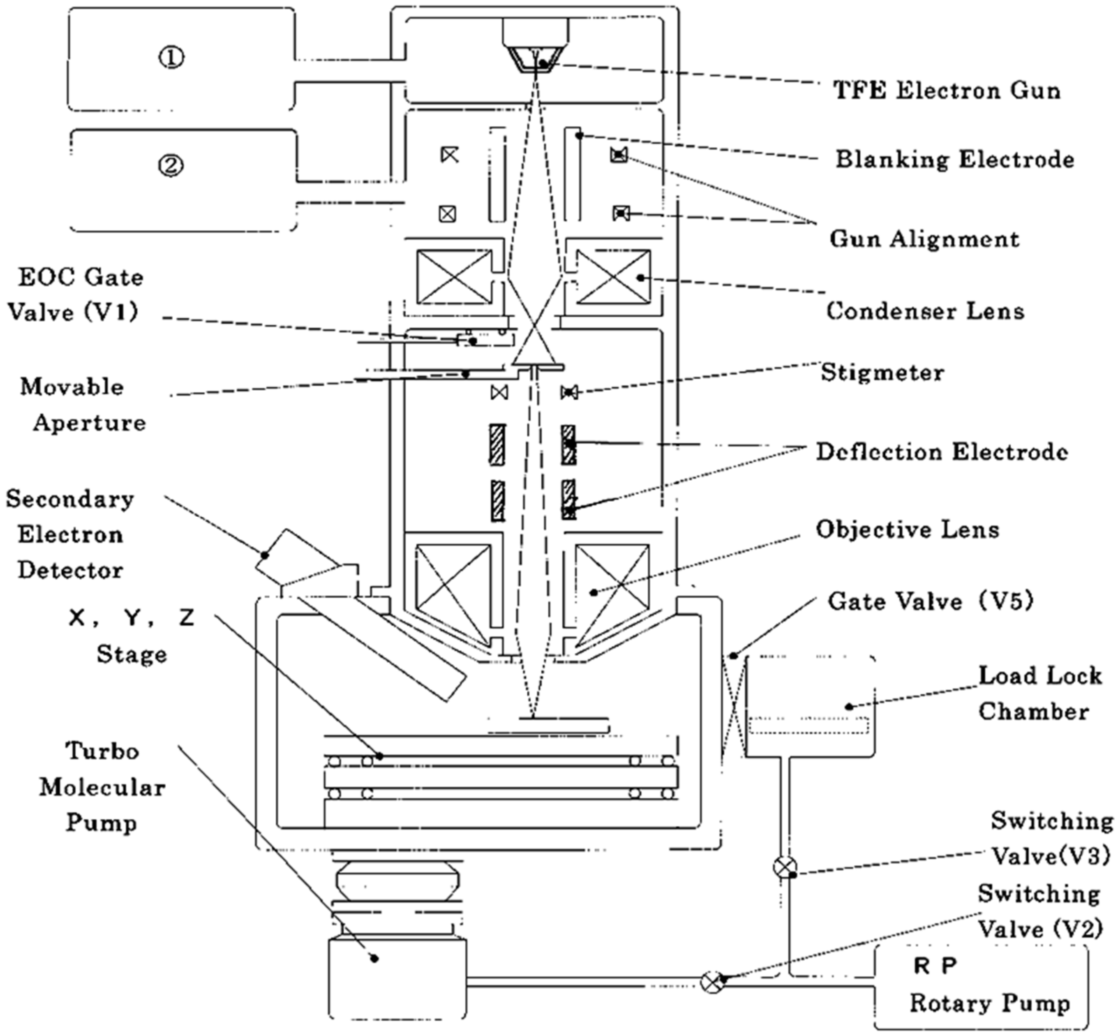


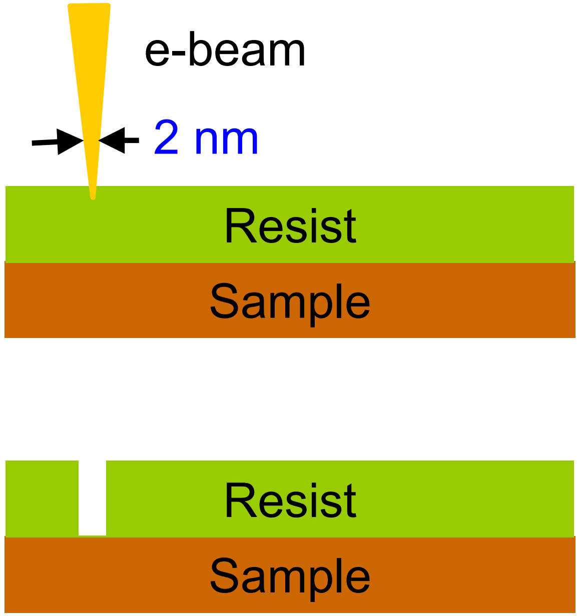




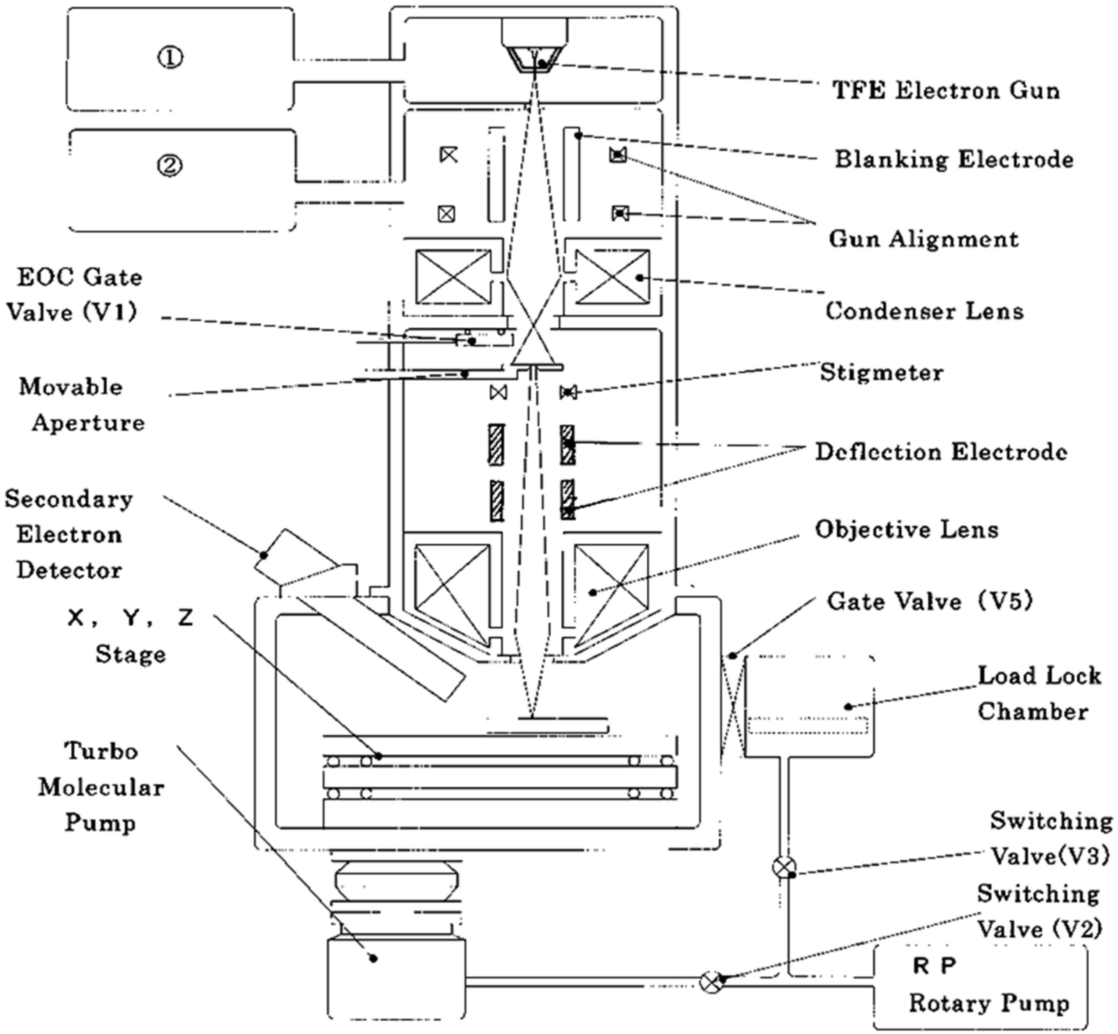


e-beam Lithography





e-beam Lithography



-Emission of Electrons
Filament or Field Emission

-Lenses

-Apertures

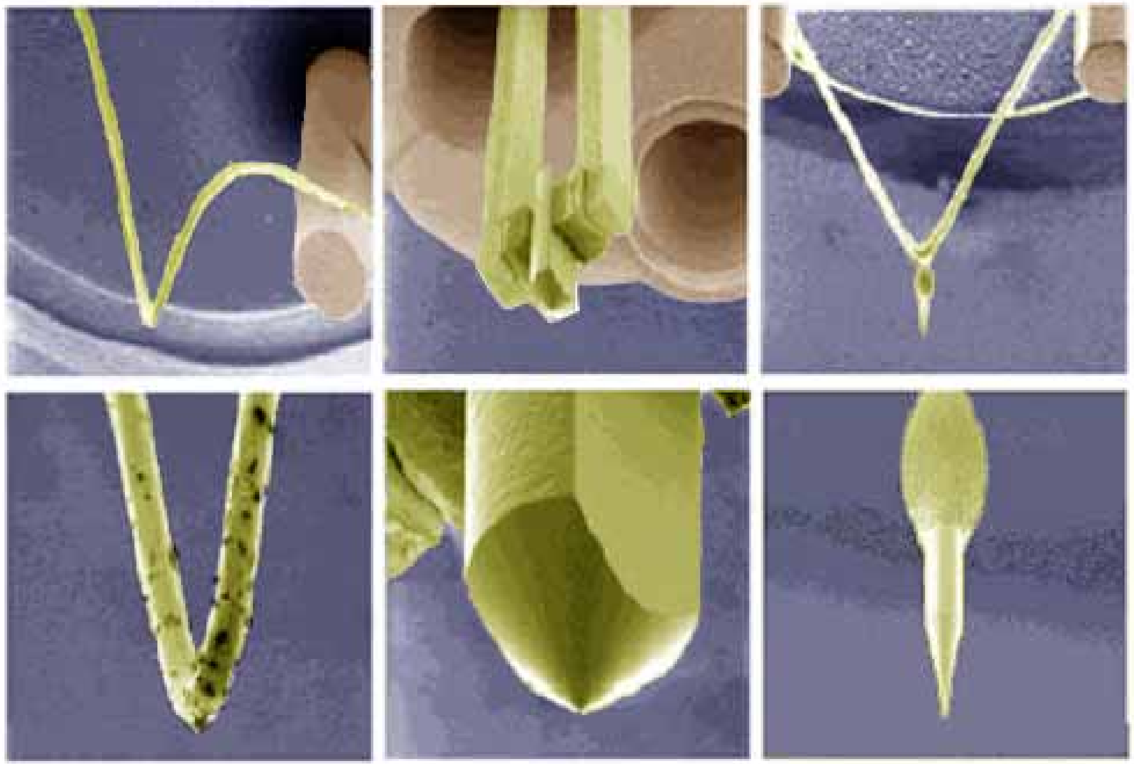
-Deflection lenses

Specific from the e-beam

-Complex Scan Generator
-Motorized stage with interferometric control of the position

Emission

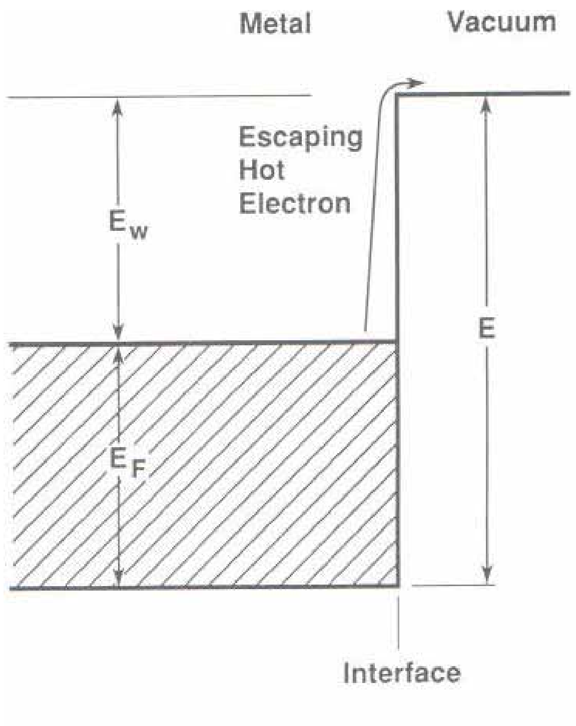
-Sources that produce the beam of electrons



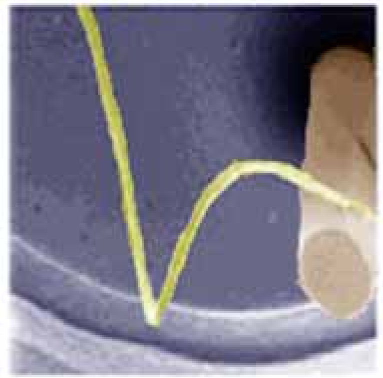
Filament | Source of LaB_6 | Field Emission

Emission

Thermoionic Emission



Supply enough temperature to overcome the work function of the metal



$$J_C = A_C T^2 \exp(-E_W / k_B T)$$

$$A_C = 120 A/cm^2 K^2$$

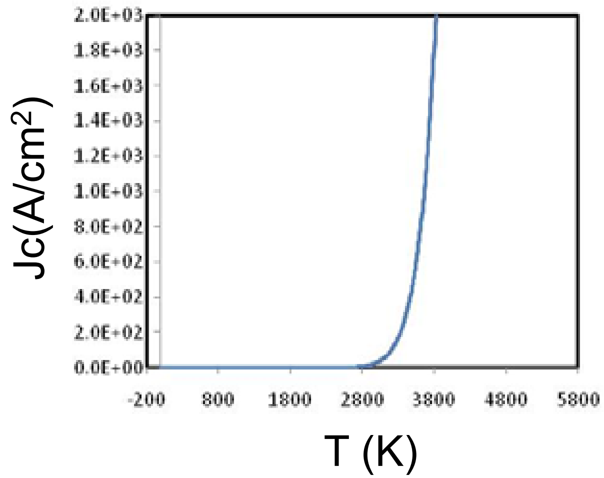
$$k_B = 8.6 eV/K$$

Ex.: Tungsten

$$T = 2700K$$

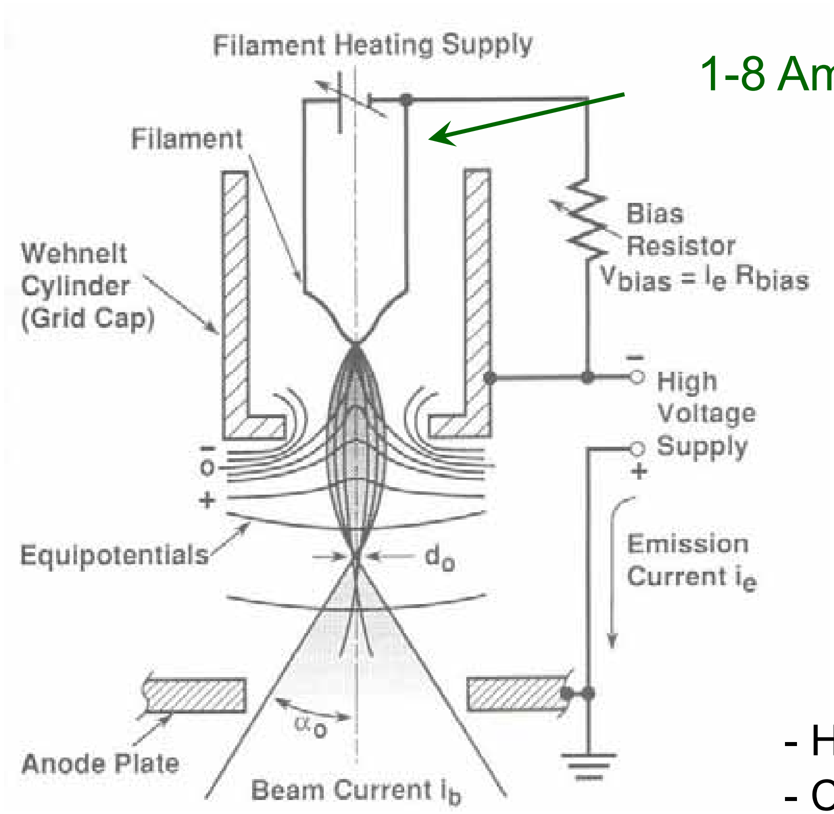
$$E_W = 4.5eV$$

$$J_C = 3.4 A/cm^2$$

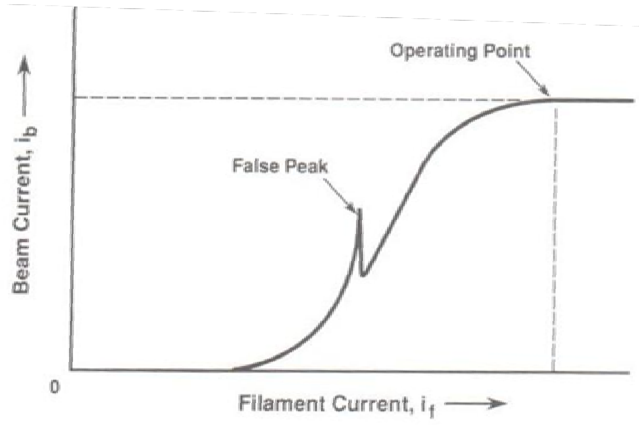


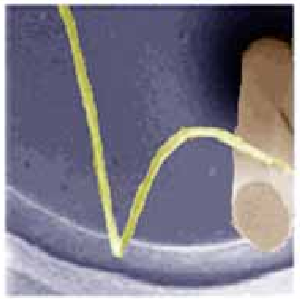
Emission

Triode Electron Gun



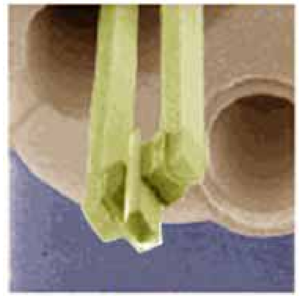
1-8 Amps





Tungsten

- Holds in a worse vacuum
- Cheaper



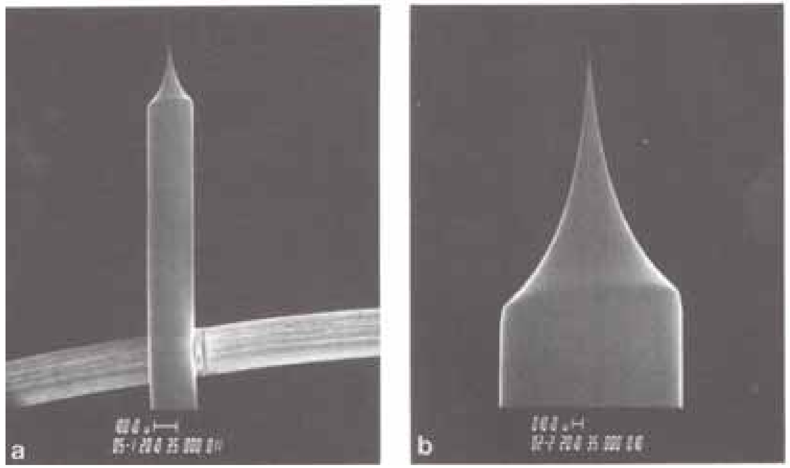
LaB_6

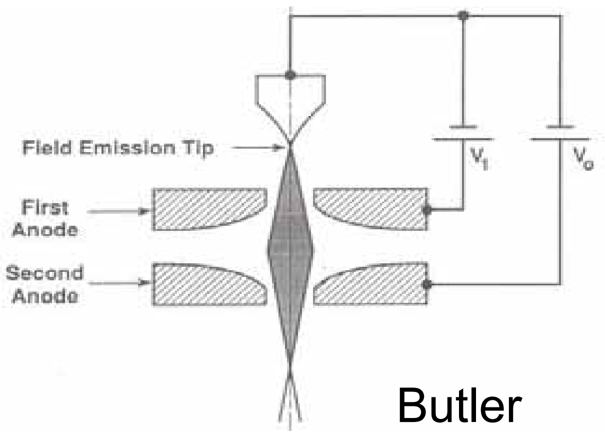
- Superior Brigthness (x5 a x10)
- Longer Life

Emission

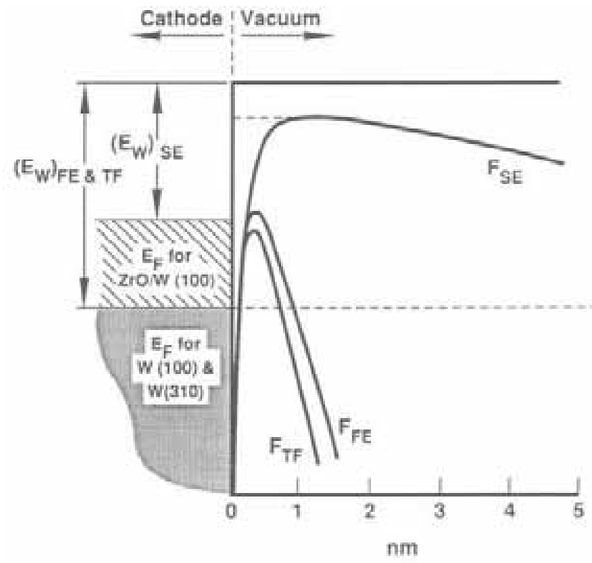
Field Emission Gun

- Field Effect
- Size of the tip < 100nm
- V (tip-anode) ~ 3-5 kV
- Electric Field > 10^7 V/cm
- Emission Jc > 10^4-10^5 A/cm^2
- Brightness ~ 10^2-10^3 times more than thermoionic
- Required vacuum < 10^{-10} torr
- Diameter of the beam 1-2 nm



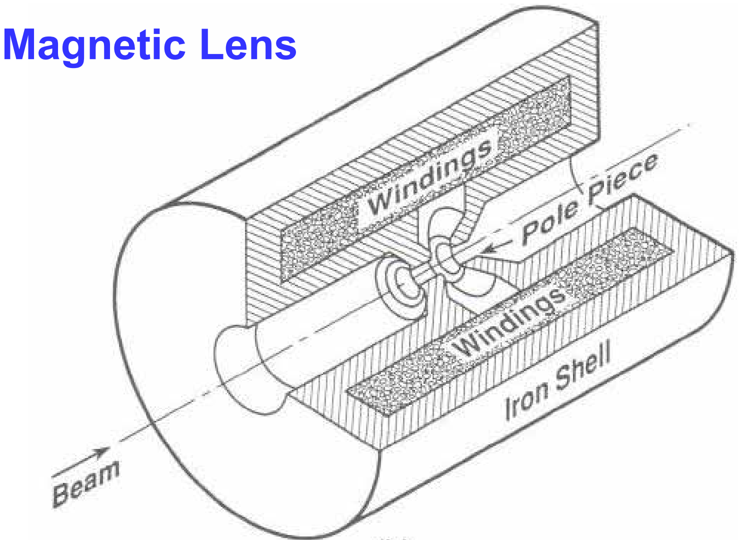


Butler

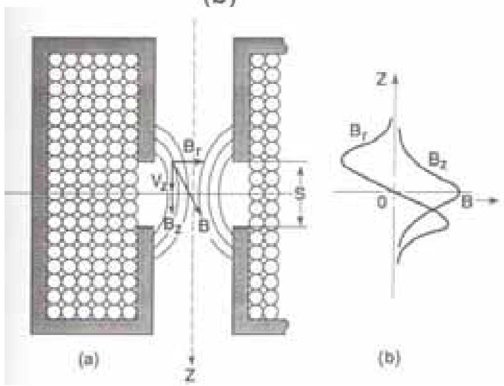


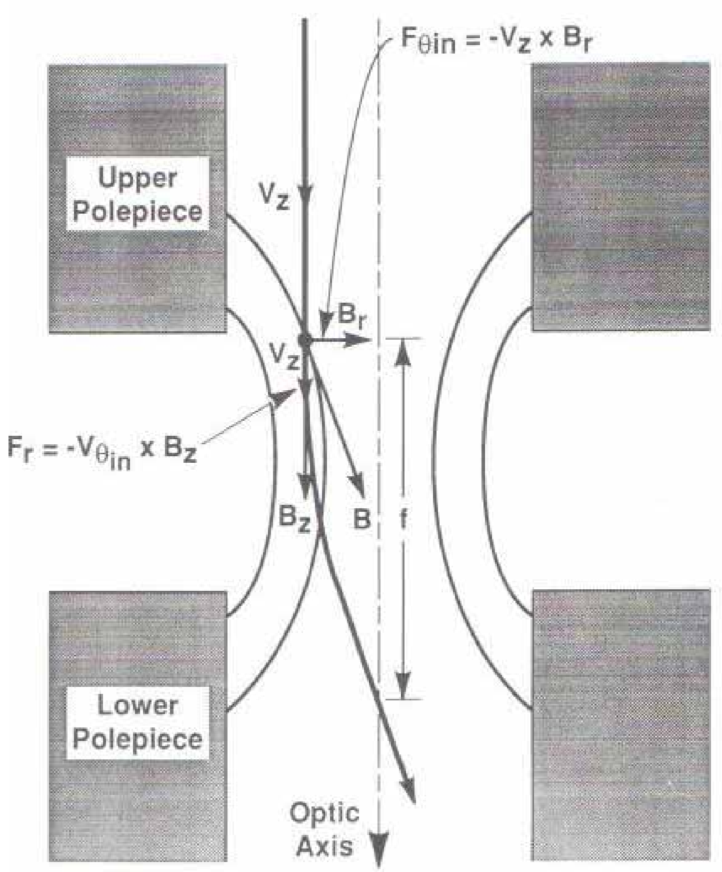
Optics

Magnetic Lens



(b)



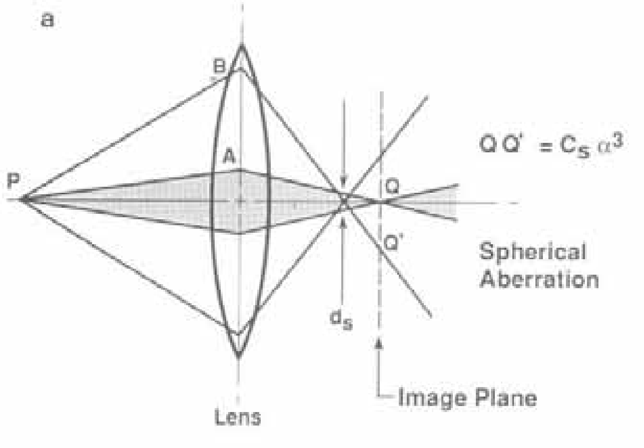


The stability of the beam depends on the stability of the lense → temperature → current that flows through the coils

Optics

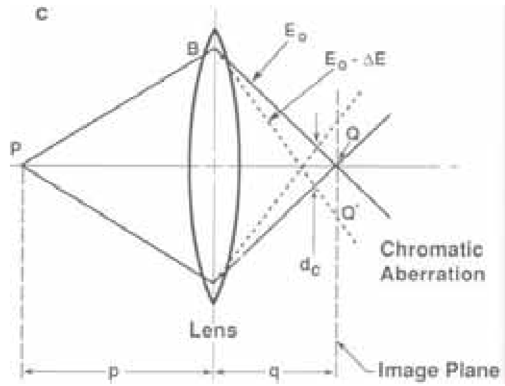
Problems that can widen the beam:

Espheric Aberration



The e- far from axis suffer larger deviation than those closer to the axis (paraxial beams)

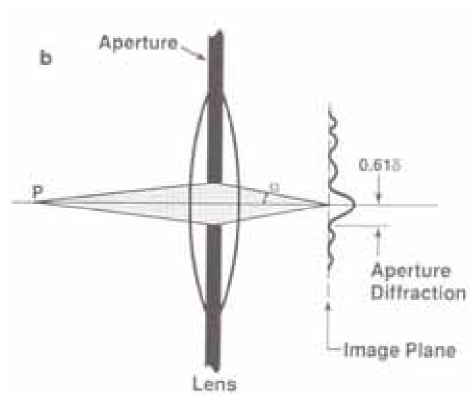
Chromatic Aberration



The e-beam is not monochromatic. Dispersion in E and v

Importance of a good emission: vacuum and temperature

Diffraction in the apertures



$$Spot\ Size = \frac{0.61\lambda}{\alpha}$$

$$\lambda = \frac{1.24}{\sqrt{E_0}}$$

Optics

Problems that can widen the beam:

Astigmatism

-The magnetic lens does not have perfect cylindrical symmetry

-One of the apertures is dirty

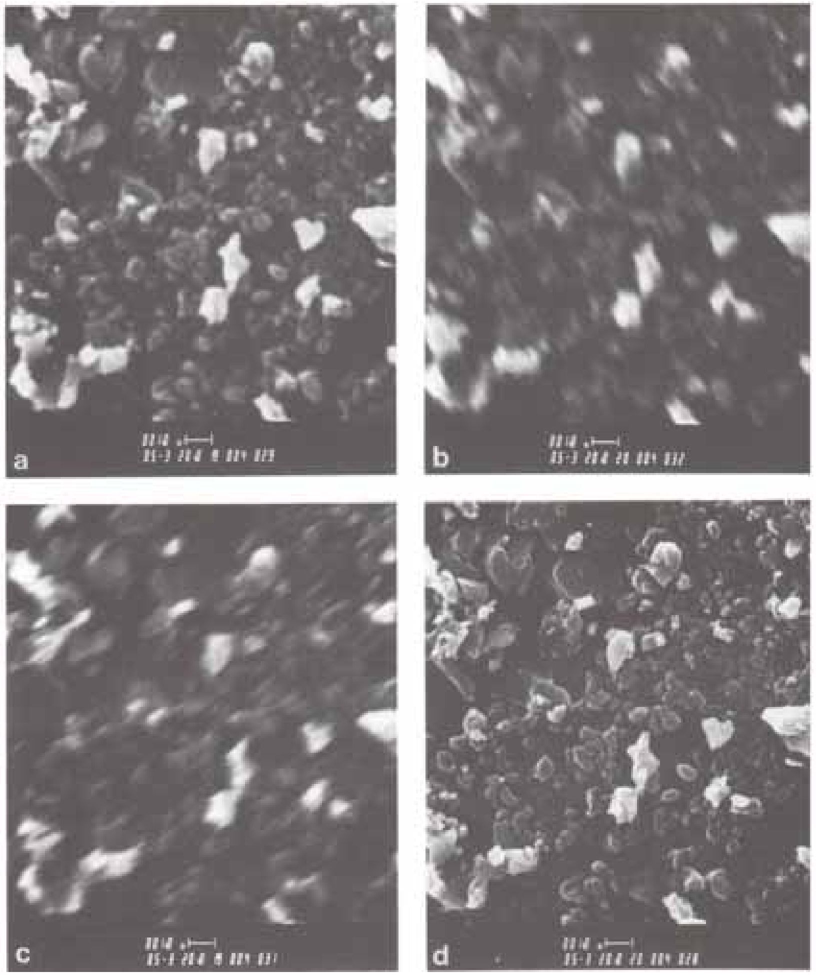
Correction with the "stigmator"

Focus

Correct Stig-X

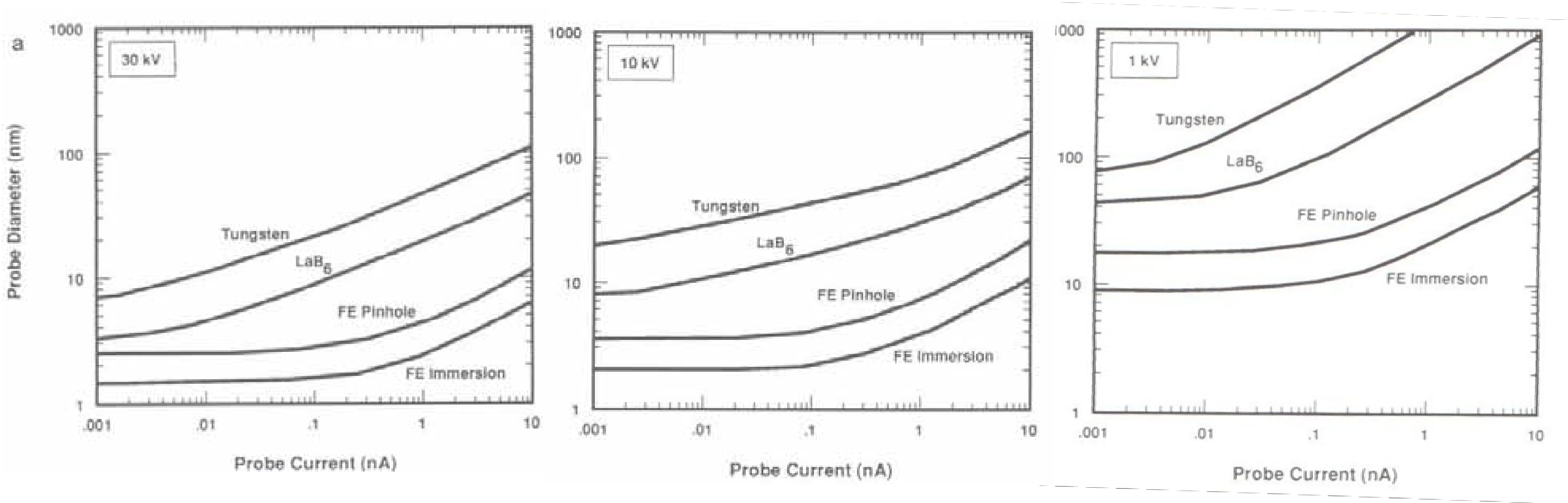
Focus

Correct Stig-Y



Optics

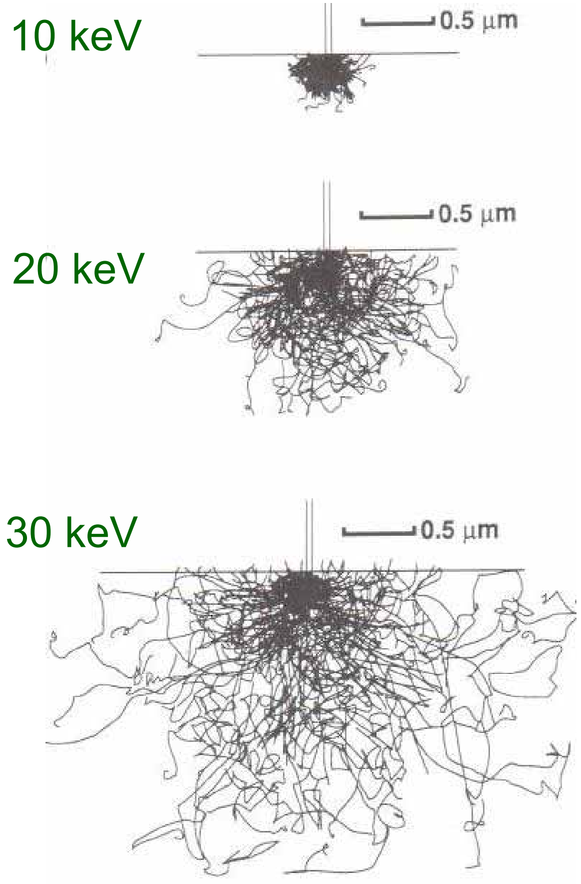
Comparison between beam sizes



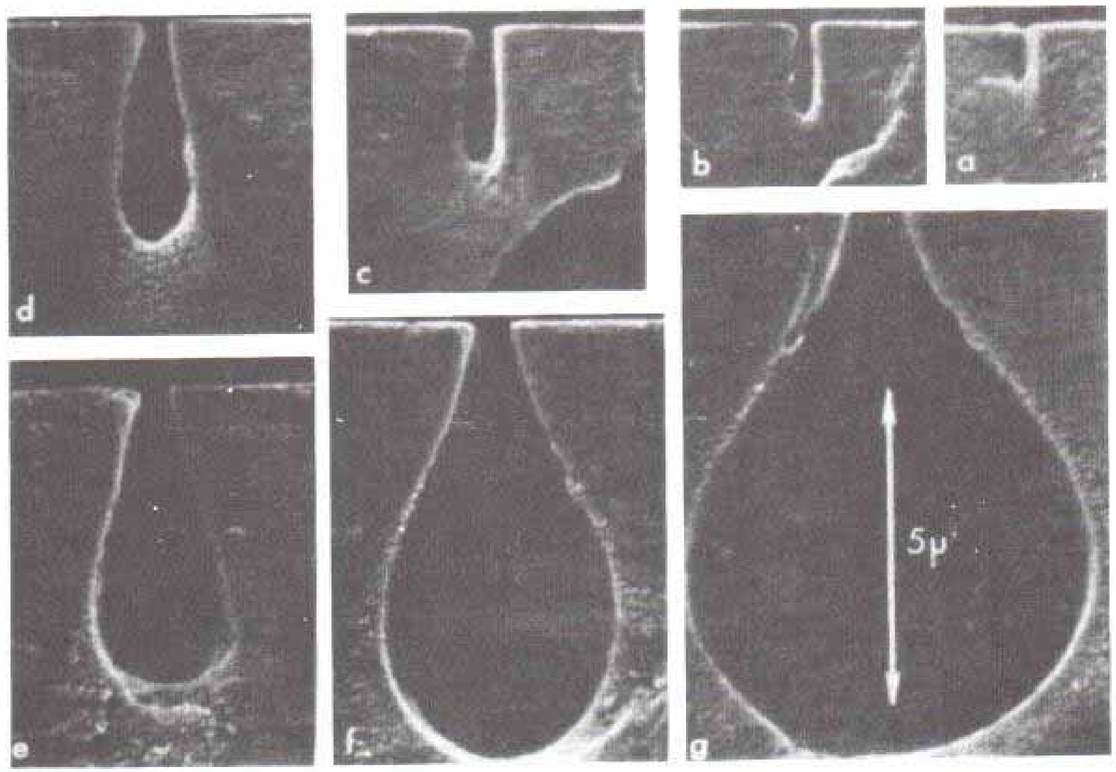
- More precission at a smaller current

- Wider range of operation at a higher voltage

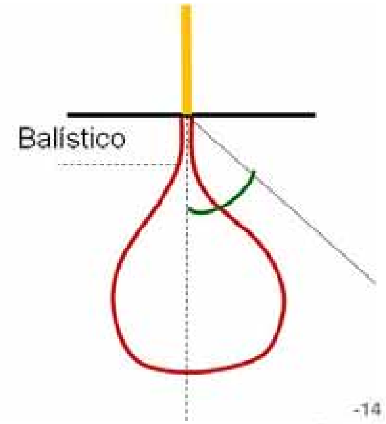
Interaction e$^-$-sample



Progresive developing of PMMA resist (same dosis)



Interaction e⁻-sample

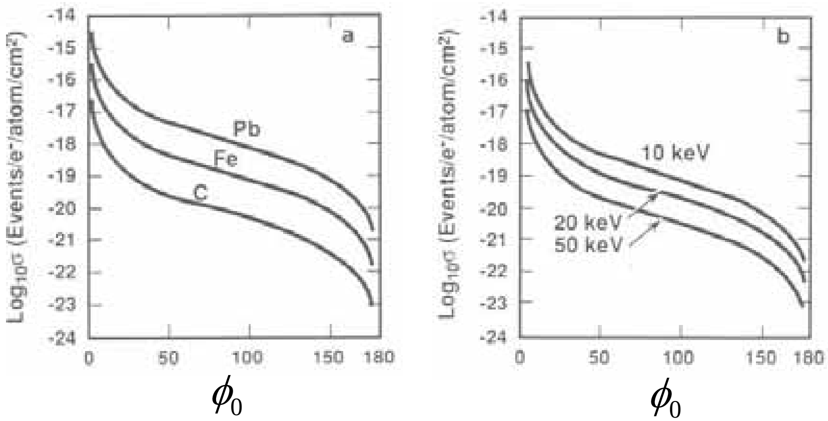


Scattering

Elastic

Increases with the dispersed angle

$$\sigma(>\phi_0) = 1.62 \cdot 10^{-20} \frac{Z^2}{E^2} \cot^2 \frac{\phi_0}{2}$$



Inelastic

Reduces the speed of e-

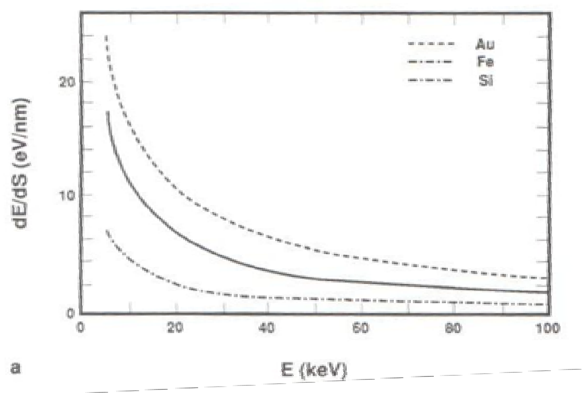
-Excitation of phonons

-Excitation of 2dary e-

-Generation R-X

-Excitation of Internal Layers

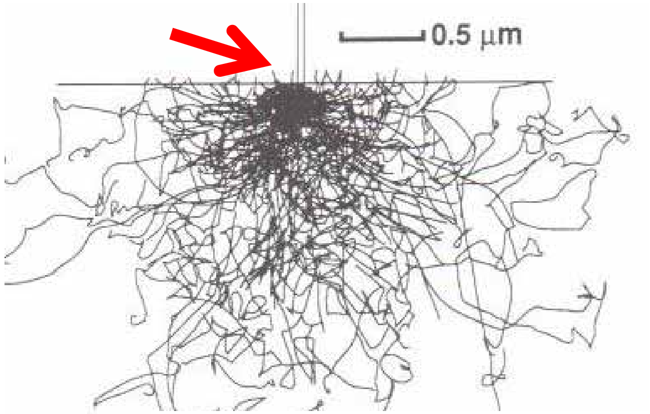
$$\frac{dE}{ds} = -7.85 \cdot 10^4 \frac{Z\rho}{AE_m} \ln \frac{1.166 E_m}{J}$$



↑↑ Energy (kV)→ ↑↑ Ballistic penetration

↑↑ Penetration for lower Z (Resist+Substrate)

Interaction e⁻-sample

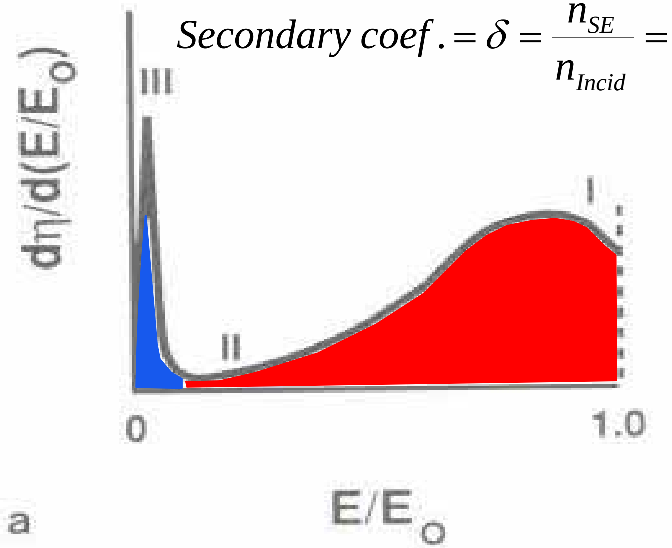


Incident energy is transformed in:

- -Backscattered Electrons
- -Secondary Electrons
- -Auger Electrons
- -X-Rays Bremsstrahlung
- -Characteristic X-Rays
- -Catodoluminiscence
- -Phonons (heat)

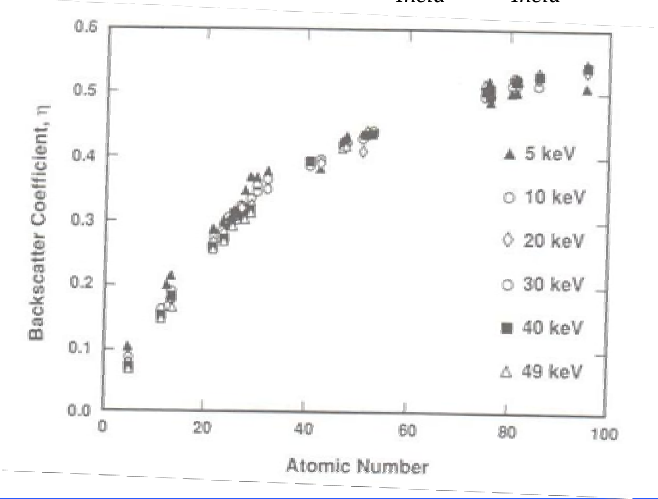
Secondary Electrons

$$Secondary\ coef. = \delta = \frac{n_{SE}}{n_{Incid}} = \frac{i_{SE}}{i_{Incid}}$$



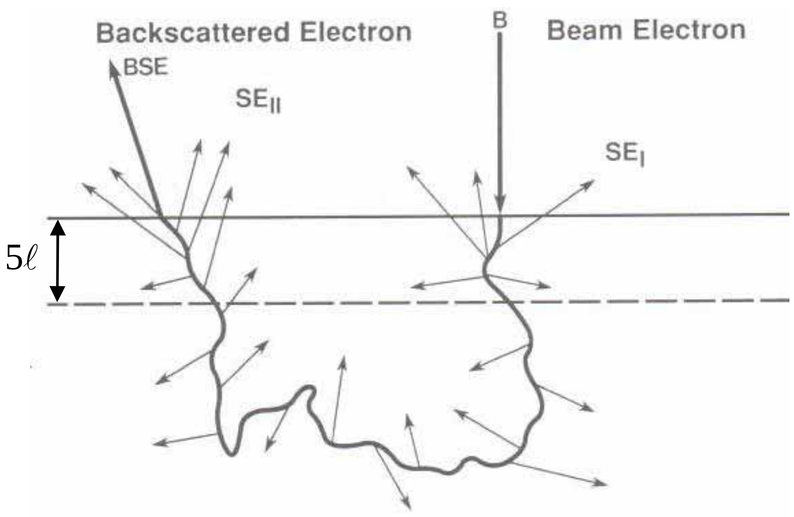
Backscattered Electrons

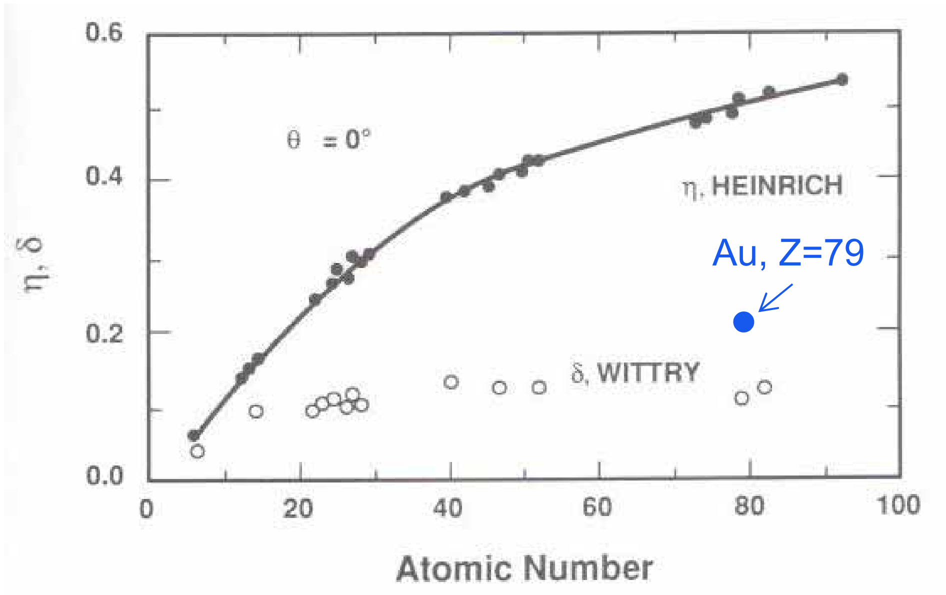
$$Backscatter\ coef. = \eta = \frac{n_{BSE}}{n_{Incid}} = \frac{i_{BSE}}{i_{Incid}}$$

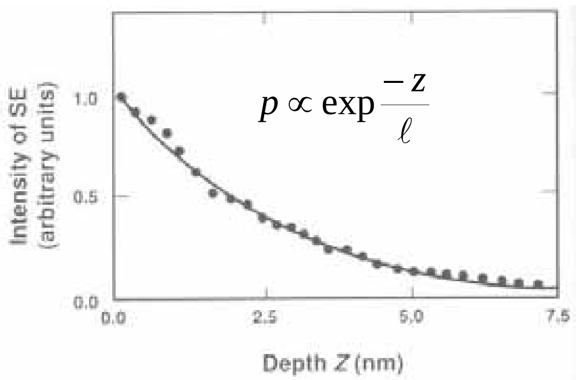


Interaction e$^-$-sample

Secondary Electrons vs. Backscatered Electrons



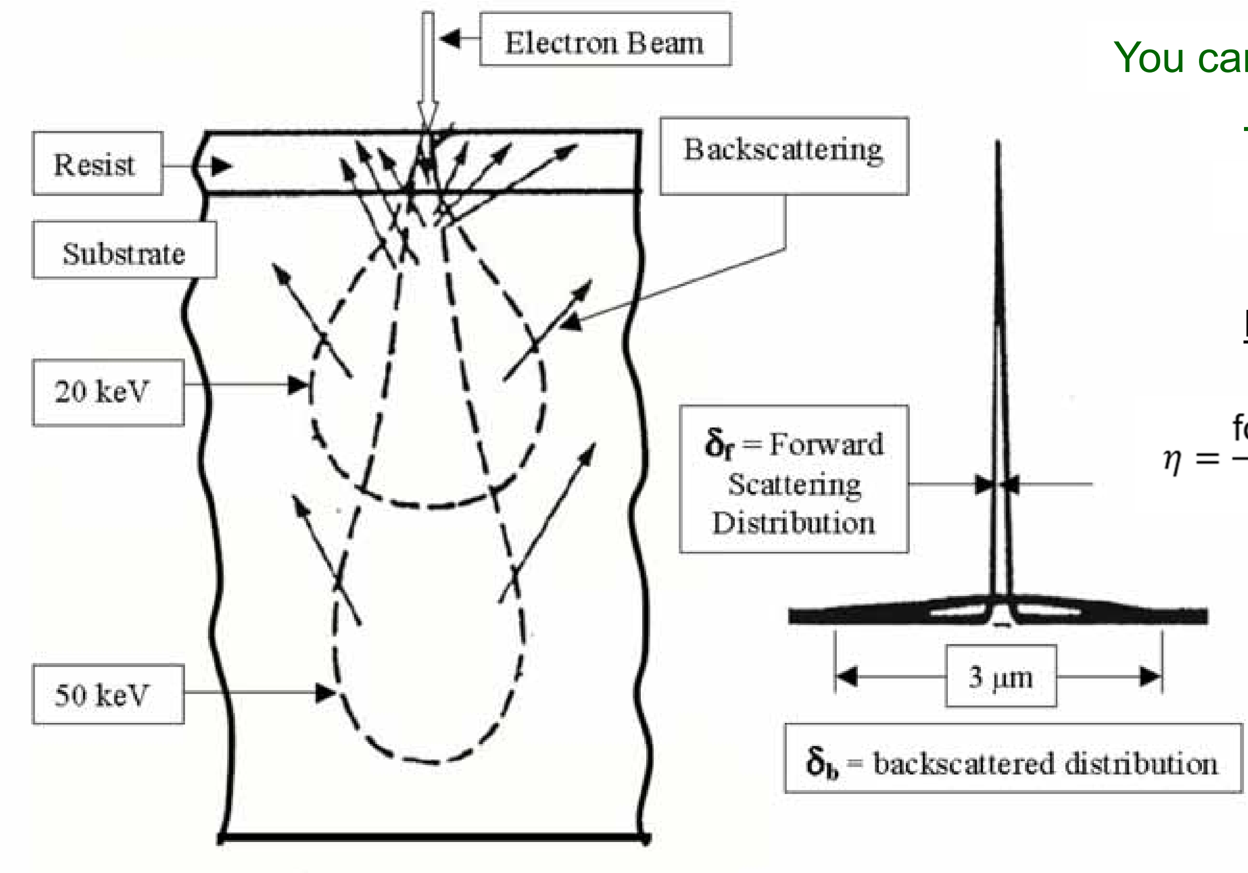




Substrates with large Z → more weakening of the resist underneath

Materials with large Z better for alignment marks, esp. Au

Proximity Effect



You can minimize the effect by:

-Design compensation

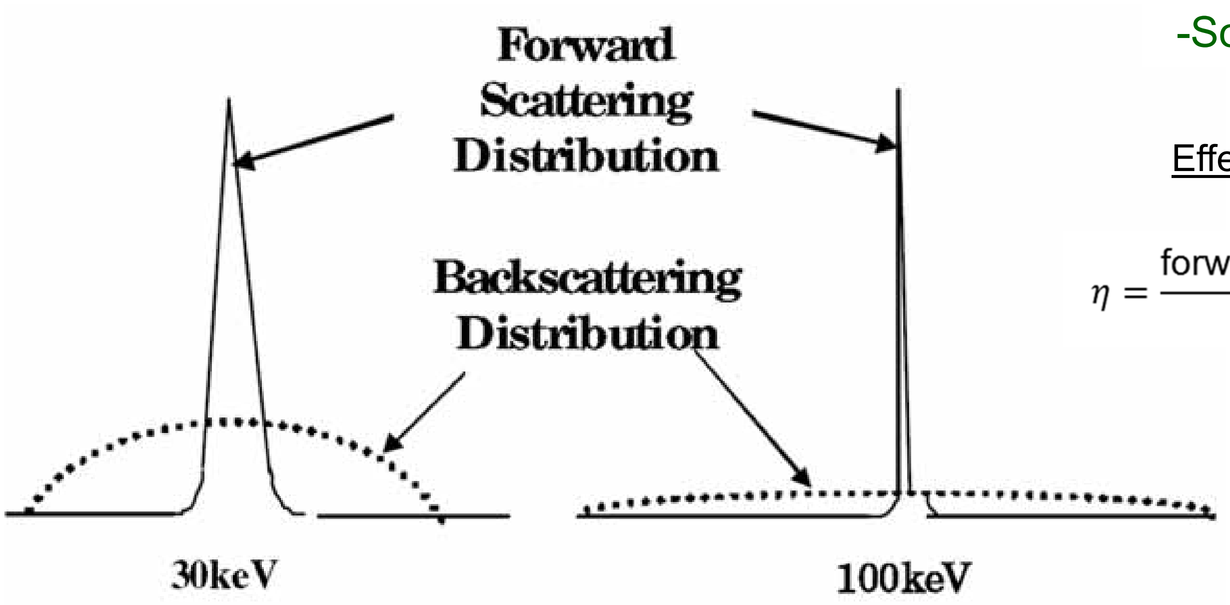
-Software compensation

↓

Effective backscatter coefficient

$$\eta = \frac{\text{forward scatter resist exposure dose}}{\text{backscatter exposure dose}}$$

Proximity Effect



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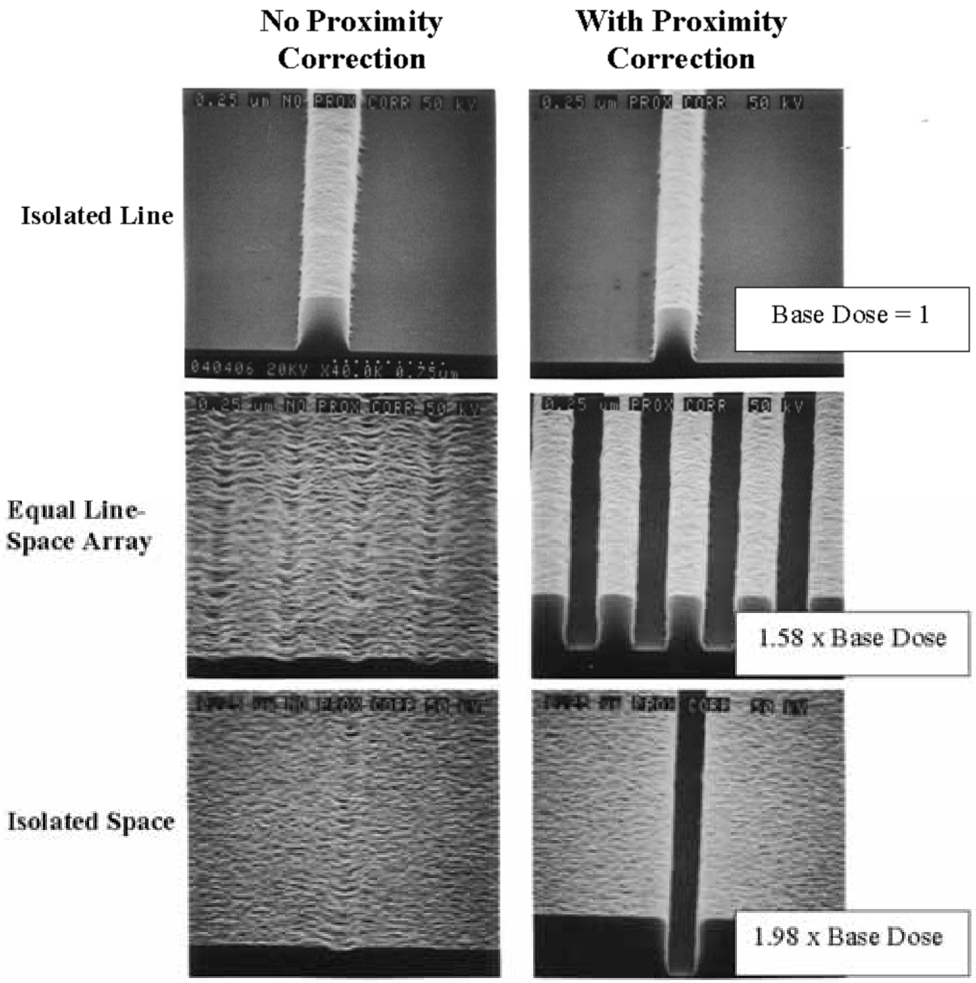
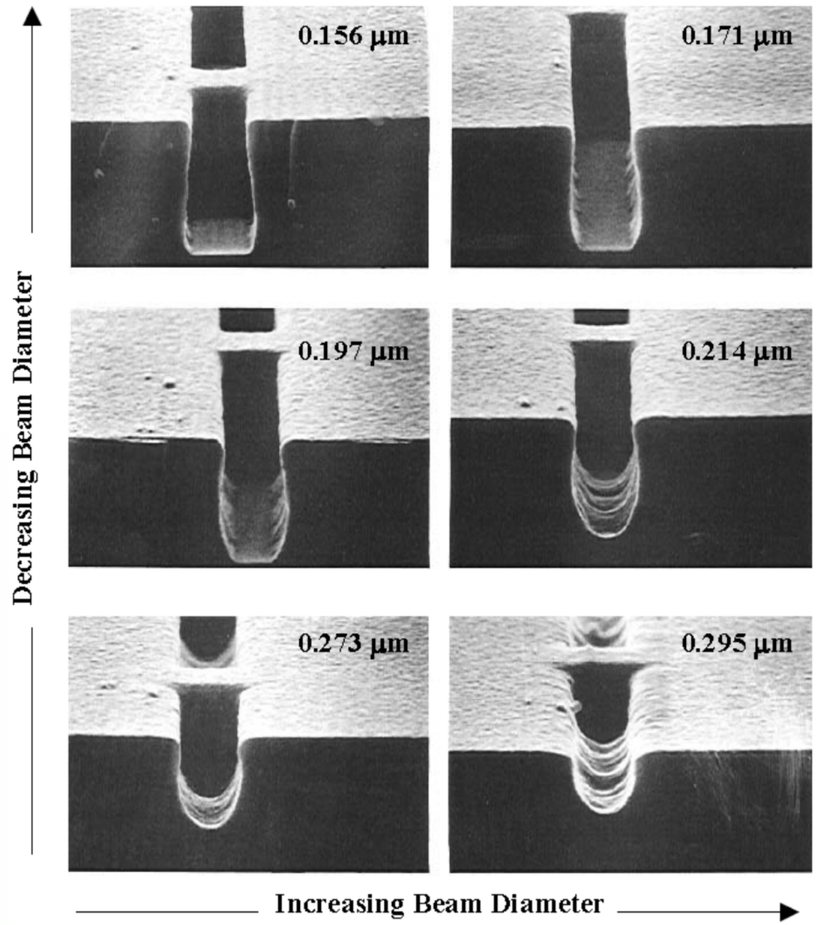
Interaction e⁻-sample

Proximity Effect

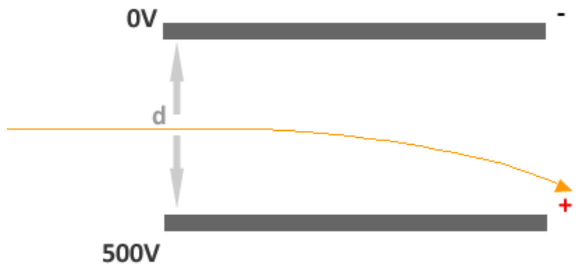


Beam Size



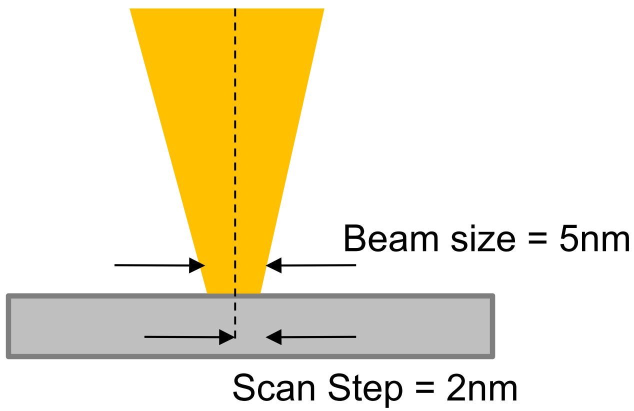
Scan Velocity

Quick deflection of the beam to do the lithography

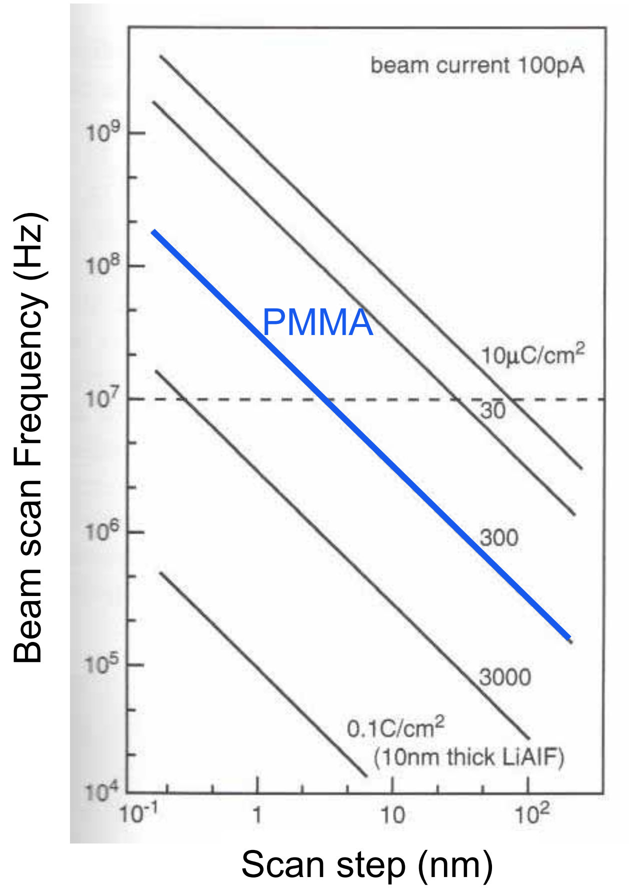


Electrostatic deflector faster than magnetic one

Electrostatic deflector more sensitive to EM noise



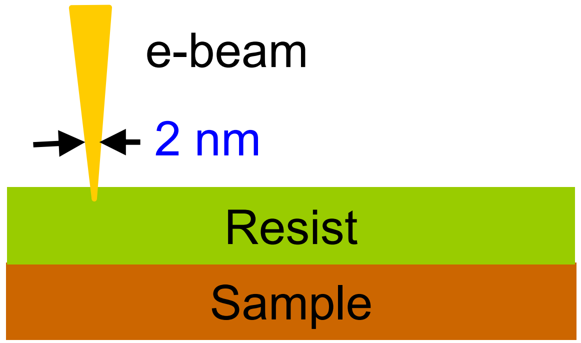
Sensitivity of the resist vs. Scan velocity

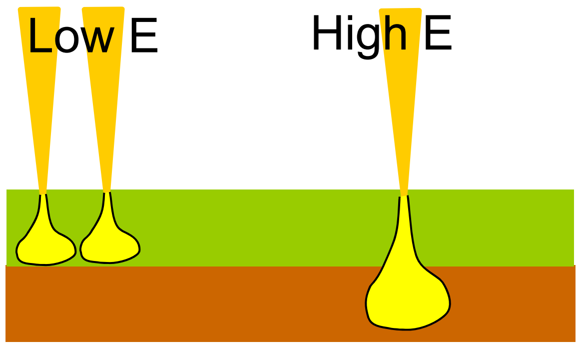


Resists

	Tone	*Resolution nm*	*Sensitivity $\mu C/cm^2$*	*Developer*
PMMA	Positive	10	100.0	MIBK:IPA
EBR-9	Positive	200	10.0	MIBK:IPA
PBS	Positive	250	1.0	MIAK : 2-pentanone 3:1
ZEP	Positive	10	30.0	xylene:p-dioxane
AZ5206	Positive	250	6.0	KLK PPD 401
COP	Negative	1000	0.3	MEK : ethanol 7:3
SAL-606	Negative	100	8.4	MF312:water

Limiting factors in e-beam lithography





-Beam Size

- -Current increases→spot increases
- -Being in focus during lithography

-Beam stability

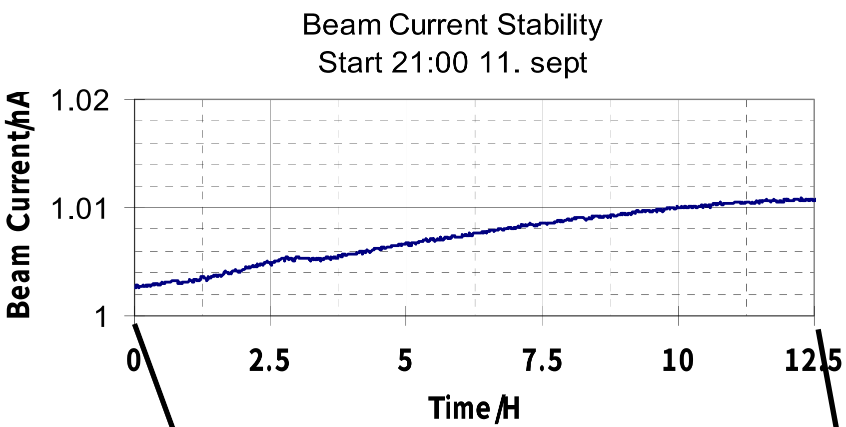
- - Stability of the FE Gun (Vac, Temp)
- - Stability of the lenses, deflectors, etc.
- - Vibration
- - EM Noise

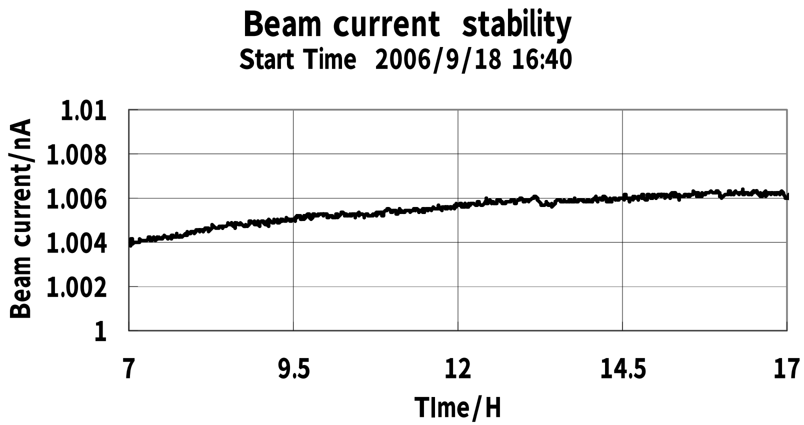
- Stability in the beam energy

- - Proximity Effect
- - Backscattered electrons

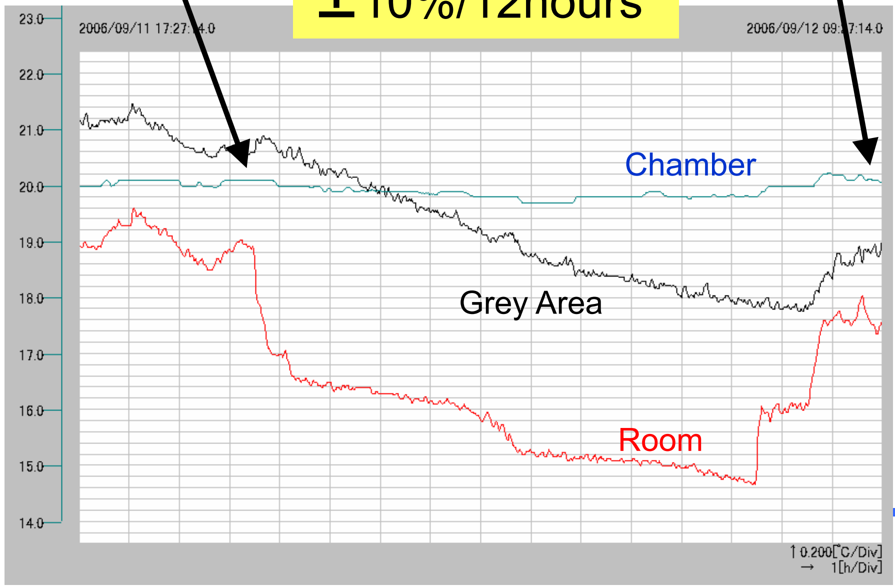
Beam Stability

BEAM CURRENT STABILITY   Specifications: < ±1%/5h

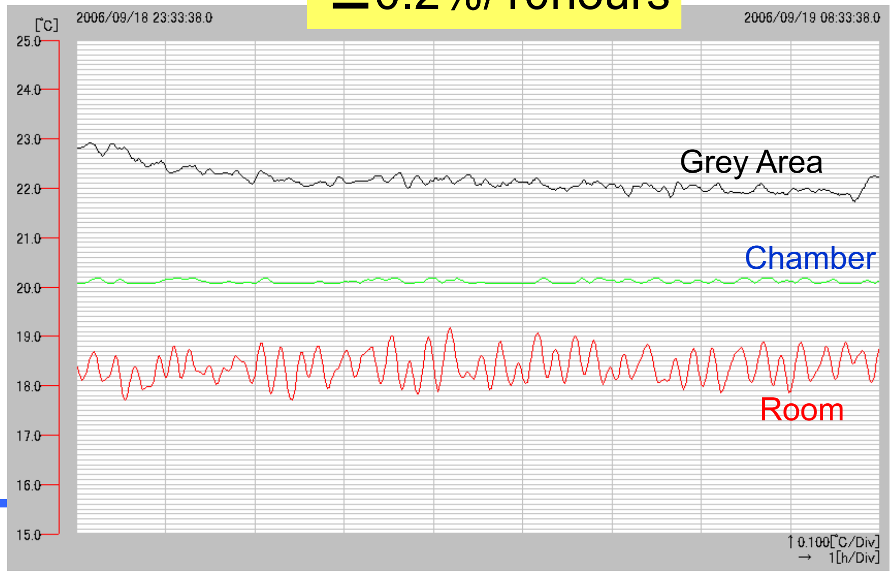




±10%/12hours



±0.2%/10hours

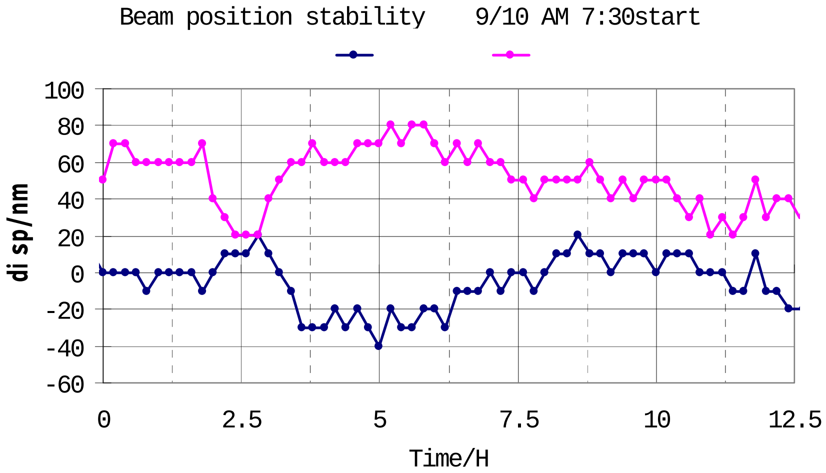


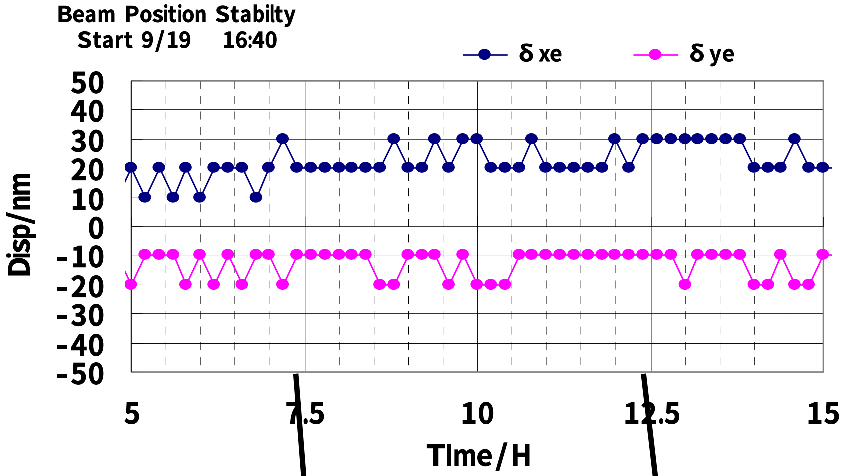
Beam Stability

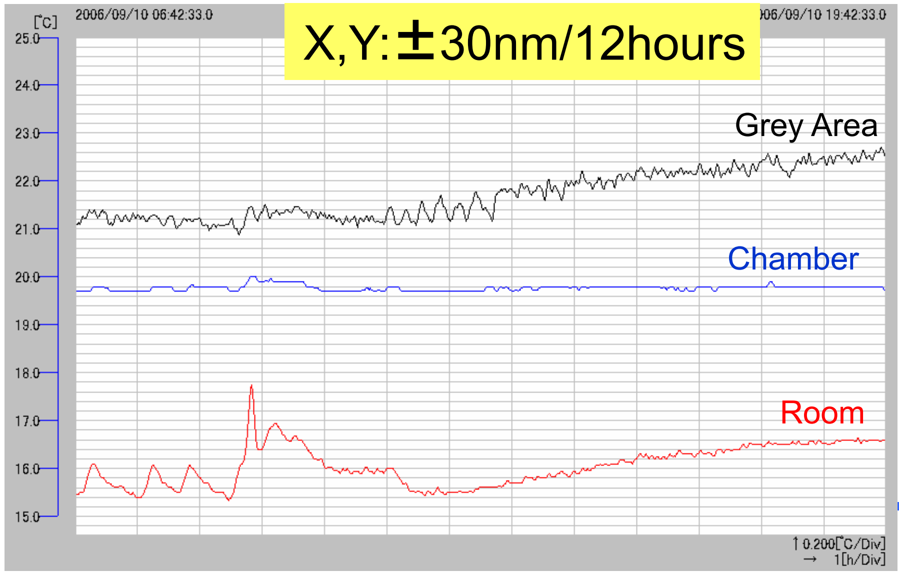
Beam current: 0.1nA

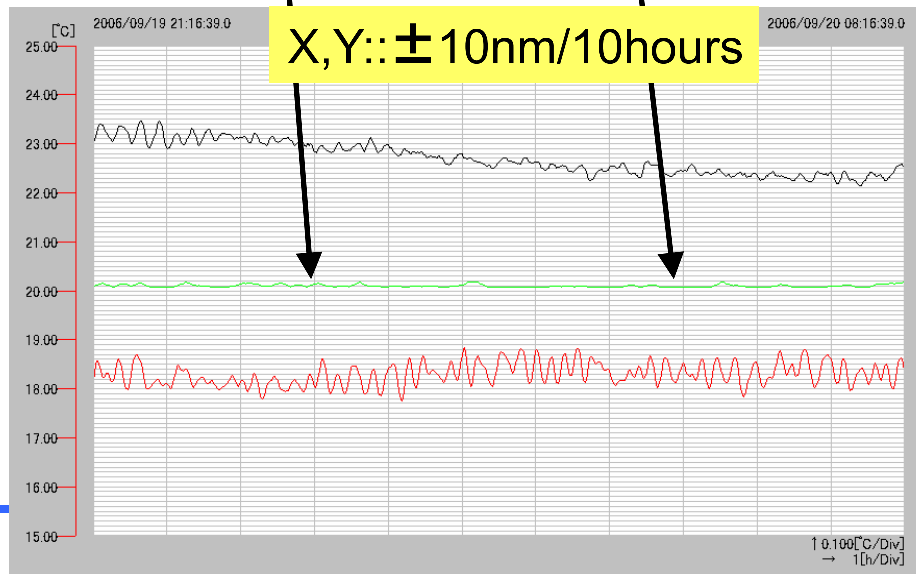
BEAM POSITION STABILITY

Spec.: ±30nm / 5hours

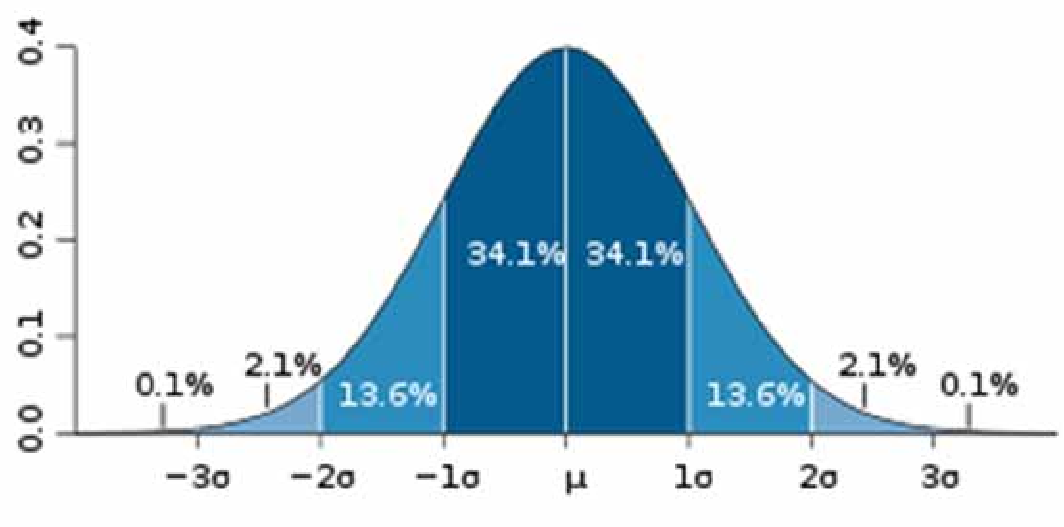






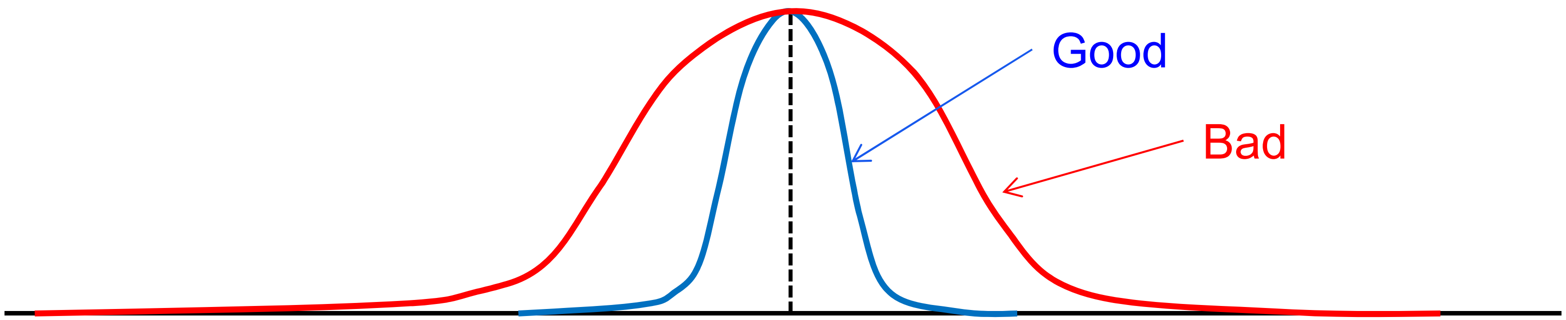


STITCHING ACCURACY TEST Spec.: 50nm (mean+3σ)



$$\mu = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu)^2}$$



Beam Stability

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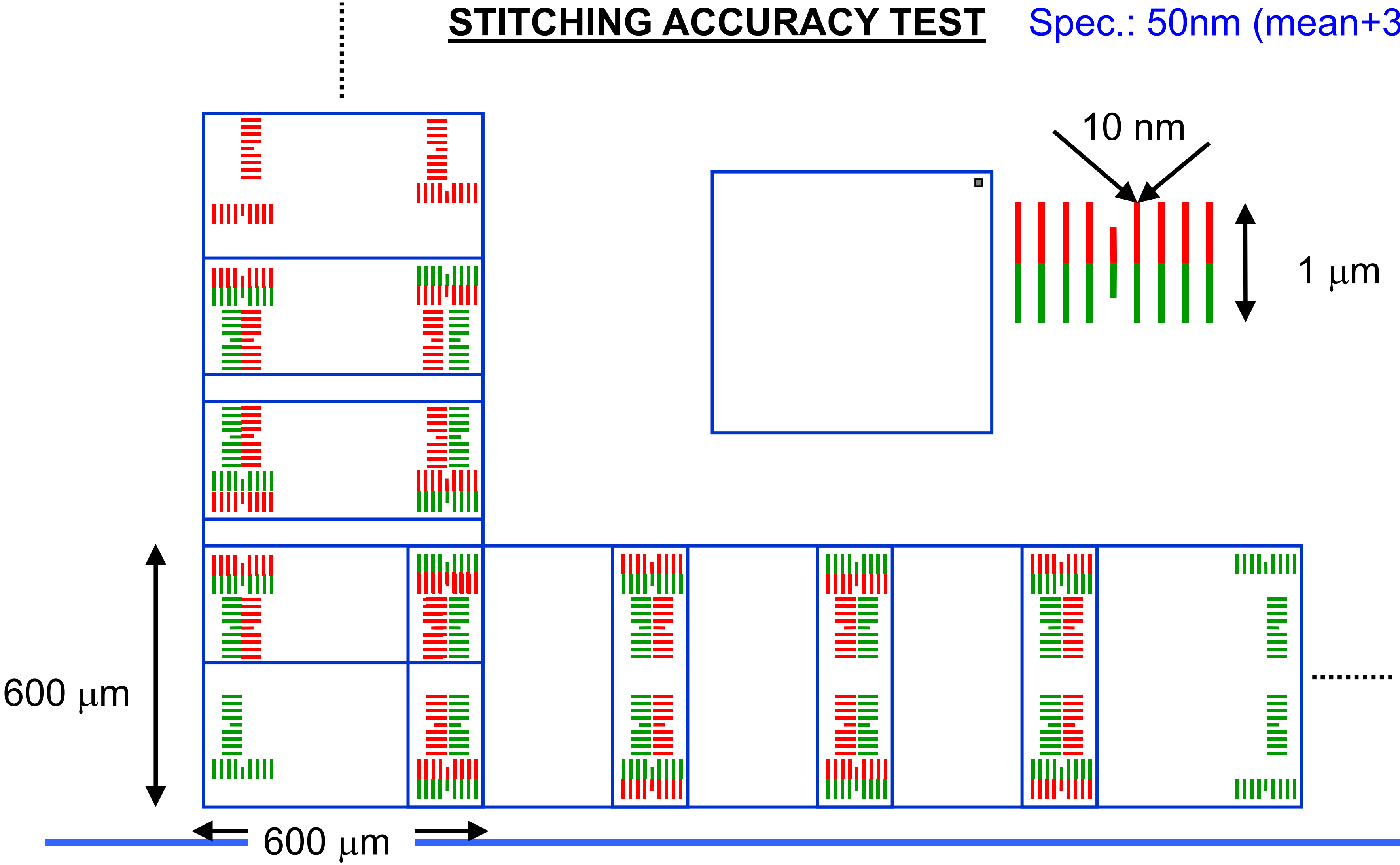

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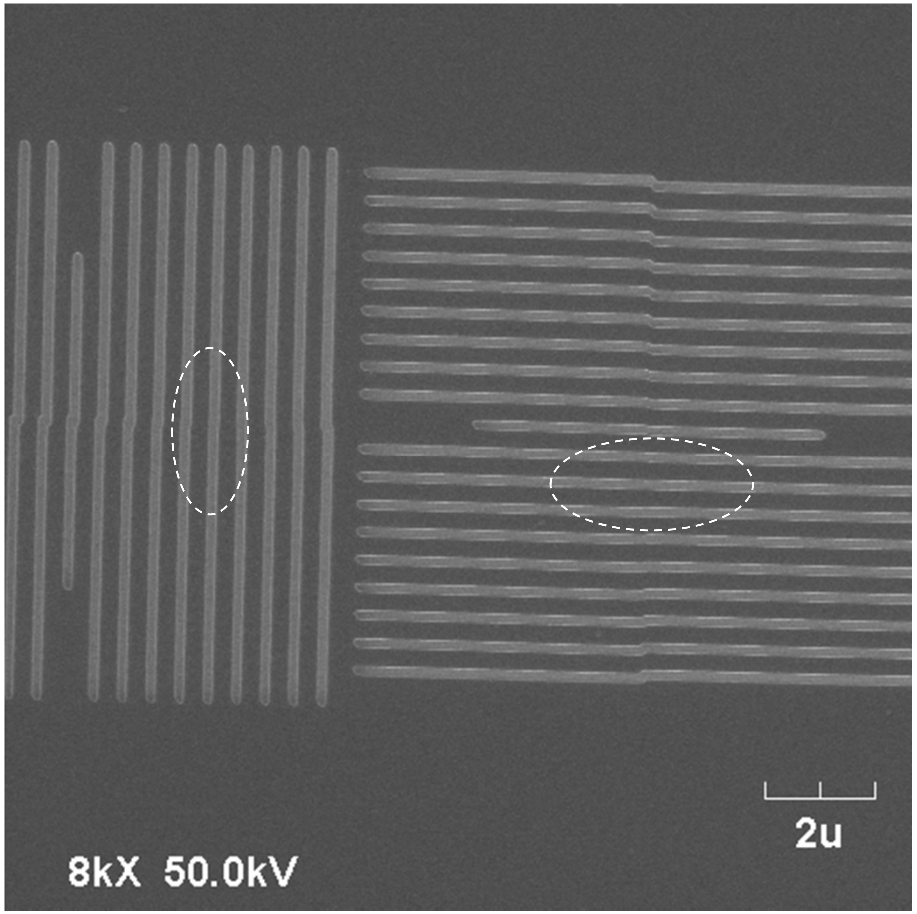
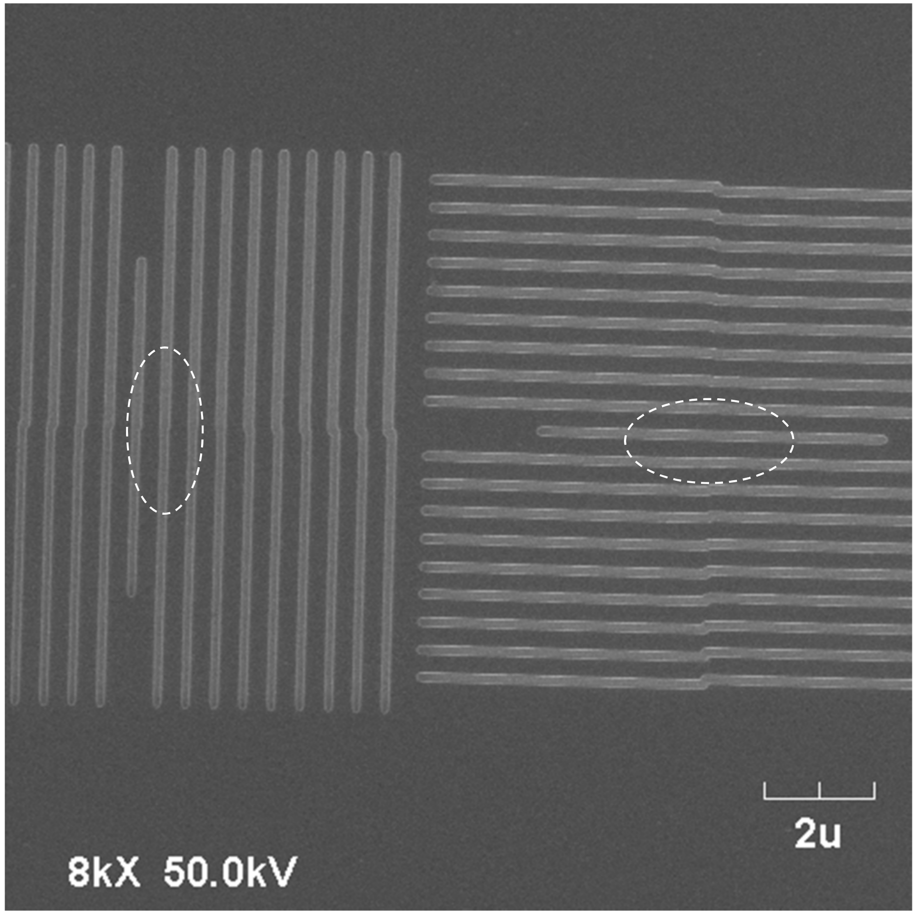




Commonly measured values < 30nm (mean+3σ)

Estabilidad del Haz

STITCHING ACCURACY EXAMPLE

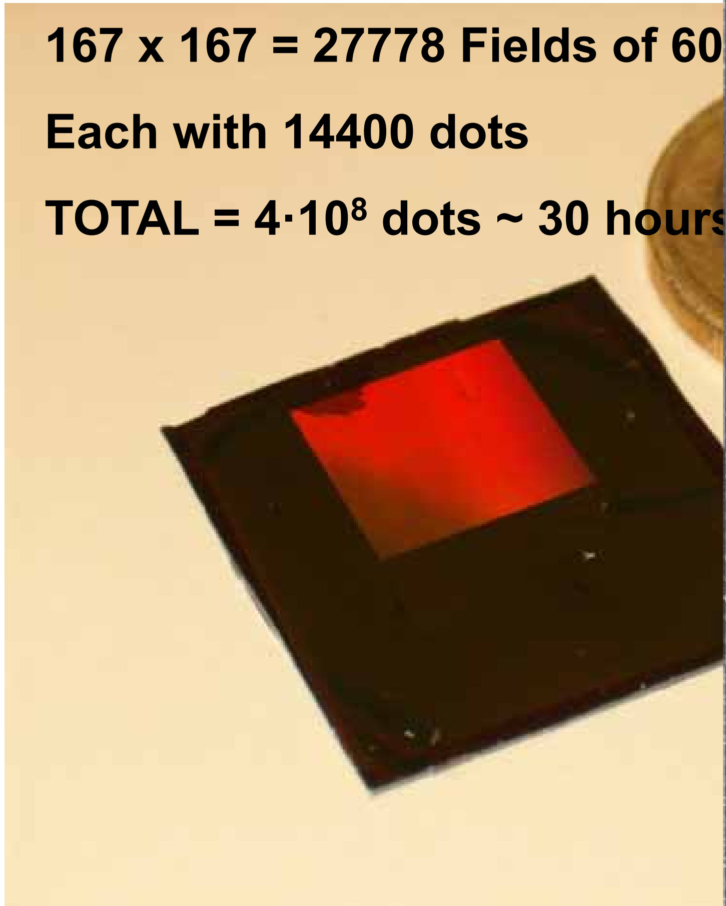
1 cm^2 of D250 nm dots separa

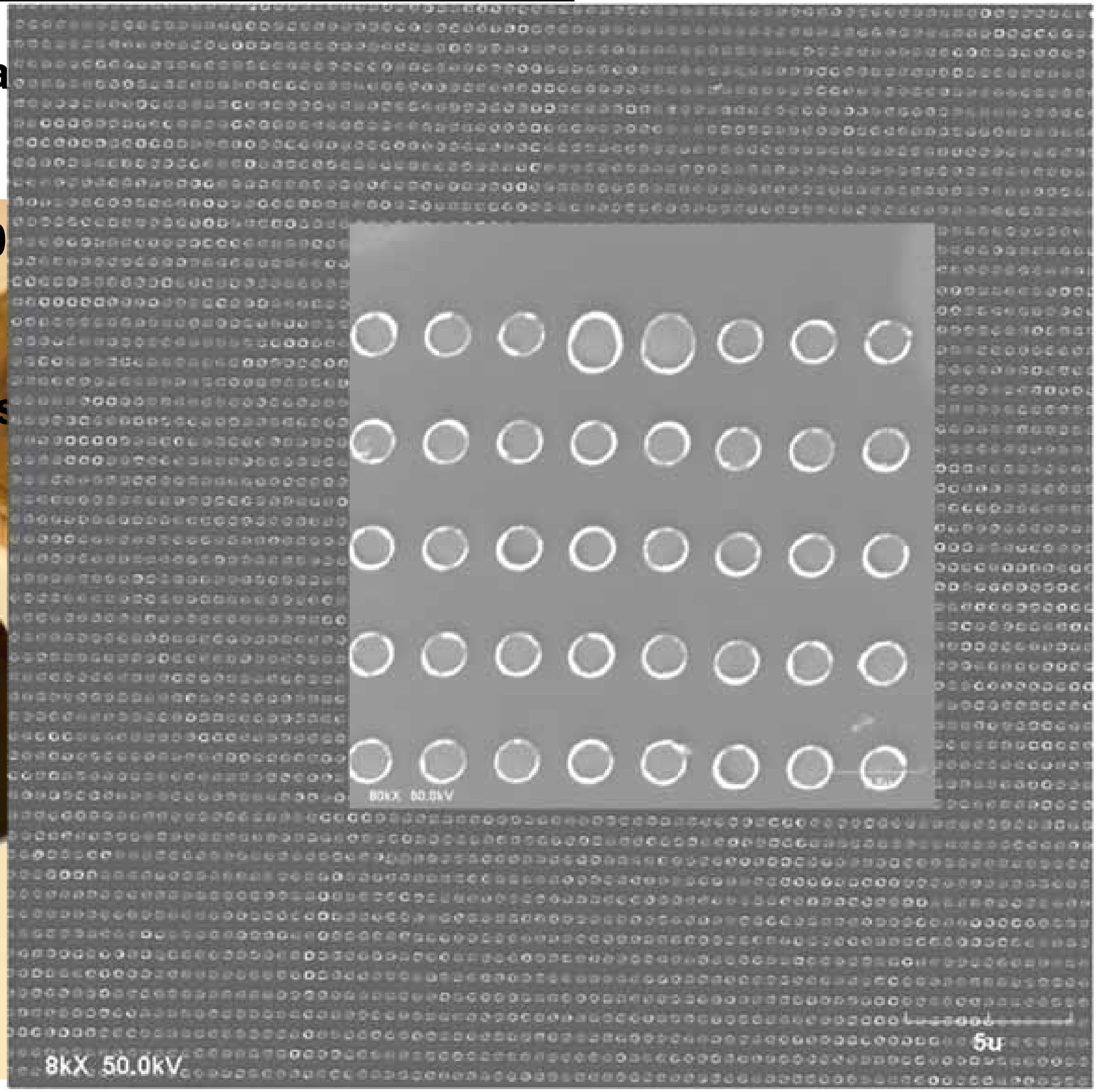
=

167 x 167 = 27778 Fields of 60

Each with 14400 dots

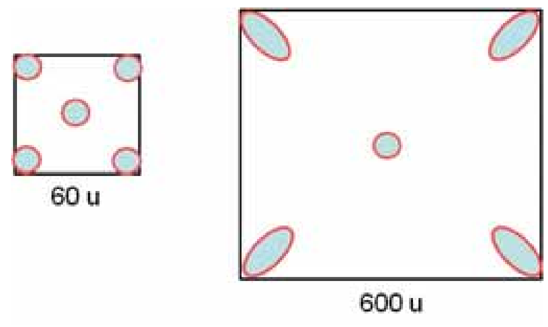
TOTAL = 4·10^8 dots ~ 30 hours





Exposure Speed

What is the best choice for field size?



Exposure time:

$$\frac{60000dots}{60u} \Leftrightarrow 1dot = 1nm$$

Resist Sensibility= 130 uC/cm^2

Current= 10 pA

$$t = SensR \cdot \frac{AreaDot}{Current} = 1.3C/m^2 \frac{10^{-18}m^2}{10^{-11}C/s} = 0.13\mu s/dot$$

If I increase the current to 100 pA ⟶ t=0.013us …. Too Fast!!

If the resist is 10 times more sensitive⟶ t=0.013us …. Too Fast!!

If I work on a 600u field ⟶ 1dot=10nm⟶ t=13 us

So, which one is the fastest choice 60u o 600 u?

60u takes (6·10^4)^2·0,13us=468s

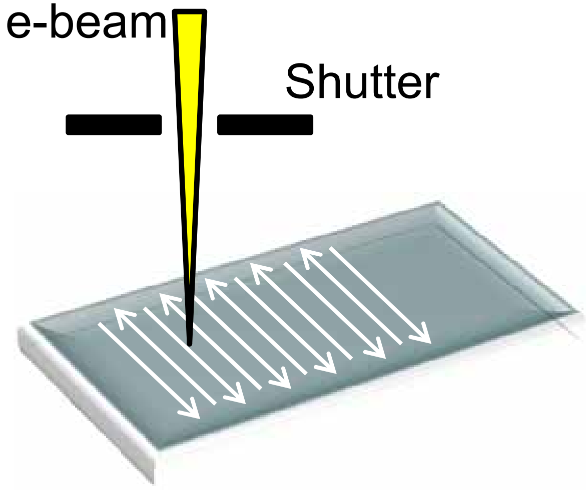
600u takes (6·10^4)^2·13us=46800s

But 600u = 100· 60 u. Then, is there any gain?

Time to move and align the stage!

Larger fields allow i ↑ and reducing t

Raster and Vector Scan



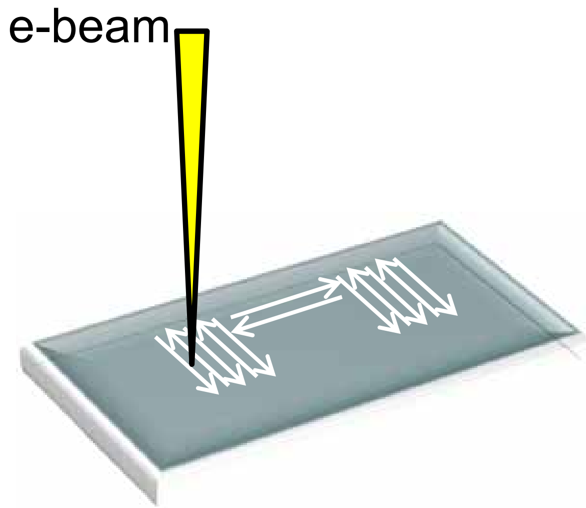
Raster Scan

-Beam scans all the surface of the chip and we blank it in the areas where we do not want to draw.

-It allows any format. Ex *.bmp

-Resolution is not optimal– speed of the“blanking”

-All drawings take as long



Vector Scan

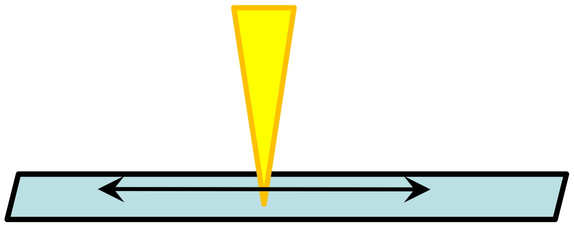
-The beam scans only the area that has to be drawn, in general, dividing it in vertical and horizontal polygons.

-Very good edge definition

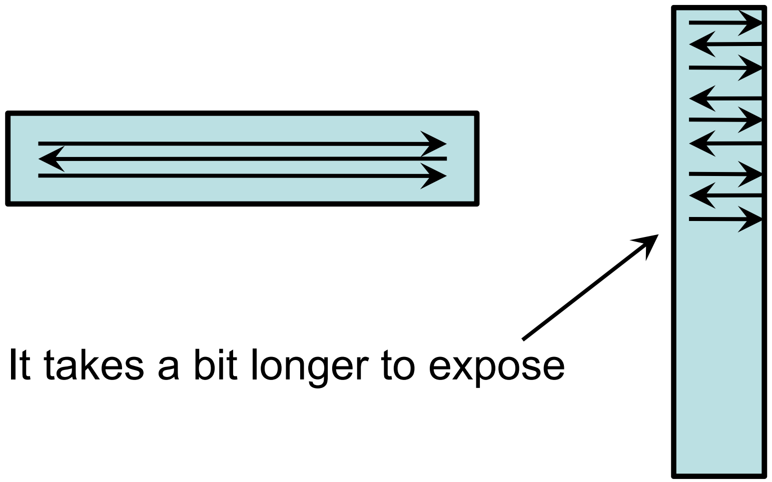
-Scanner might have a more limmited life

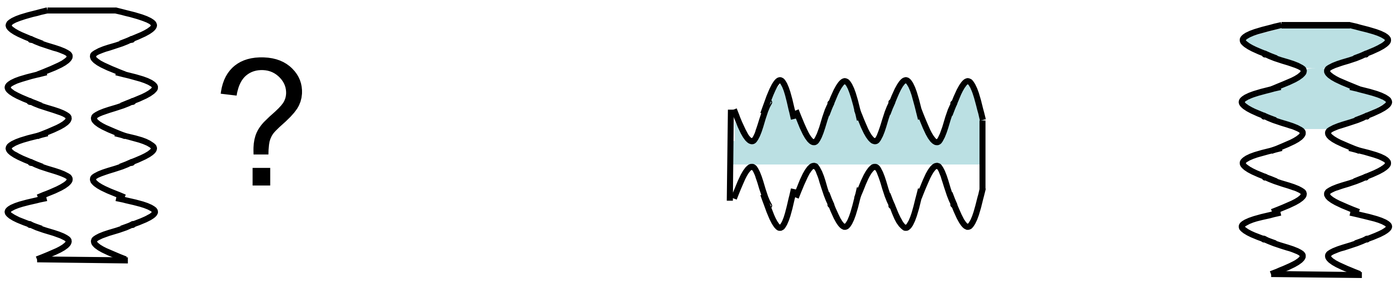
-Longer settling time of the beam is required

Direction of your drawing



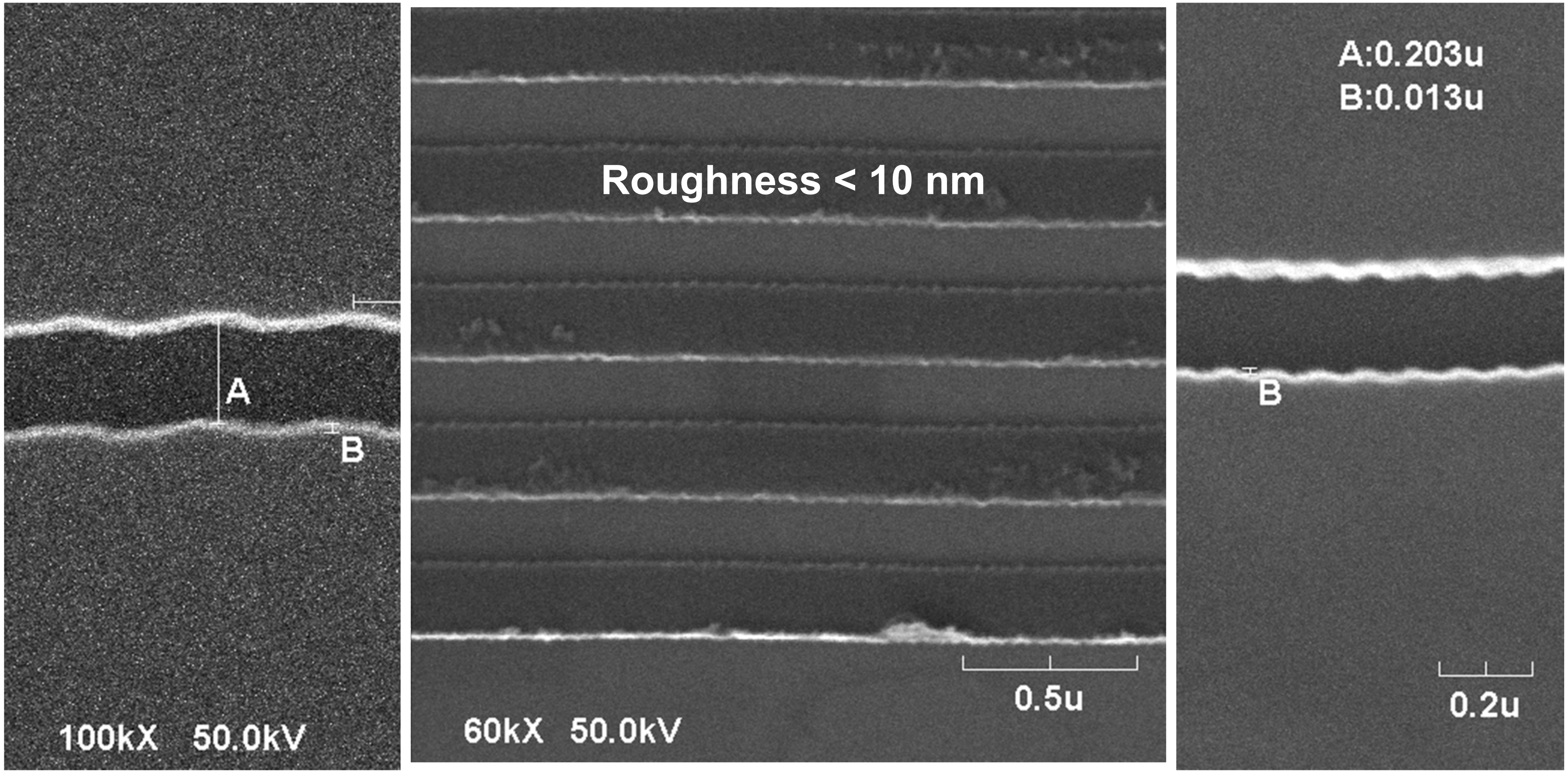
Direction of the scan



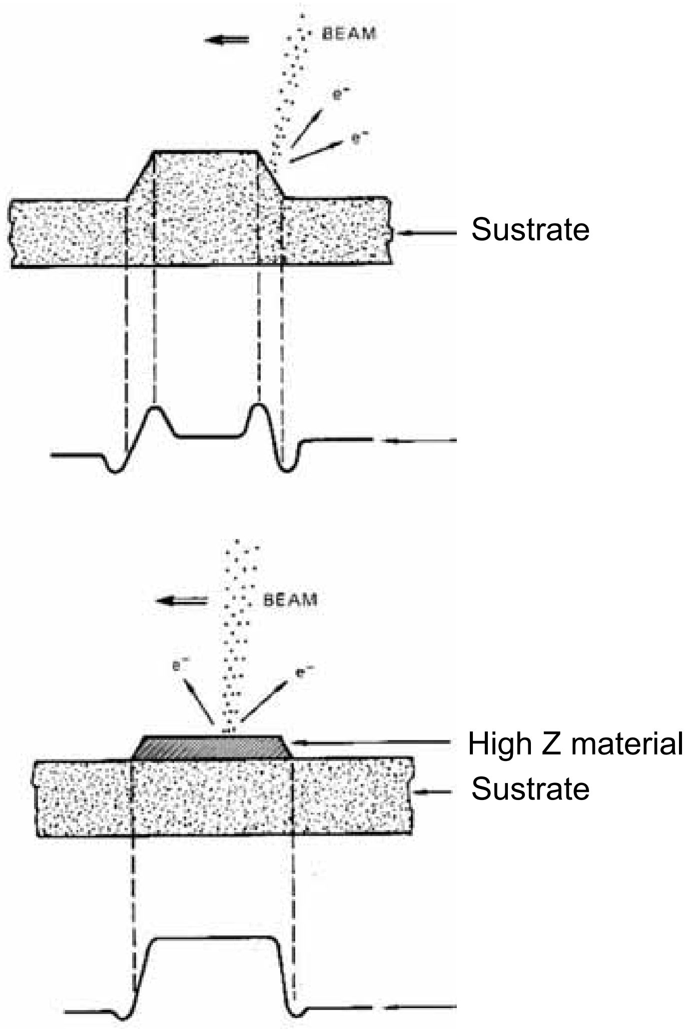


Direction of your drawing

Evaporation of Very Thin Layers

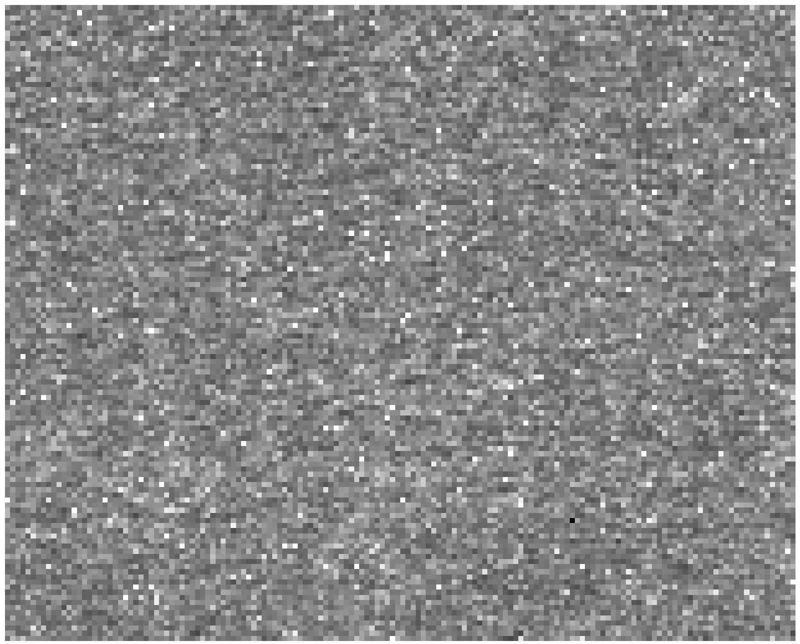


Alignment Marks

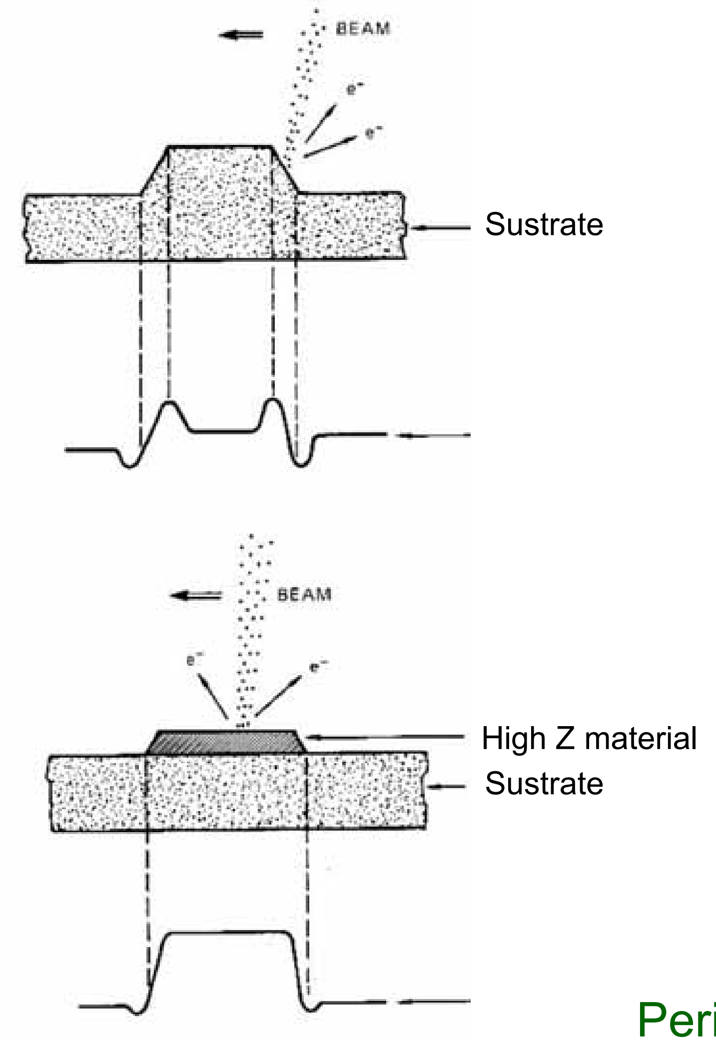


Backscattered e- are better to detect a mark. Secondary electrons get absorbed easily by the resist.

Alignment marks at low j, (10 pA)

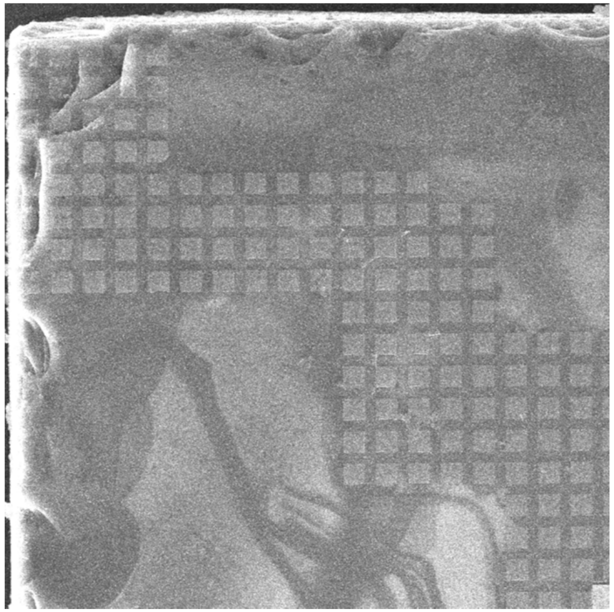


Alignment Marks



Backscattered e- are better to detect a mark. Secondary electrons get absorbed easily by the resist.

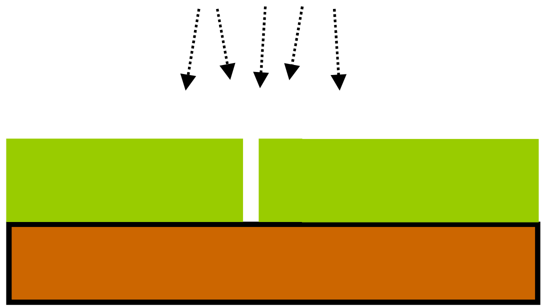
Alignment marks at low j, (10 pA)



Periodic features starting from the edge of the sample

Pattern Transfer

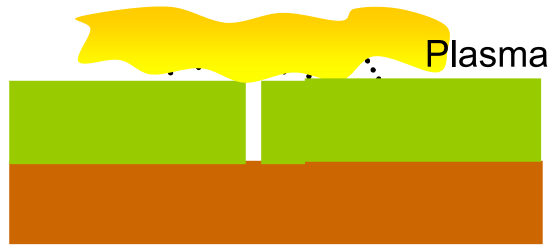
Evaporation

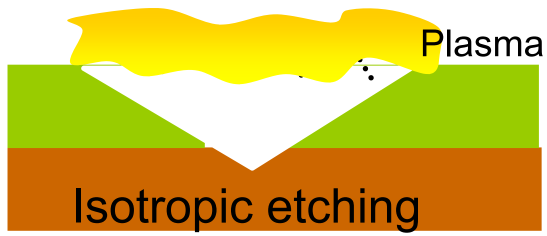


1.-Aspect ratio!!: Poor filling

2.- Lift-off

Dry Etching (RIE)





Pattern Transfer

Sputtering Deposition