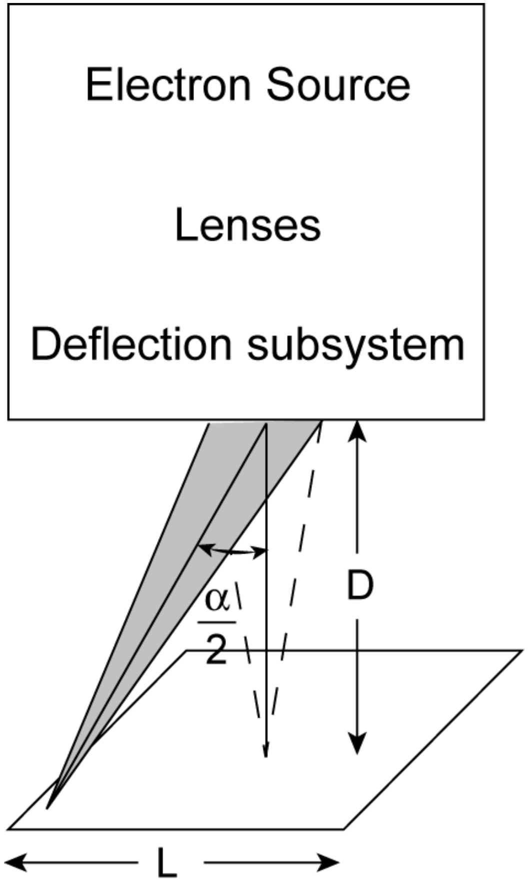
Nanometer Scale Patterning and Processing

Spring 2016

Lecture 18

Electron Beam Lithography

Electron Beam Lithography



Electron Source

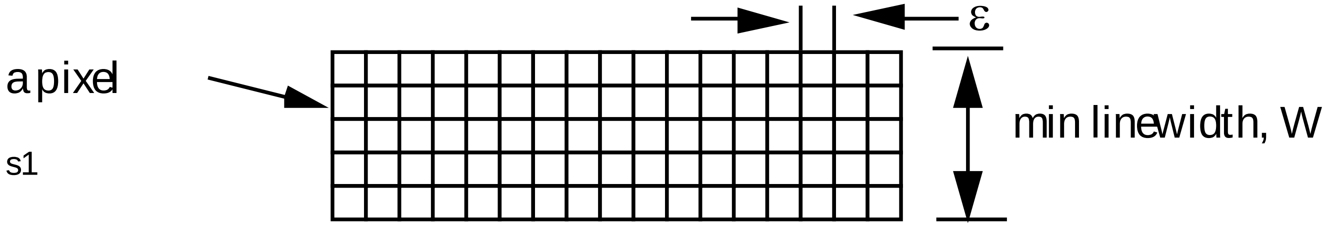
Lenses

Deflection subsystem

Arbitrary Patterns

- Leica VB6 HR (will be converted to UHR-EWF)
- Currently being installed in the Birck Nanotechnology Center

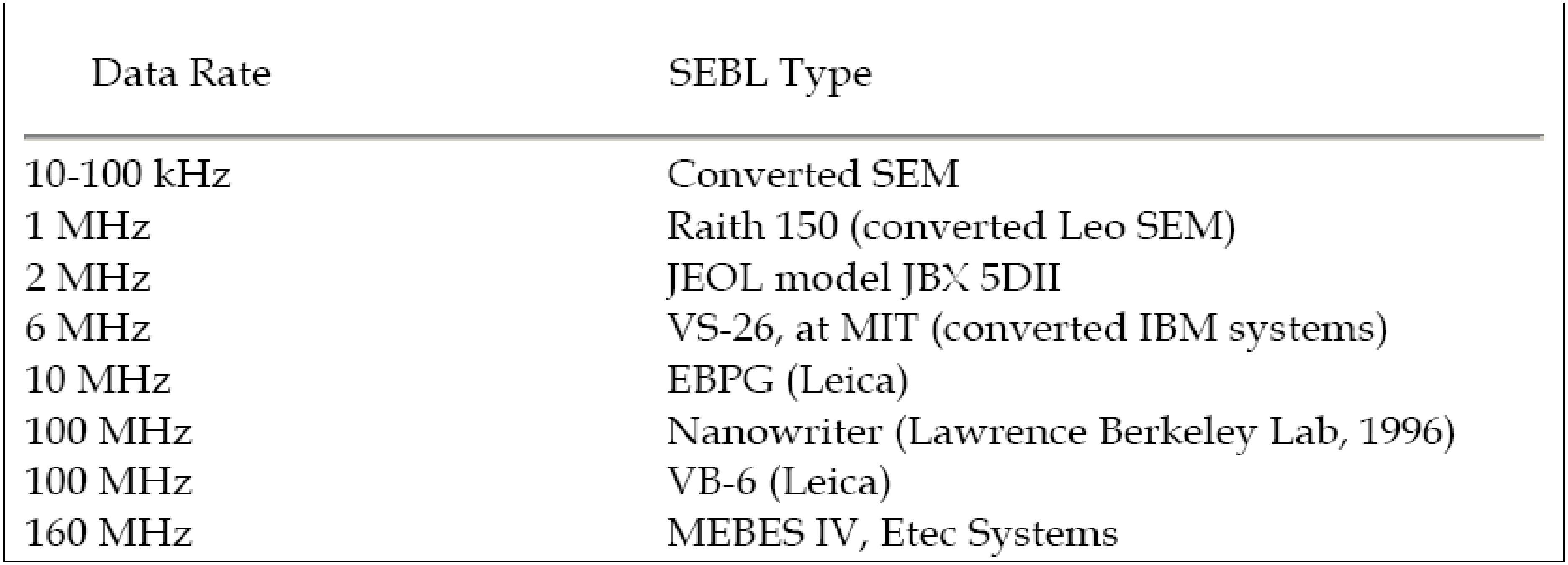
Pixel Exposure Model



Minimum linewidth typically 5x of pixel size

Pixel transfer rate or data rate, or deflection speed: the maximum rate (in Hz) at which distinct pixels can be addressed by the beam

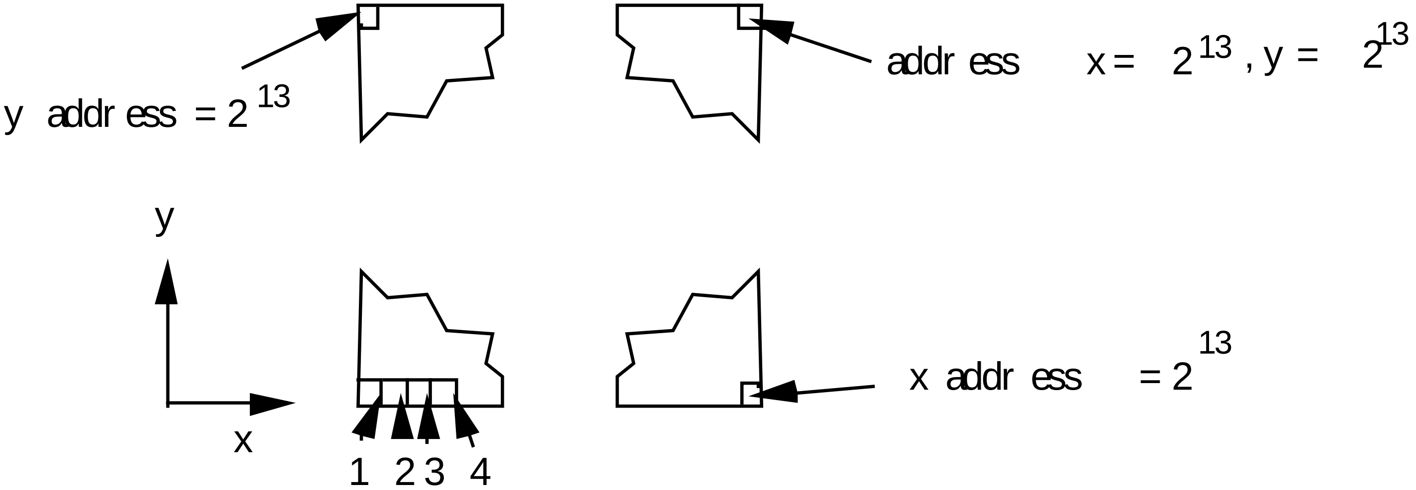
Deflection Speed of typical E-beam systems



Data Rate	SEBL Type
10-100 kHz	Converted SEM
1 MHz	Raith 150 (converted Leo SEM)
2 MHz	JEOL model JBX 5DII
6 MHz	VS-26, at MIT (converted IBM systems)
10 MHz	EBPG (Leica)
100 MHz	Nanowriter (Lawrence Berkeley Lab, 1996)
100 MHz	VB-6 (Leica)
160 MHz	MEBES IV, Etec Systems

Writing Strategies

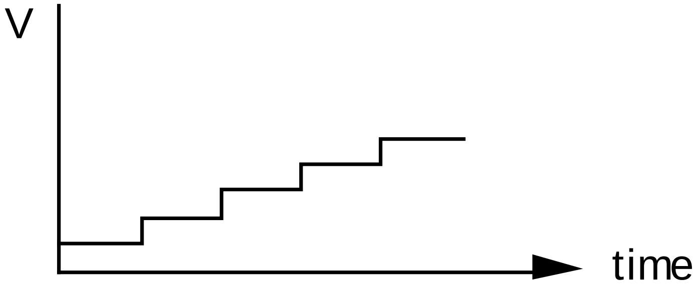
bit-by-bit addressing



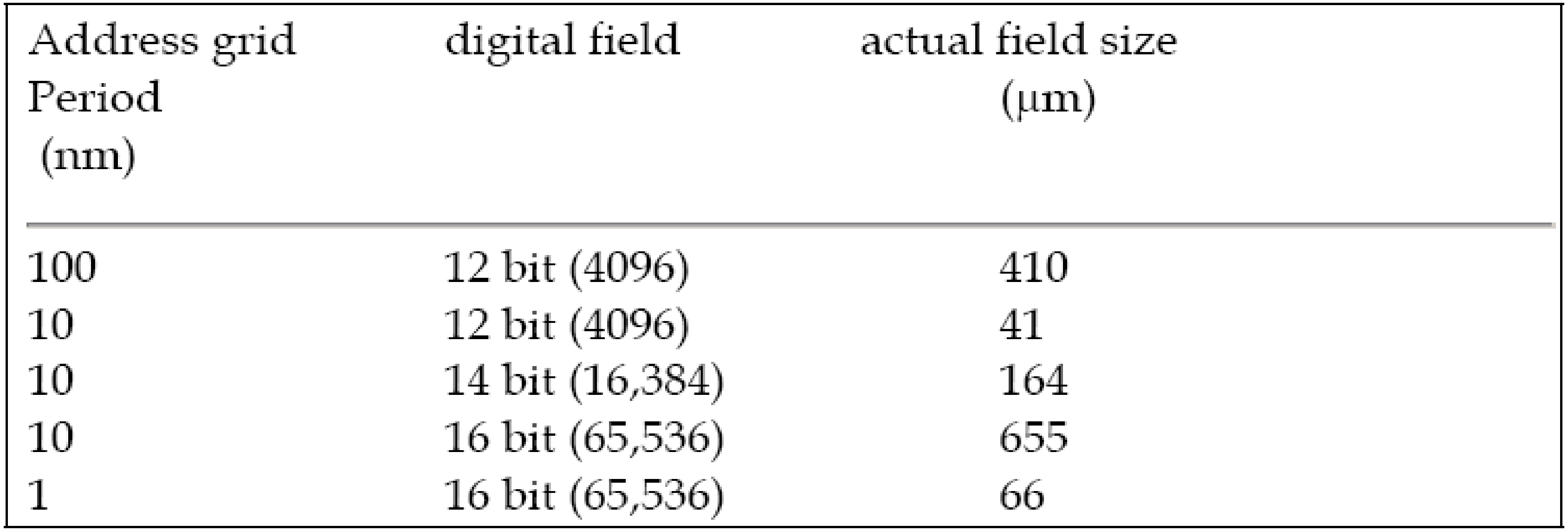
s3

Waveforms of deflection voltages (x or y)

s4



Field Sizes



Address grid Period (nm)	digital field	actual field size (µm)
100	12 bit (4096)	410
10	12 bit (4096)	41
10	14 bit (16,384)	164
10	16 bit (65,536)	655
1	16 bit (65,536)	66

Finer address grid provides higher flexibility in patterning,

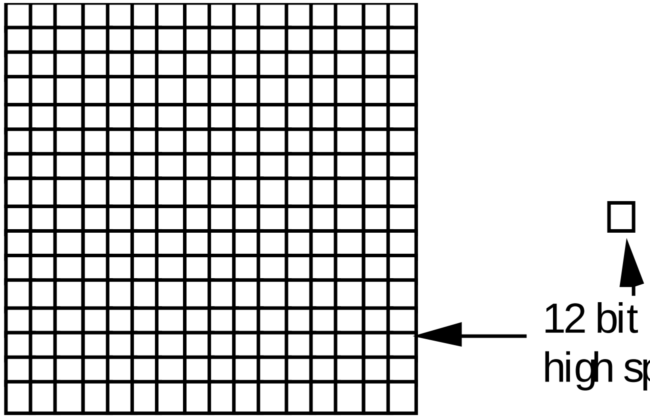
Large field size reduces field stitching error (discussed later) and enables higher throughput,

But DAC bits and accuracy are limited.

Dual DAC Strategy

Dual DAC Strategy

16 bit field



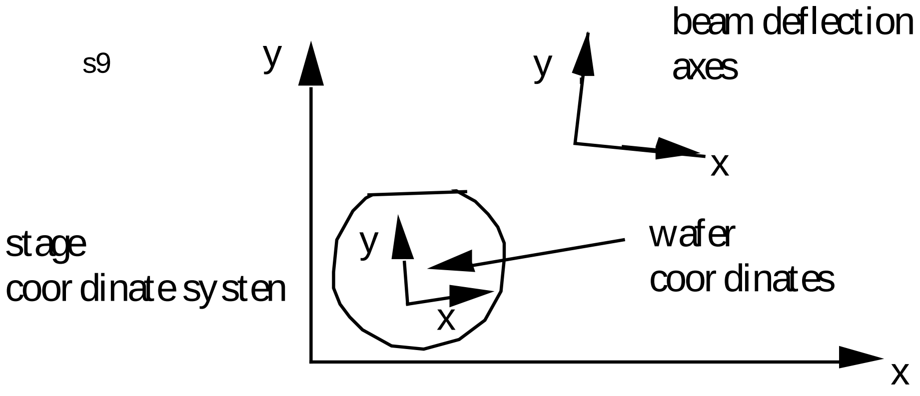
s5

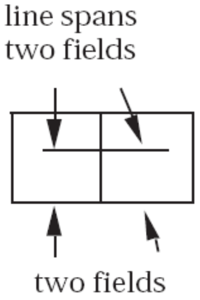
12 bit subfield, can be written at high speed

Deflection speed is the speed of the subfield DAC

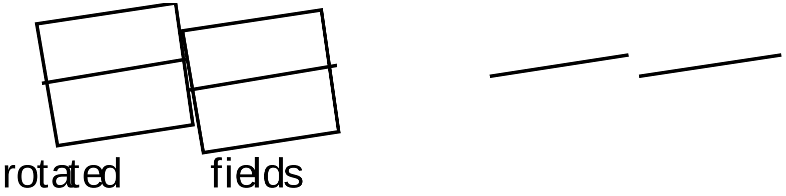
Field Stitching

s9



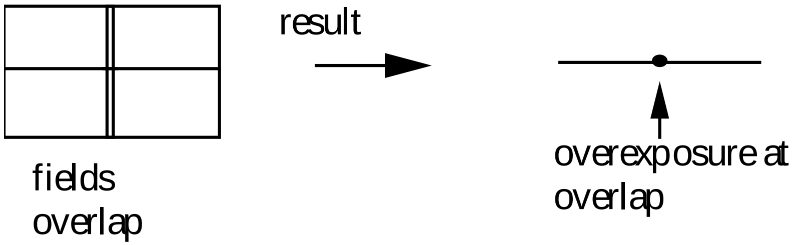


this results in a straight, continuous line
if the scan and sample axes are aligned
and magnification is correct

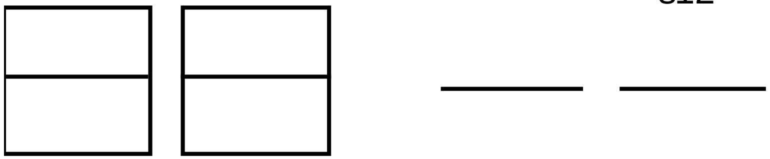


s11

Typically caused by focus change



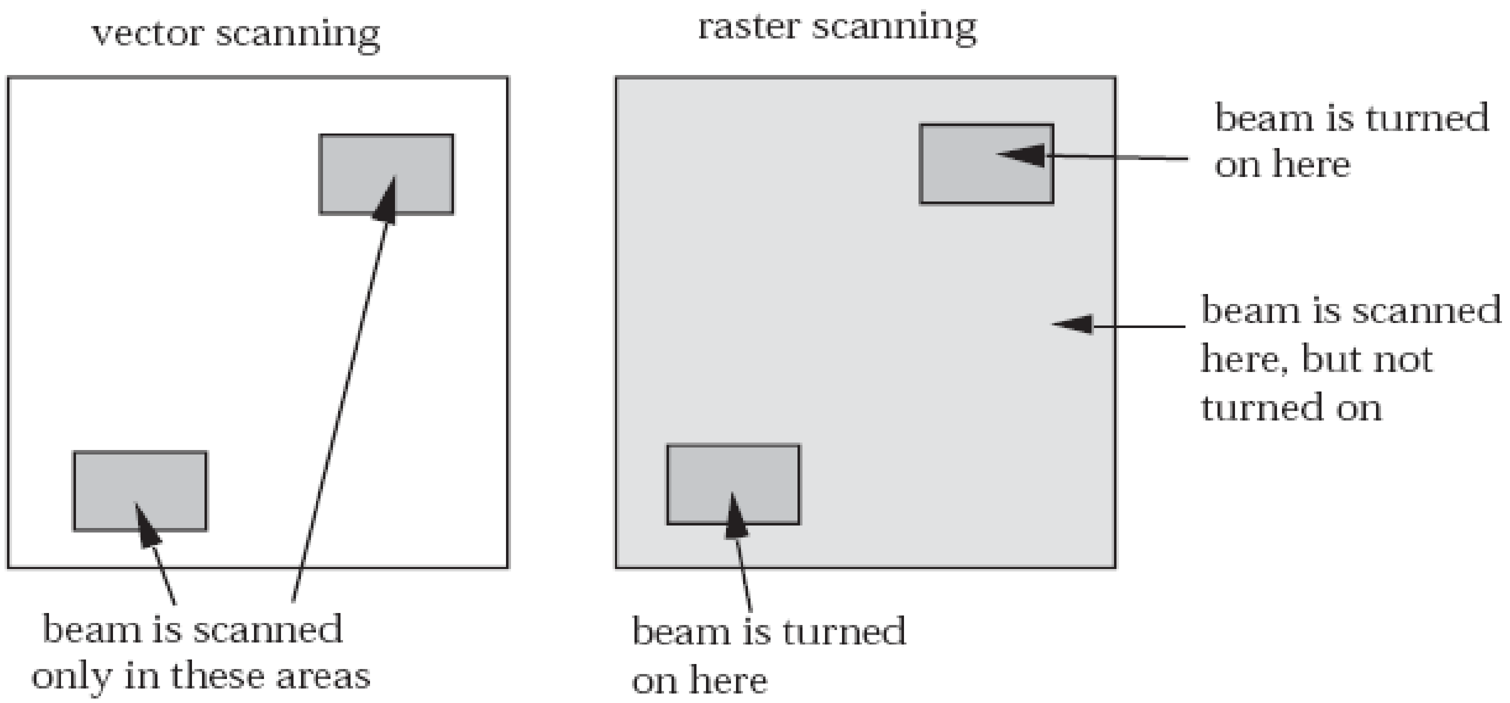
s12



s13

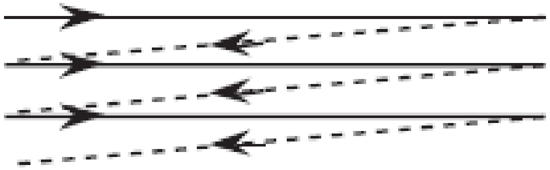
Field calibration is needed before exposure

Types of Scanning within a Field

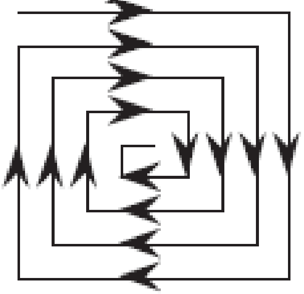


Vector scanning methods of writing fundamental shapes

flyback

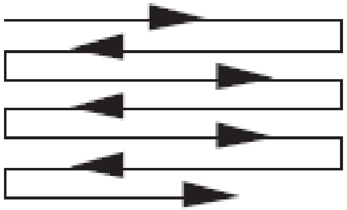


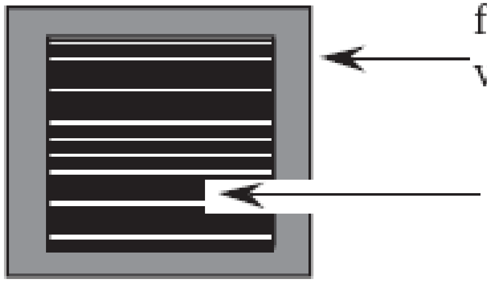
spiral



s7

boustrophedonic

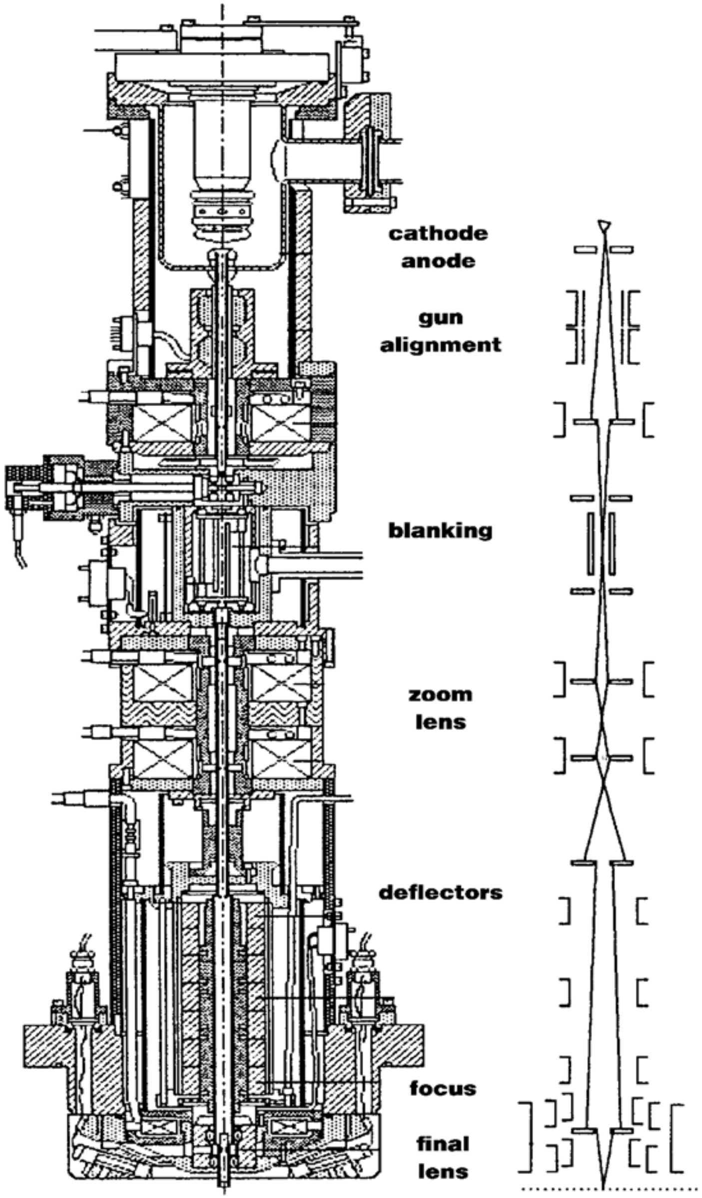




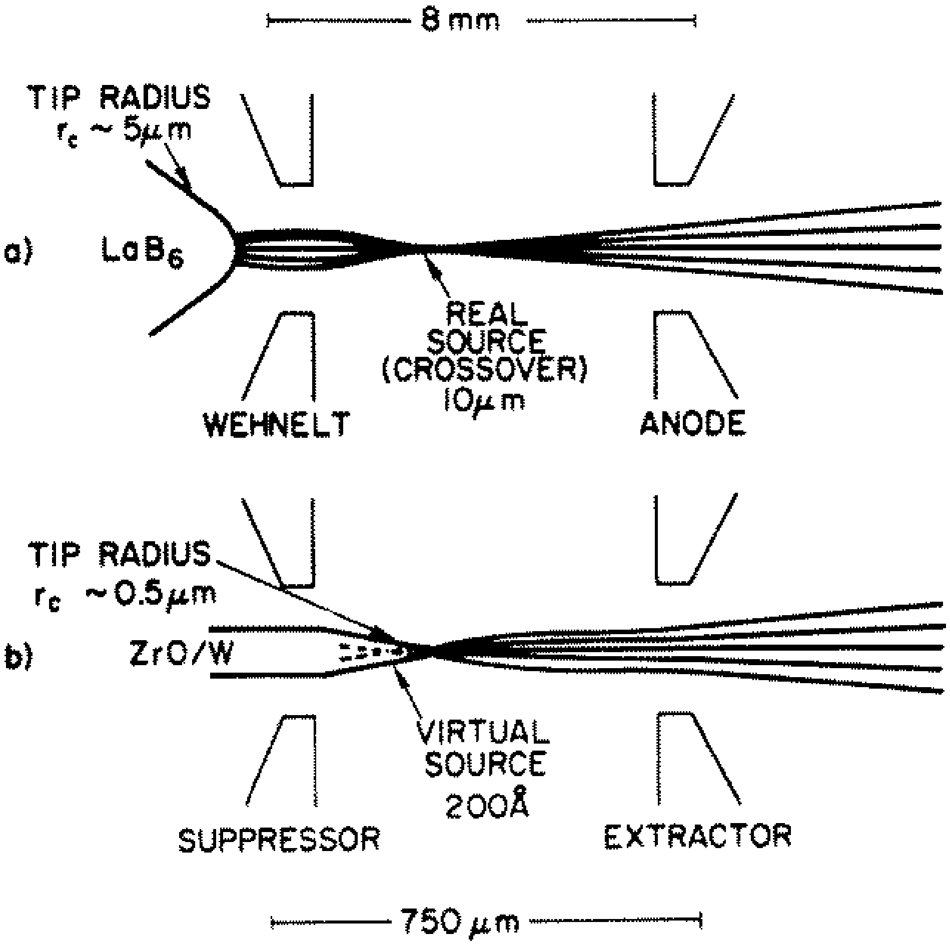
framing, i.e., border area is written with a fine beam

central area is written with a coarse beam

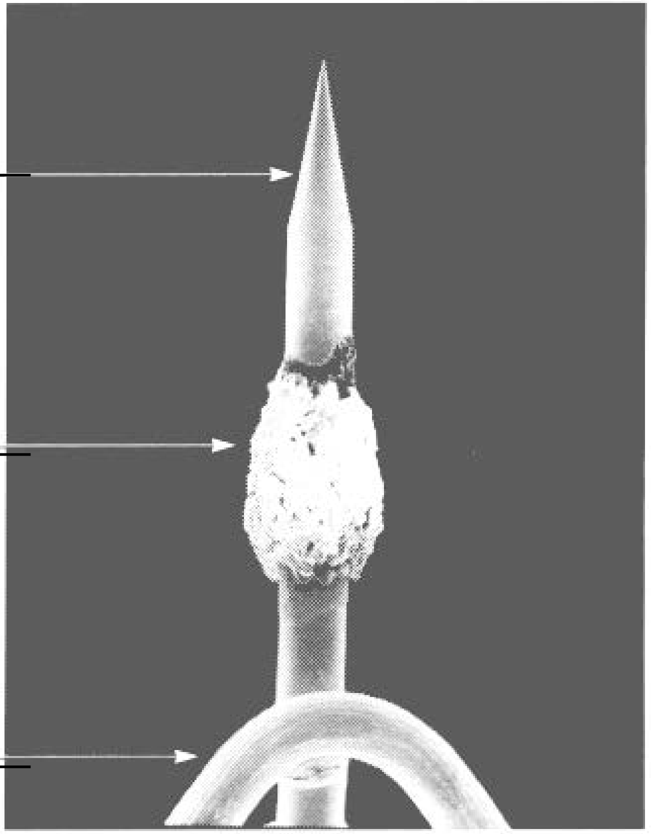
A typical e-beam column



Electron Source



Schottky Emitter Tip (Thermal field emission)

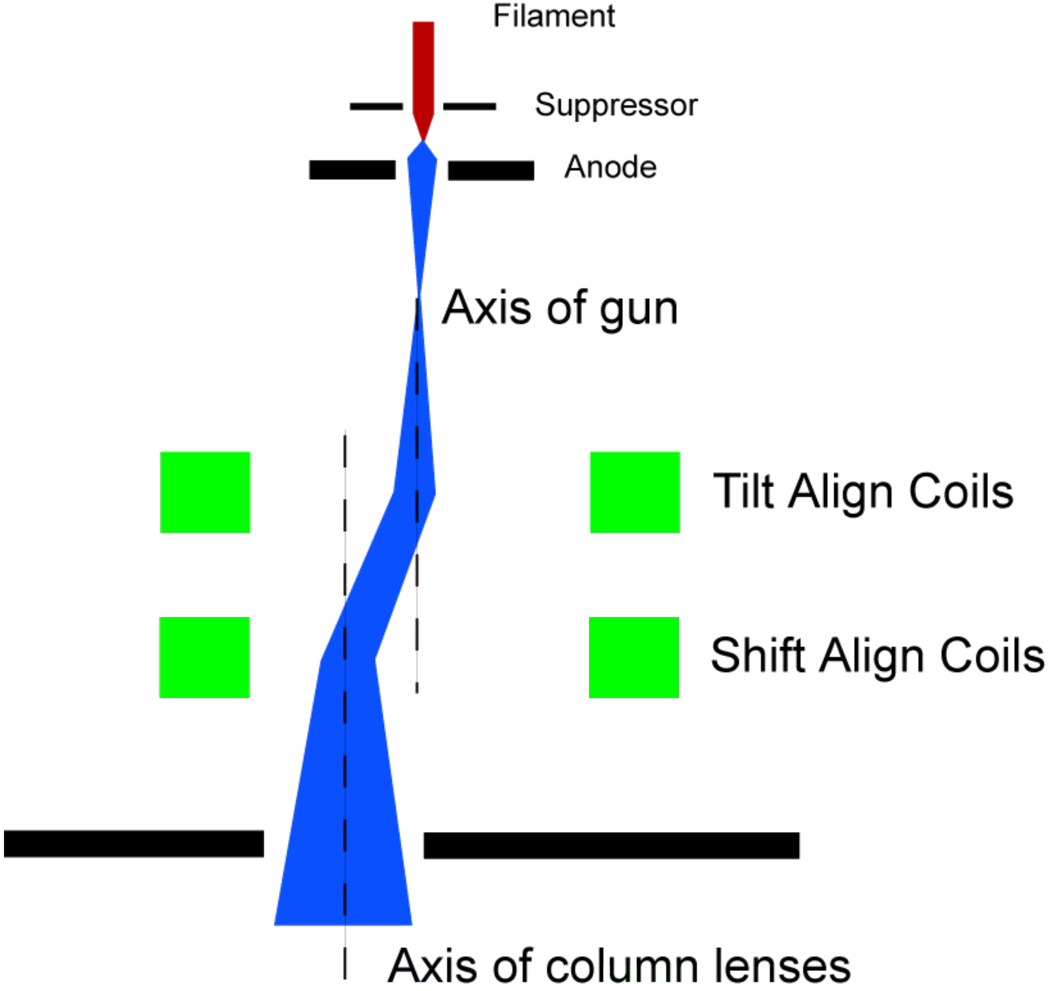


<100> W Crystal

ZrO Reservoir

Polycrystalline tungsten heating filament

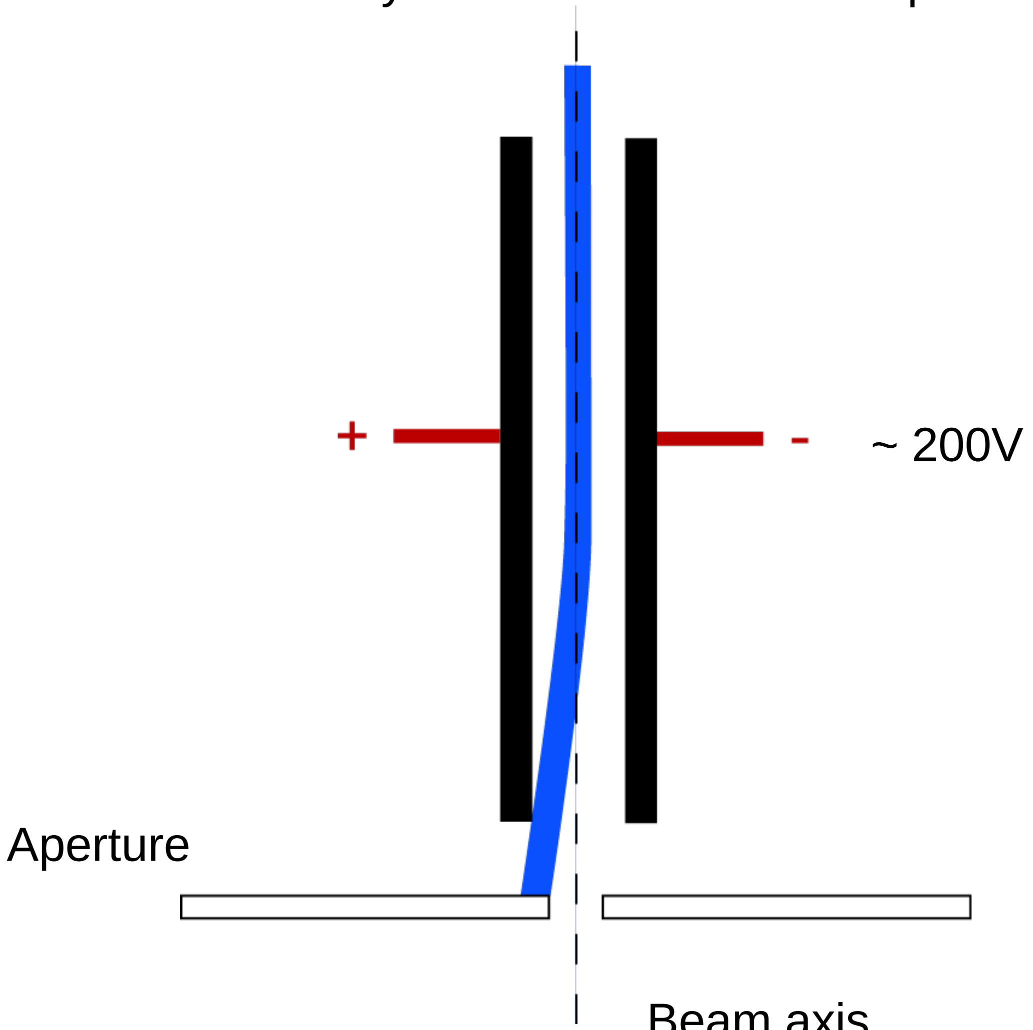
Tilt and Shift Alignment



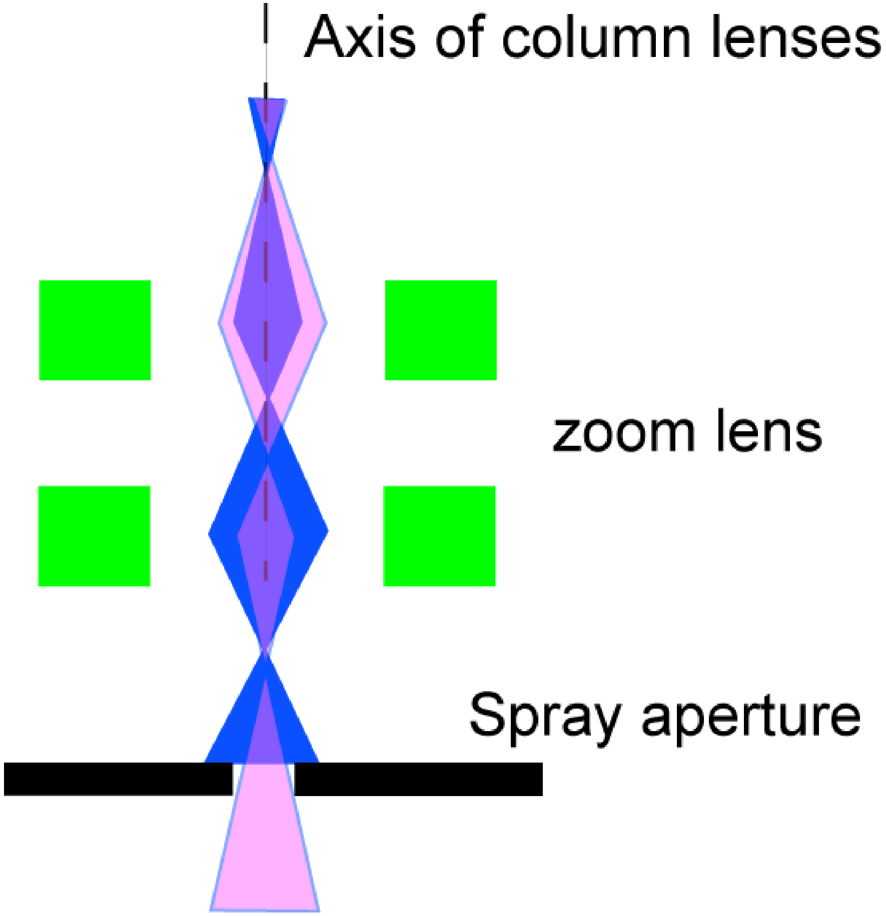
Align the axis of gun with column lenses

Beam Blanker

Deflects the beam away from the axis onto an aperture surface

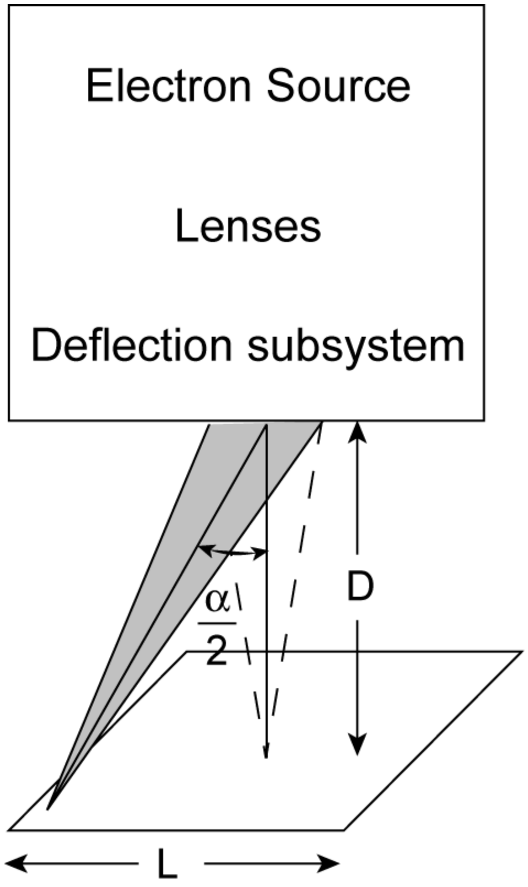


Zoom lens and current adjustment



Currents in zoom lens can be adjusted

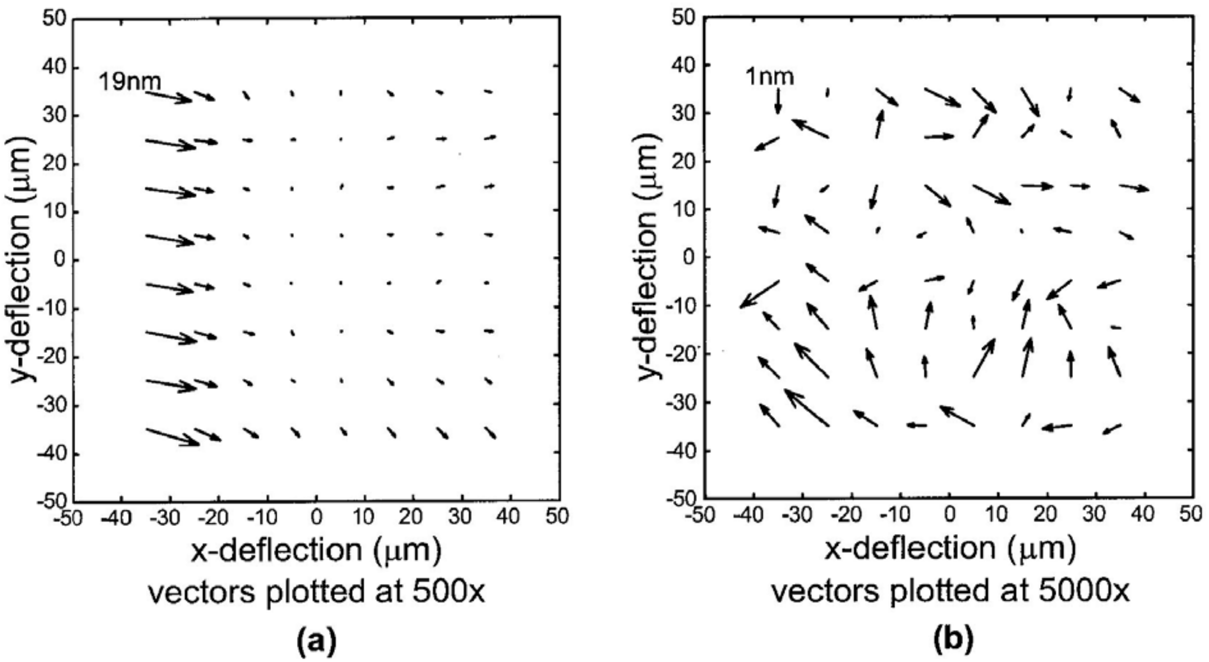
Beam deflection system requirements



D=25 cm for Leica VB6-UHR

- A accuracy of 1 part in 10^5 or better. Dynamic correction of the deflection distortion can be implemented.
- Aberrations, especially astigmatism, must be minimized, and for large fields, corrected dynamically.
- Focus changes with distance off axis. For large fields, focus changes and the associated field rotation must be corrected.
- Telecentricity: vertical landing of the beam is desirable, so that magnification does not change as the beam is deflected away from the axis.

Field Distortion Maps



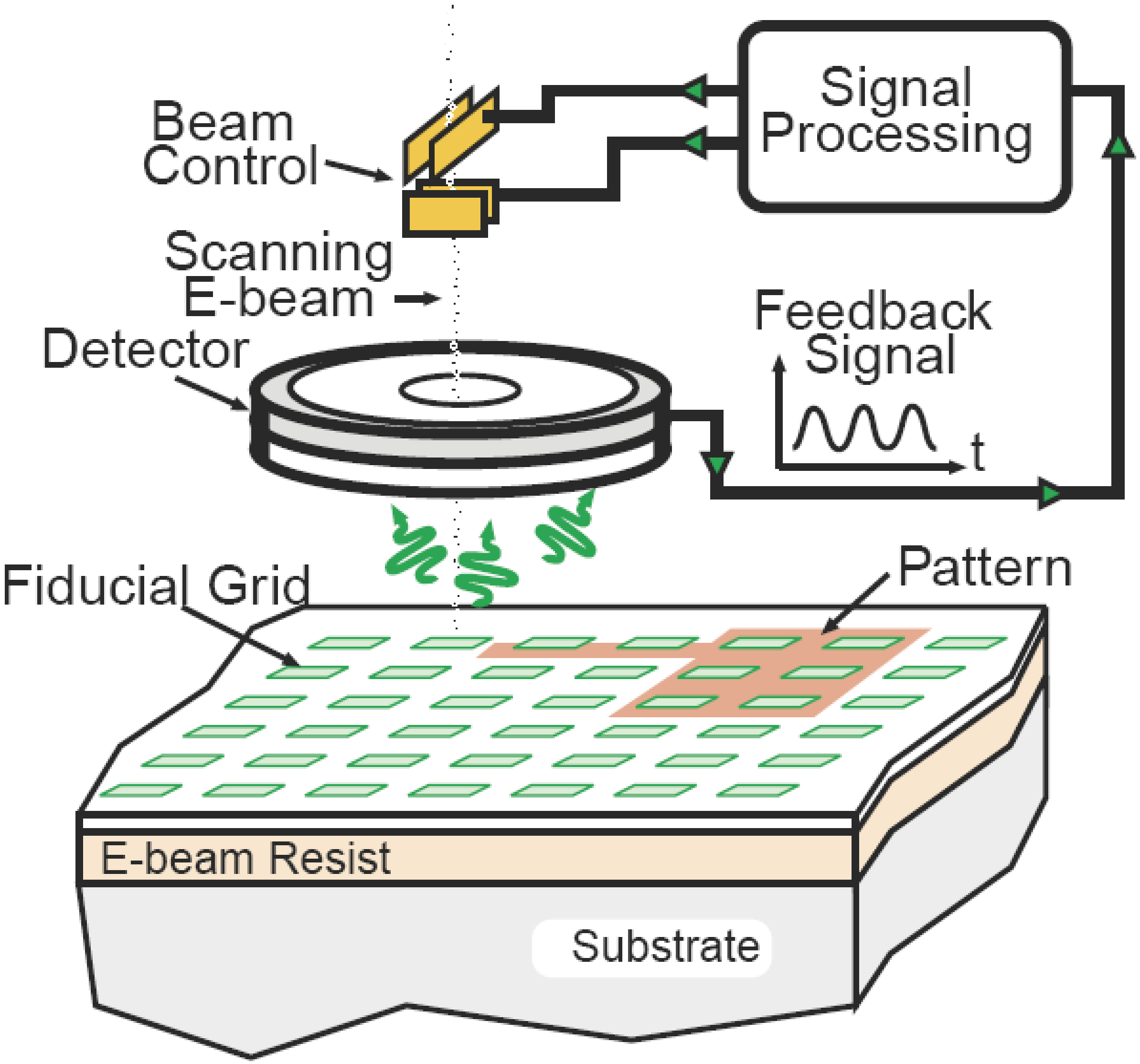
(a) First order correction only. (b) Correction through third order. Vectors indicate beam displacement from desired position for each point in the field.

Pattern Placement Errors in E-Beam Lithography

Time Scale (seconds)	10^{-6}	10^{-2}	10^{1}	10^{4}	
	Pixel to Pixel	Feature to Feature	Field to Field	Exposure to Exposure	Quasi-static
	DAC quantization	charging vibration stray EM fields interferometer quantization deflection hysteresis	sympathetic beam/stage motion thermal gradiants and variations	field calibration substrate mounting distortion	deflection non-linearity electron-optics distortions interferometer mirror errors stage calibration

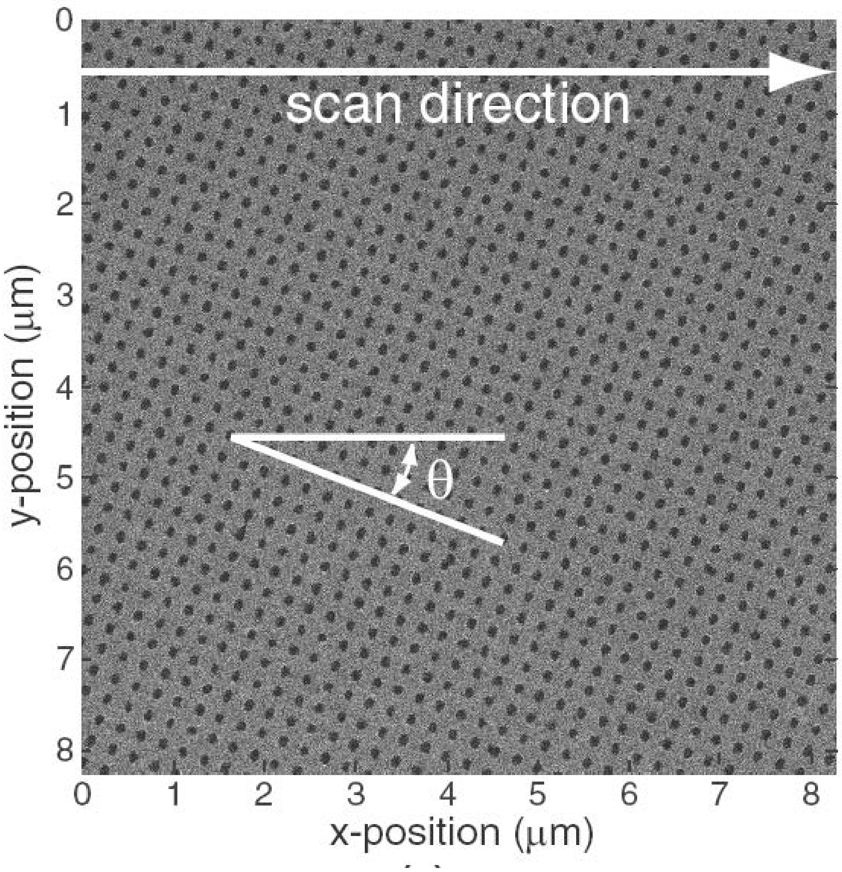
Many red zones in ITRS roadmap are caused by these placement errors.

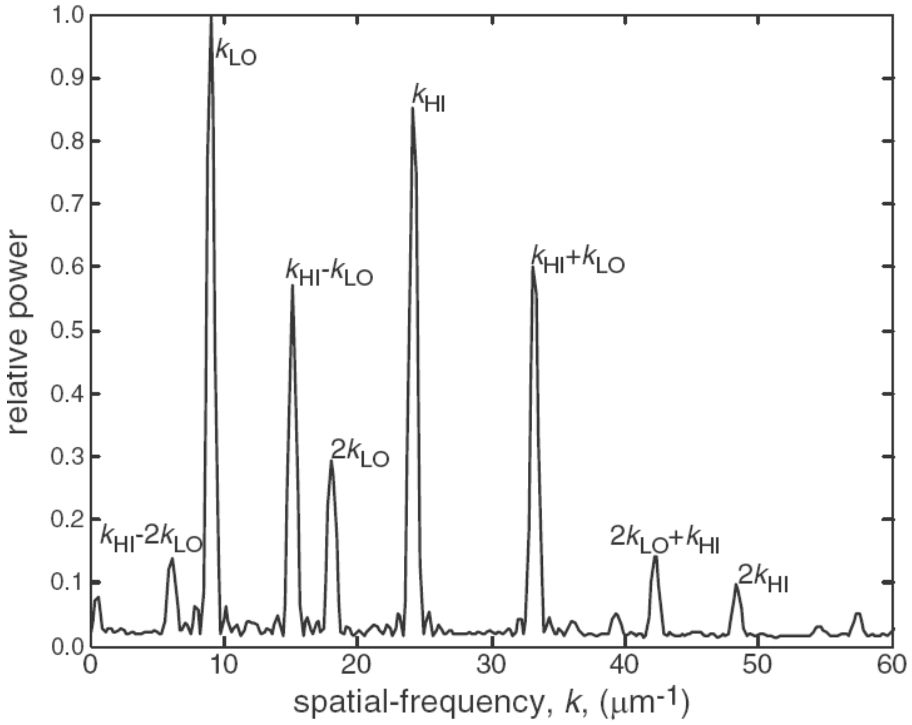
Spatial-Phase-Locked E-beam Lithography



Further development at Purdue (in collaboration with Leica)

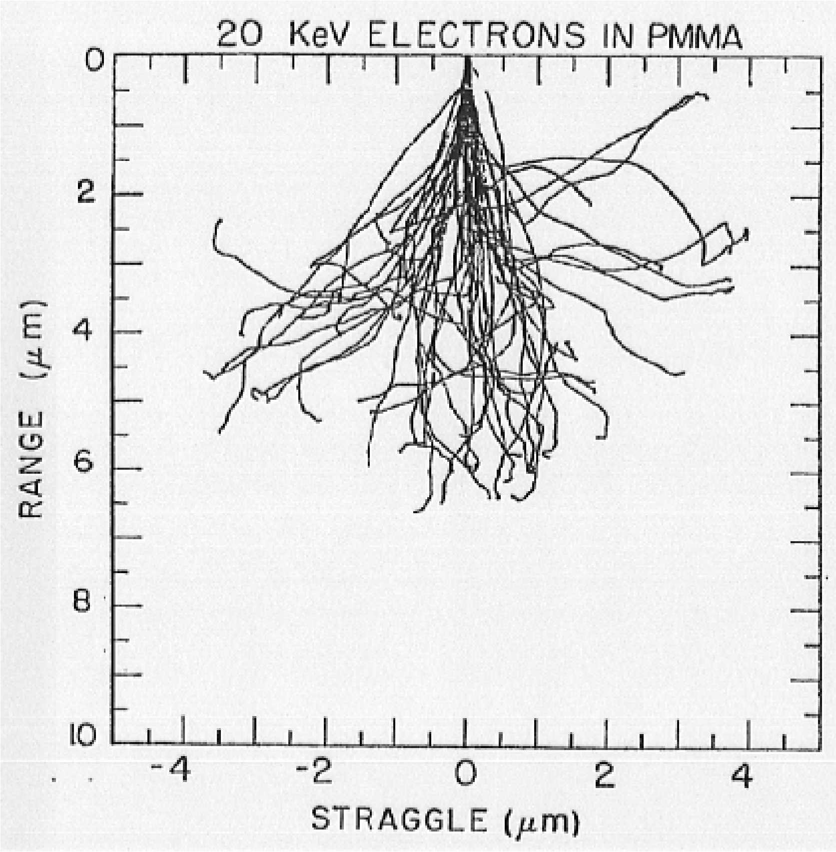
Phase-Locking Strategy





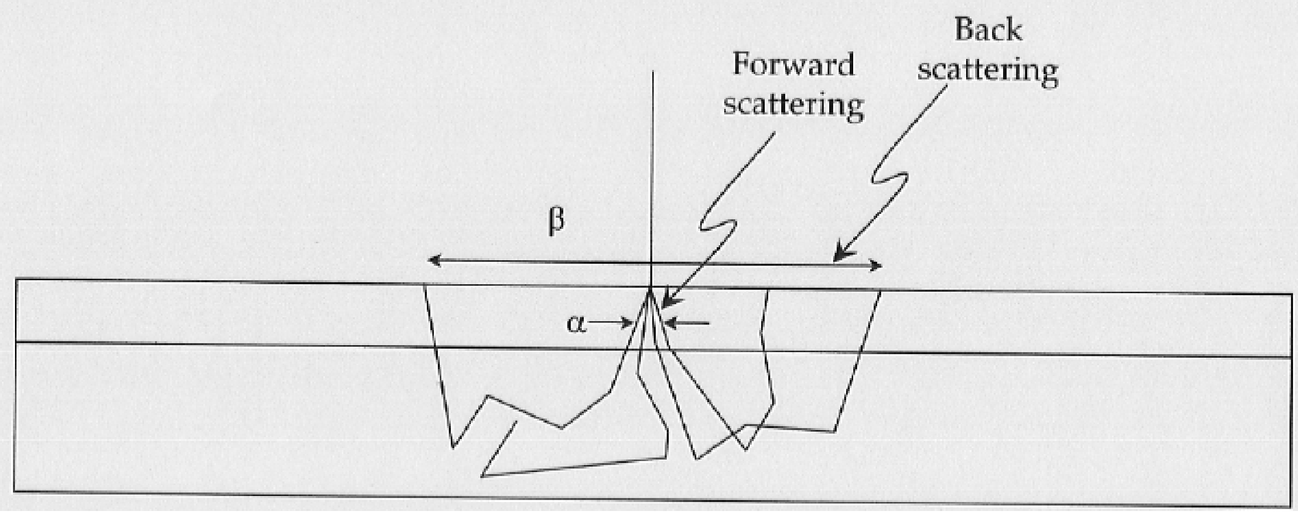
Phase detection can be accurate down to a few nanometers (2~4 nm)

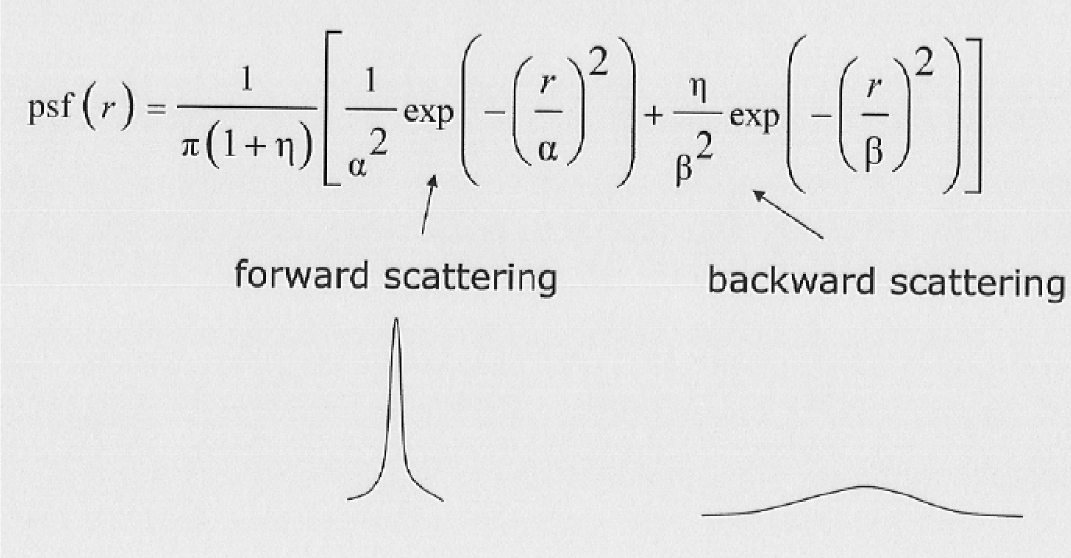
Interaction between high-energy electrons and resist (PMMA)



Monte-Carlo calculation of Electron trajectory in PMMA

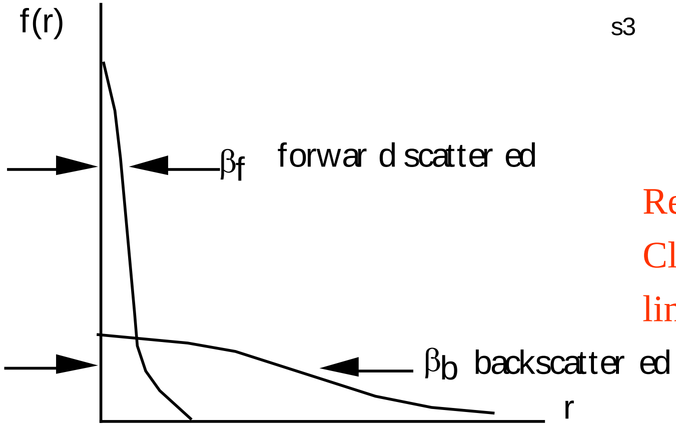
Point-Spread Function and Double-Gaussian Model



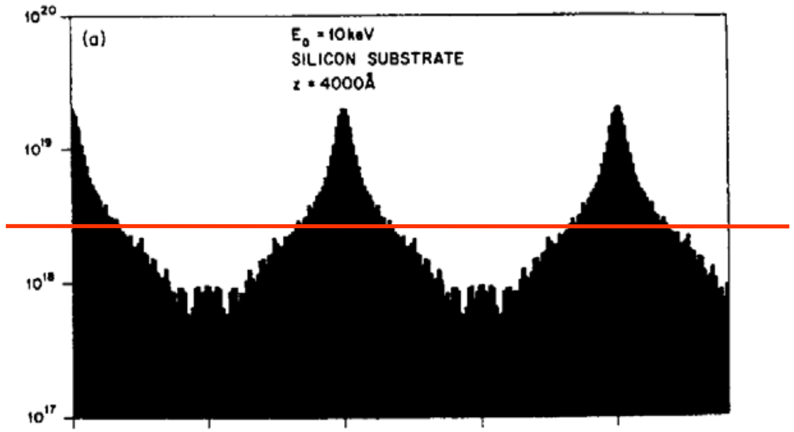


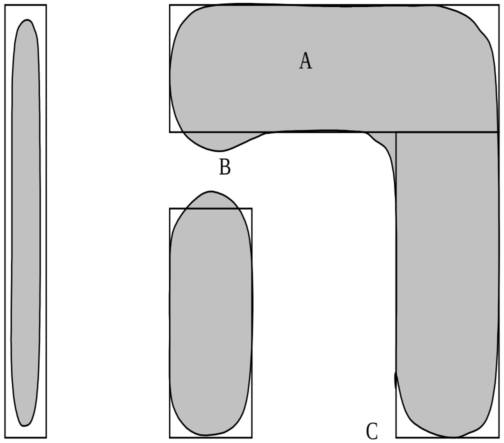
$$\mathrm{psf}(r) = \frac{1}{\pi(1+\eta)}\left[\frac{1}{\alpha^2}\exp\left(-\left(\frac{r}{\alpha}\right)^2\right) + \frac{\eta}{\beta^2}\exp\left(-\left(\frac{r}{\beta}\right)^2\right)\right]$$

Proximity Effect Distorts the Patterns

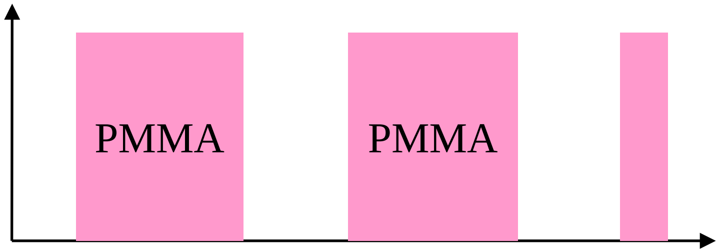


Lateral density distribution of an incident e-beam





Exposed pattern as a result of proximity effects



Upper: plot of energy deposited per unit volume by electrons in passing through a 400nm PMMA film on a Si substrate

Lower: Resist profile as the result of clipping effect in development

Proximity Effect Reduces Contrast

Plots of energy deposited per unit volume by electrons in passing through a 400 nm thick PMMA film on a Si substrate, normalized by dividing by the charge per unit length put down by the electron beam. The incident electron energy is 10 keV, and the depth is 400 nm below the top of the PMMA (i.e., at the interface with the Si substrate). Note how the background comes up (i.e., the contrast goes down) as the spatial period is reduced.