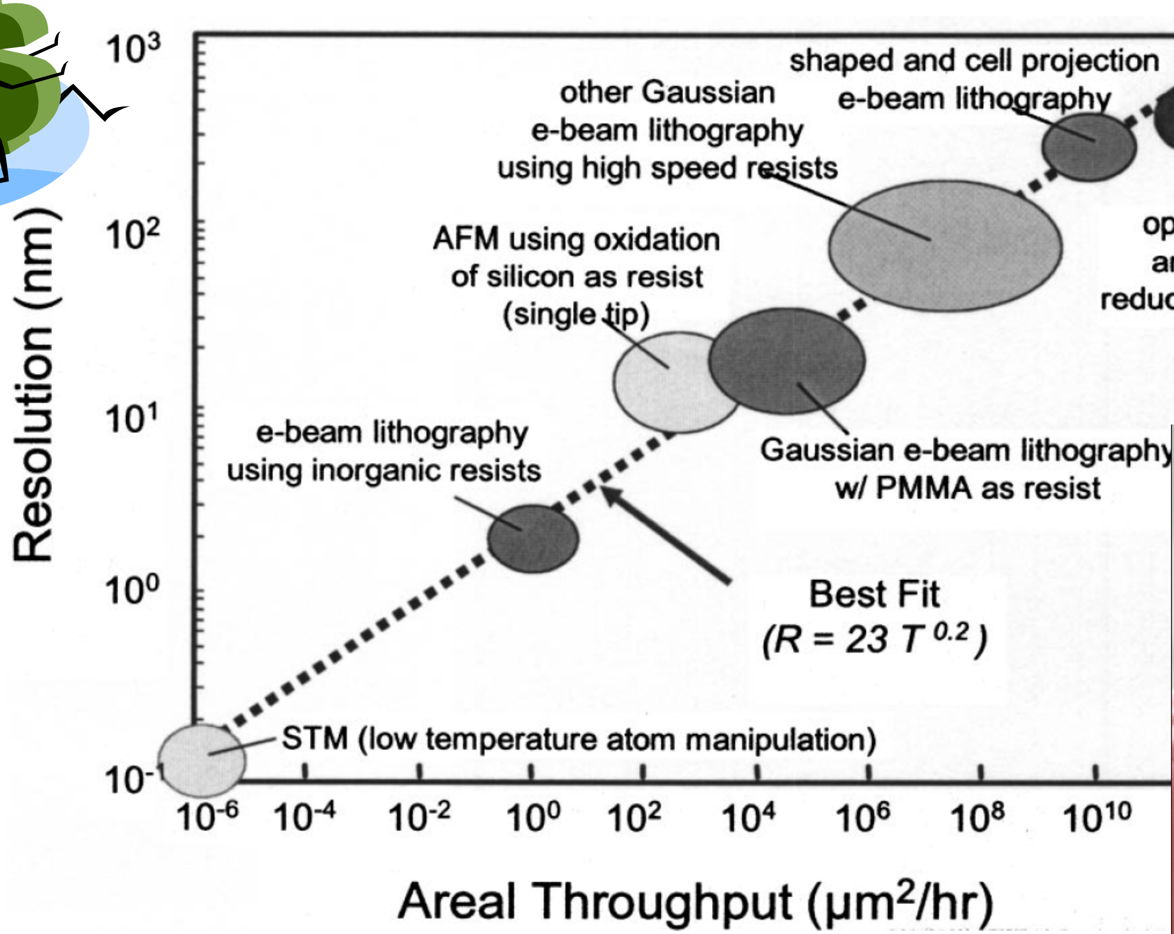
Nanometer Scale Patterning and Processing

Spring 2016

Lecture 16

Electron Optics and Lithography

Resolution and Throughput for Lithography



Tennant's Law

Courtesy of Donald Tennant, Cornell Nanofabrication Facility

Electron-optics

$\lambda \sim 0.004$ nm (0.04Å) at 100keV

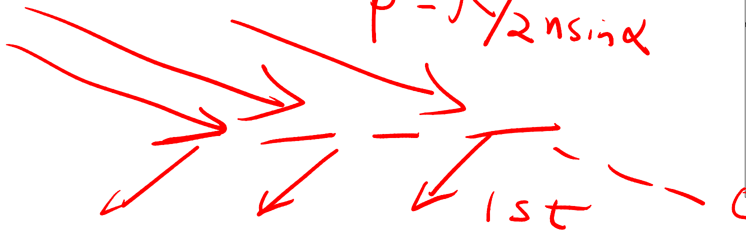
$p = \lambda / \sin\alpha$ (only normal incidence)

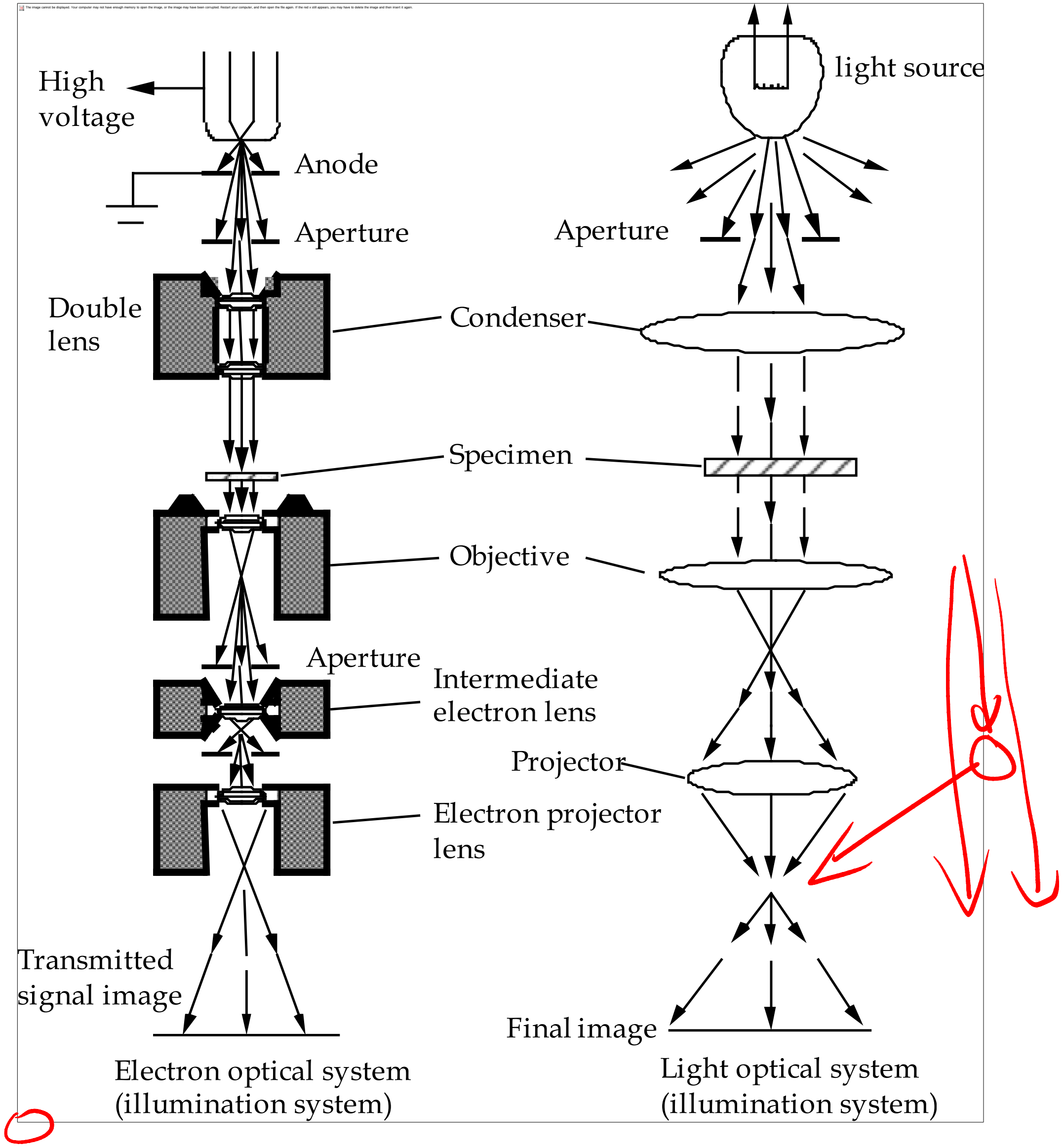
$\alpha \sim 10^{-2}$ radians $\frac{\pi}{2}$

large angle scattering are inelastic → wavelength changed → reduced image contrast

$p \sim 0.4$ nm

$p = \lambda / 2n\sin\alpha$





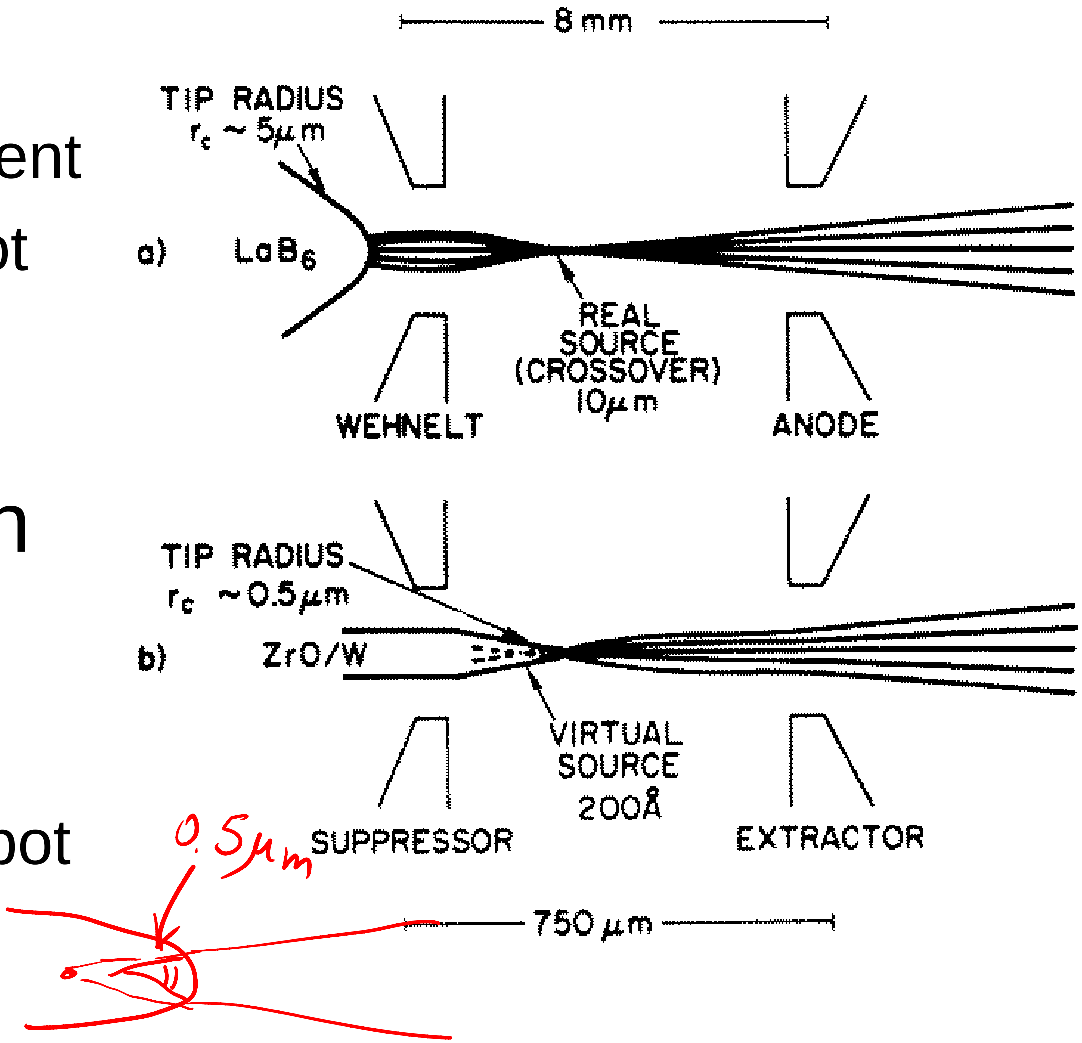
Electron Source

LaB_6

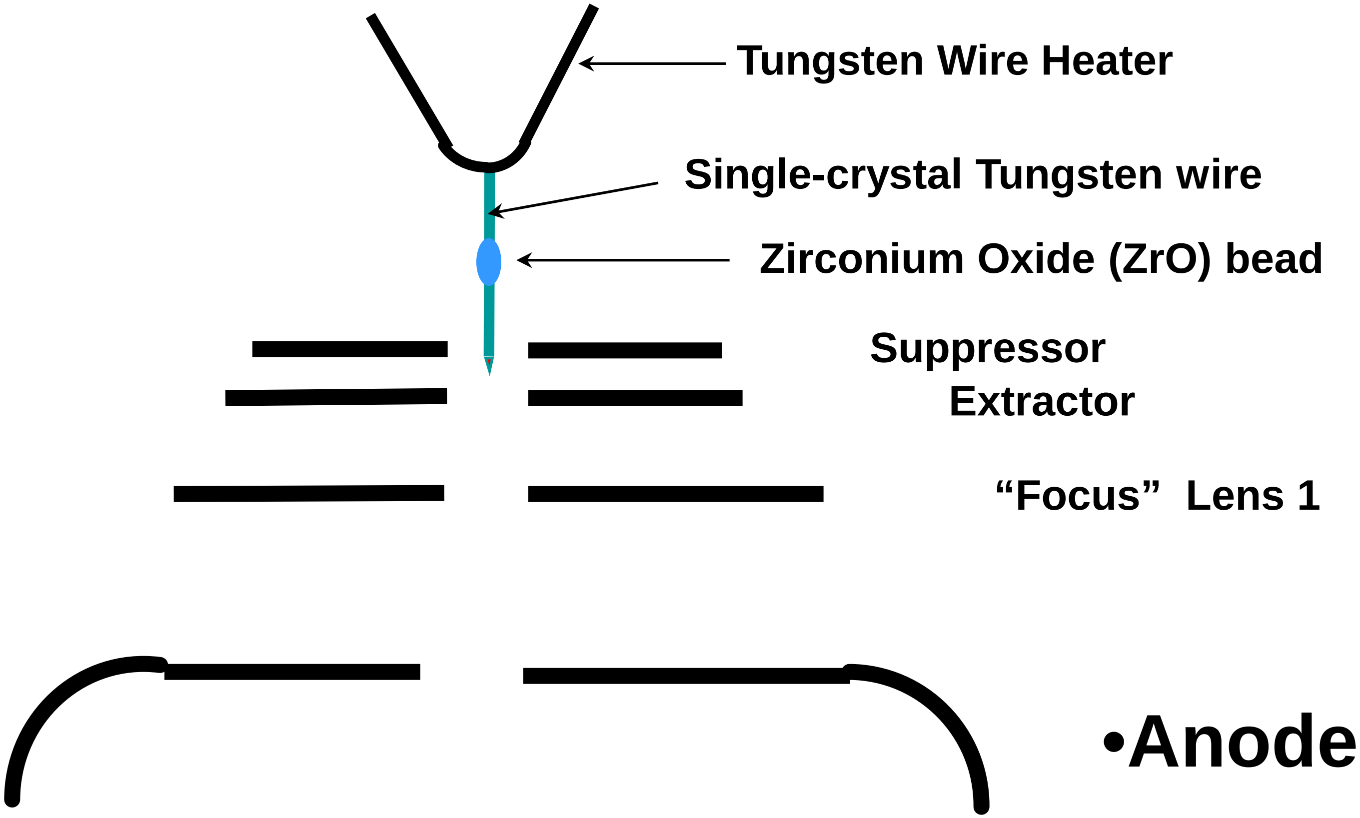
- higher total current
- larger beam spot

Field Emission

- no crossover
- lower ΔE
- smaller beam spot



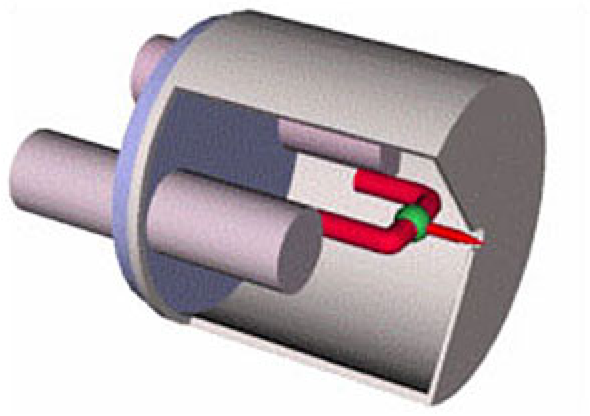
The Schottky Emission Gun

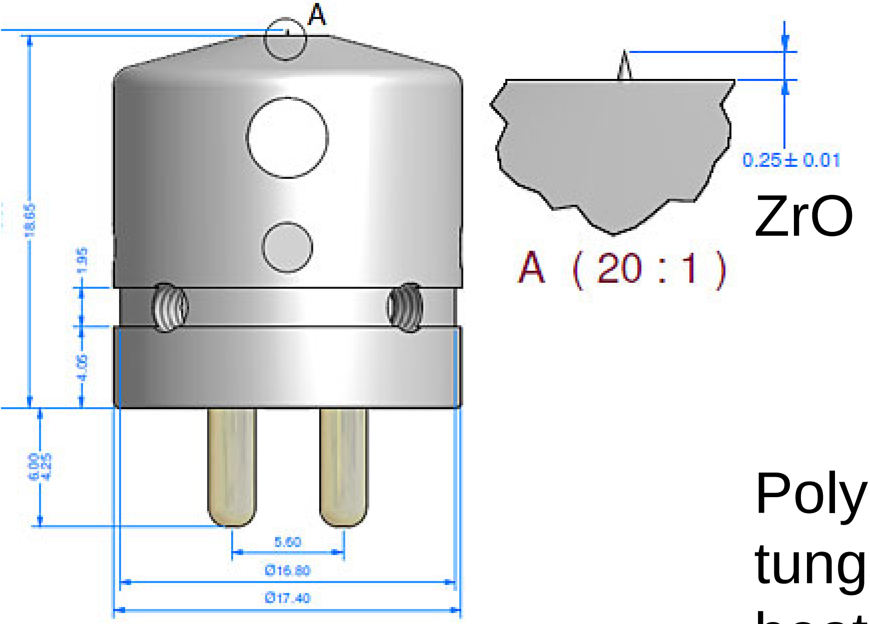


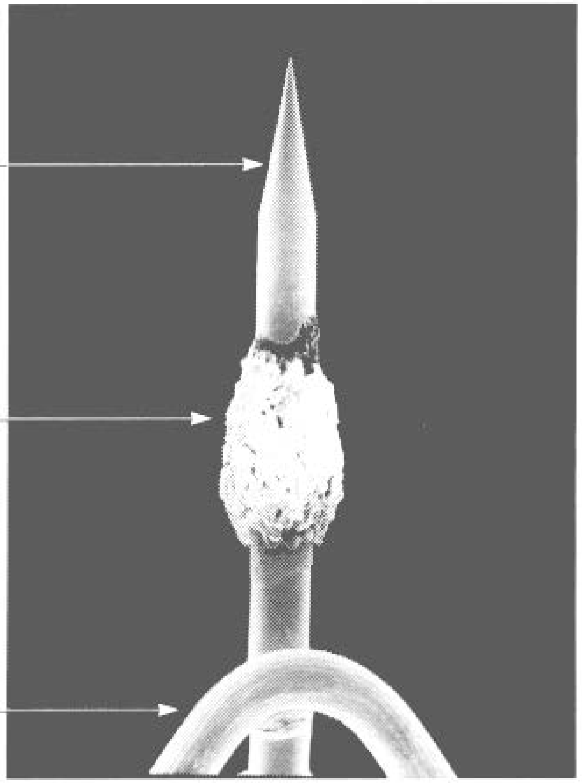
The emitter is heated to 1800K causing ZrO to migrate from the bead to the emitter tip.

The ZrO is adsorbed onto the emitter tip which lowers the work function to 2.9eV

Schottky Emitter Tip







<100> W Crystal

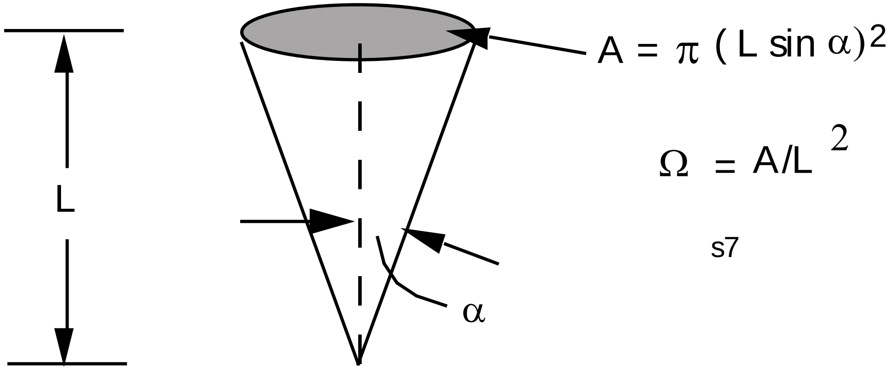
ZrO Reservoir

Polycrystalline tungsten heating filament

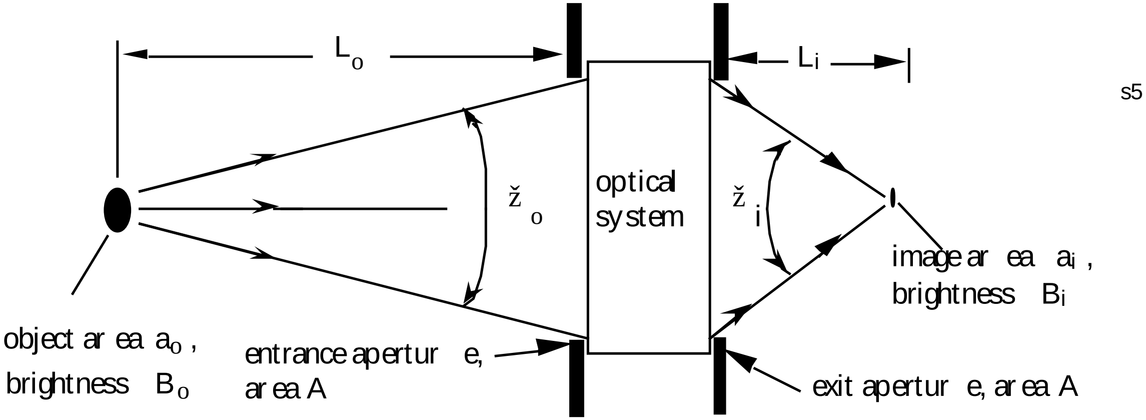
Source Brightness

Units for Brightness:

$$amp/(cm^2 \bullet steradian)$$



Brightness is conserved

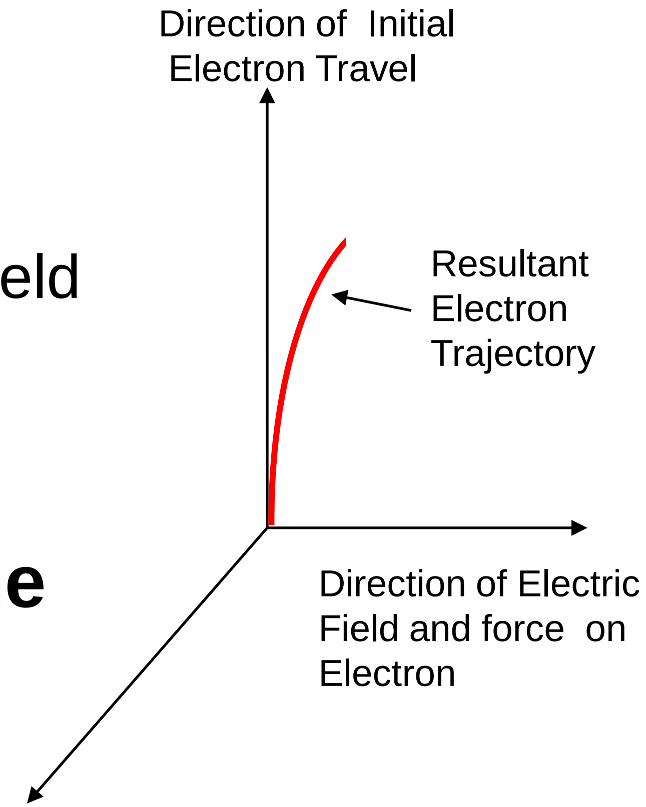


Current Electron Sources

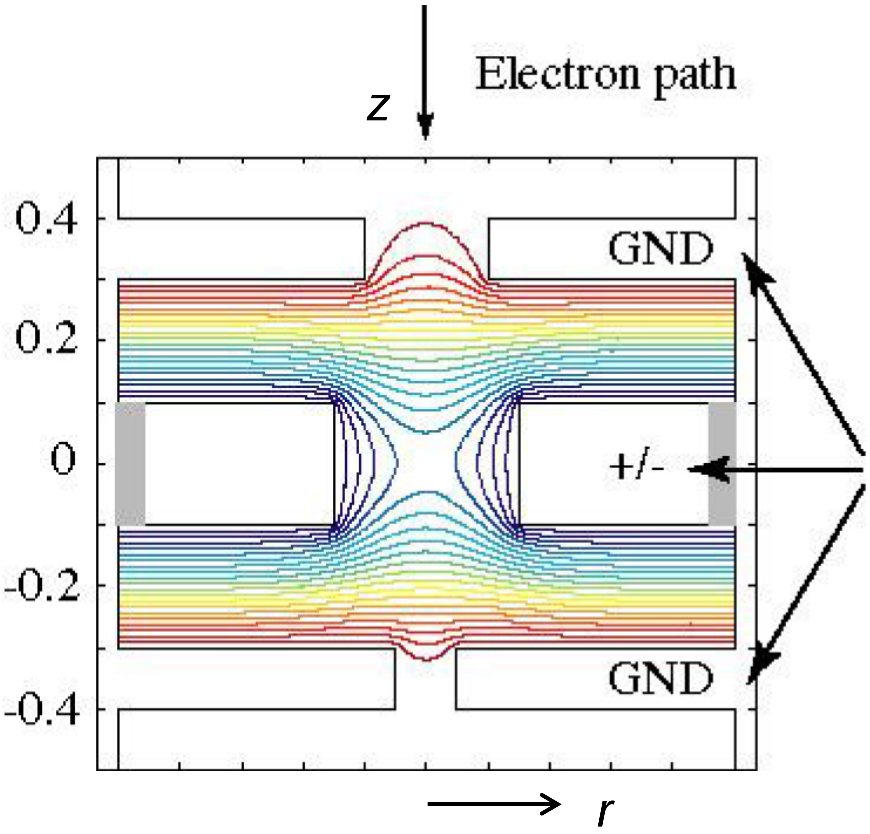
Source	Lifetime (hrs)	B @ 25 KV (amp/cm^2 Sr)	ΔE (eV)	Applications
W	100	$2 \times 10^5 @ 2900 K$	2-3	Low cost SEM
LaB$_6$	1000	$5 \times 10^6 @ 2000 K$	2-3	SEM, shaped-beam lithography system
W, FE tip, "cold"	>1000	$5 \times 10^8 - 10^9$	0.5	High resolution SEM
Zr/O/W thermal FE	>1000	$2 \times 10^8 @ 1800 K$	0.5	SEM and Gaussian-beam lithography

Electrons in Electrostatic Fields

- **Electrons are accelerated towards any positive voltage**.
- The acceleration force:
  - Is proportional to the electric field strength (volts/distance).
  - Is in the same direction as the field.
- **The velocity and energy of the electron are increased.**
- There is no rotation effect.



Electrostatic Lenses for charged particles



Axially symmetric potential distribution

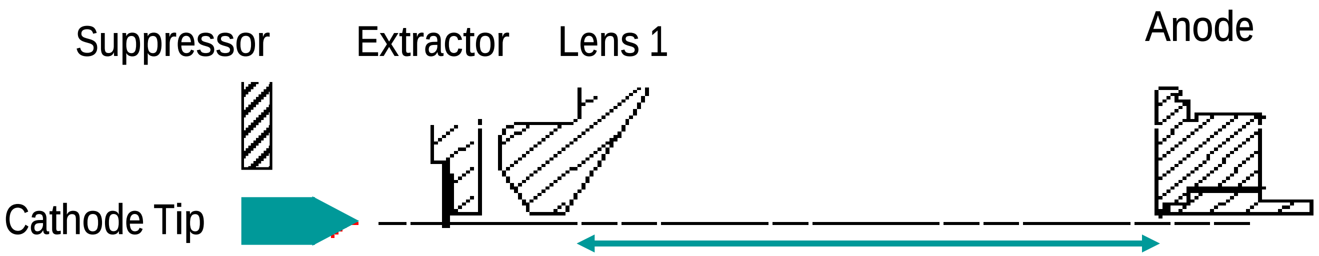
3~5 orders more effective than magnetic lenses

Subject to contamination build up → charging and distortion

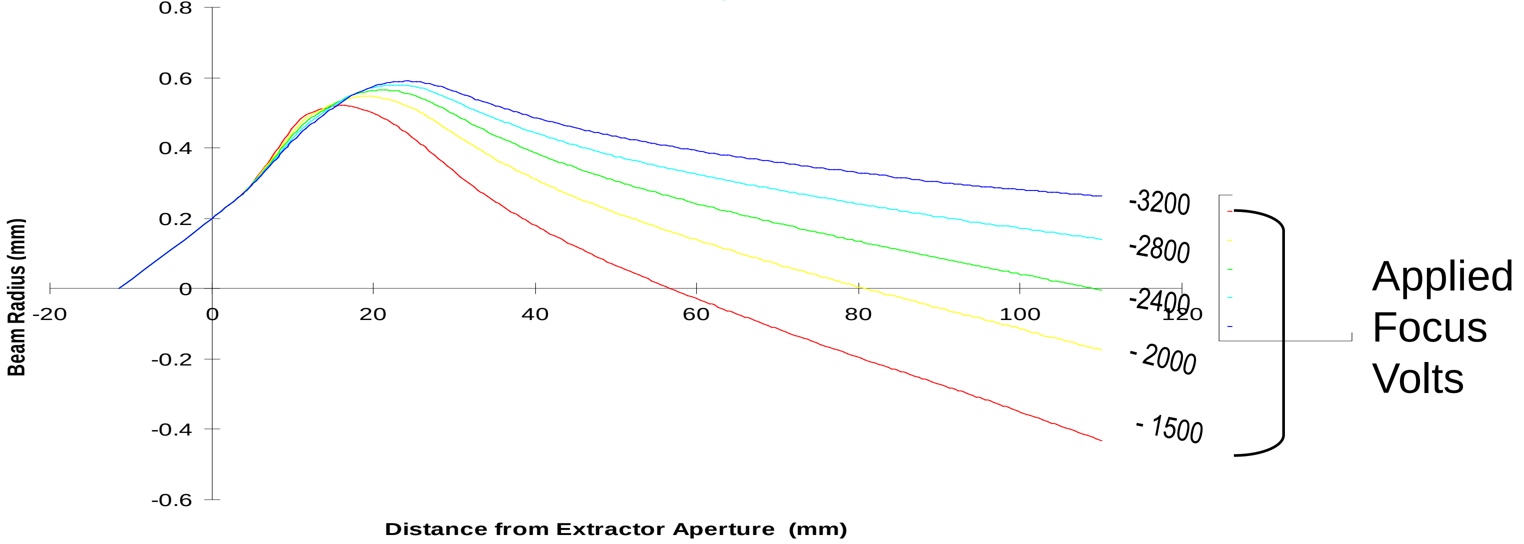
$$\Delta v_r = \int \frac{qE_r\left(r,z\right)}{mv_z}dz$$

Δv_r: the change in radial velocity of a charge particle.

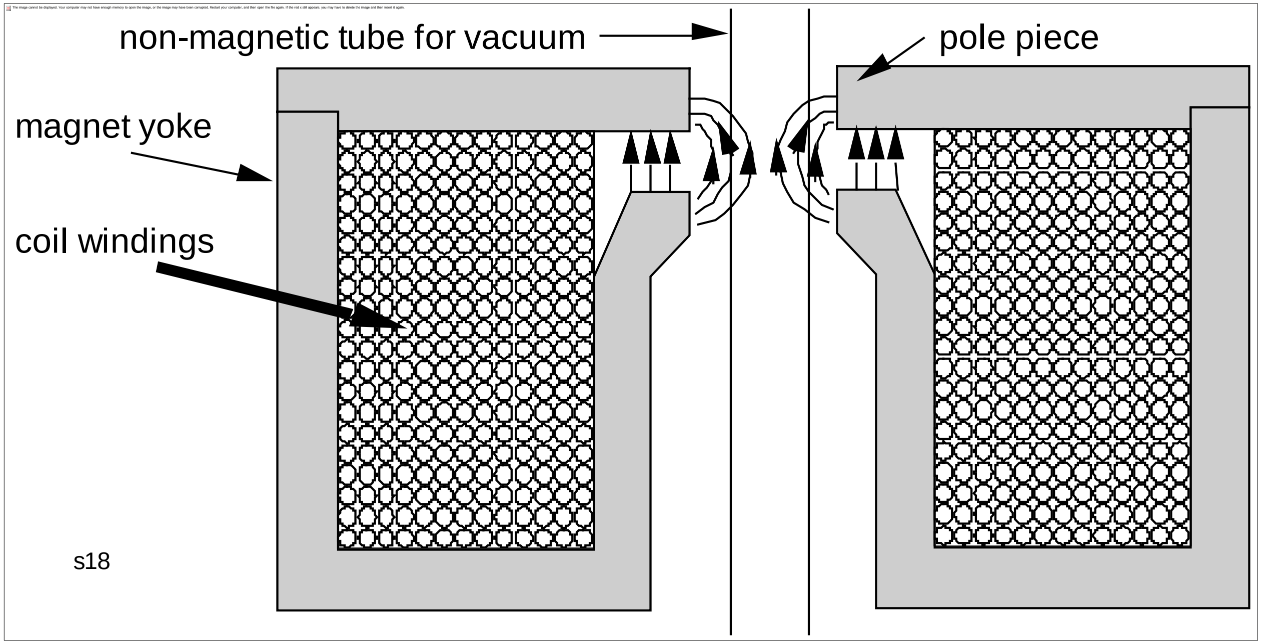
Electron paths through the Electrostatic Lens



The greater this voltage difference the stronger the lens



Magnetic Lenses for charged particles



Axially symmetric field distribution

No contamination build up: can be outside vacuum.

Weak focusing, proportional to *q/m*, can not focus heavy ions in FIB

Electrons in Magnetic Fields: The Left hand Rule

•An electron moving through a magnetic field receives an accelerating force which is:

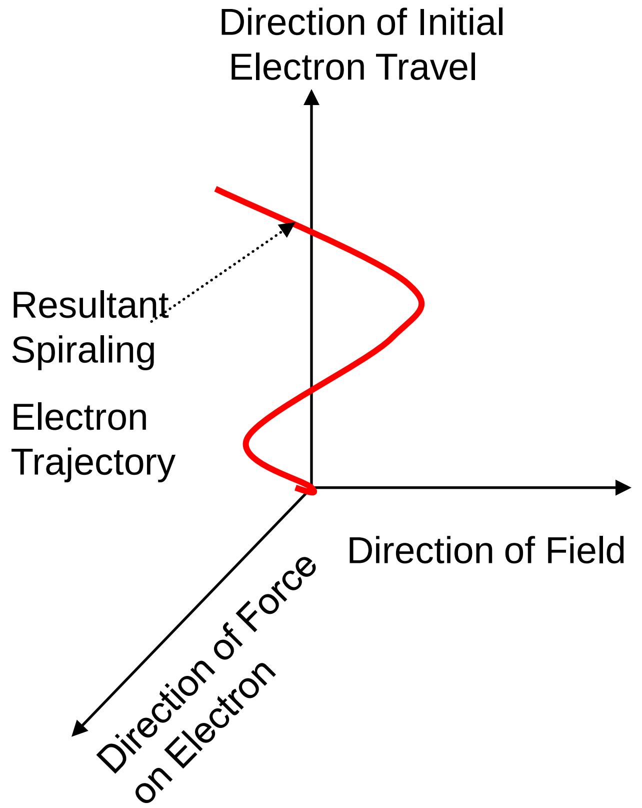
- perpendicular to the direction of the field
- perpendicular to the direction of the electron
- proportional to the flux density in the field
- proportional to the speed of the electron

•**The velocity of the electron is not altered**.

•This means:

•Electrons travelling parallel to the field are not affected.

•In general, electrons travel through the field in some form of corkscrew path.



$$F \propto q\left(\bar{v} \times \bar{B}\right)$$

How do Magnetic Lenses work?

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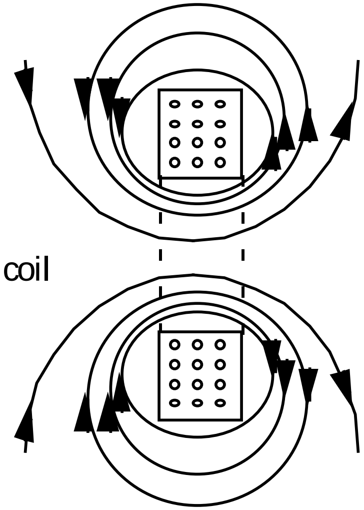

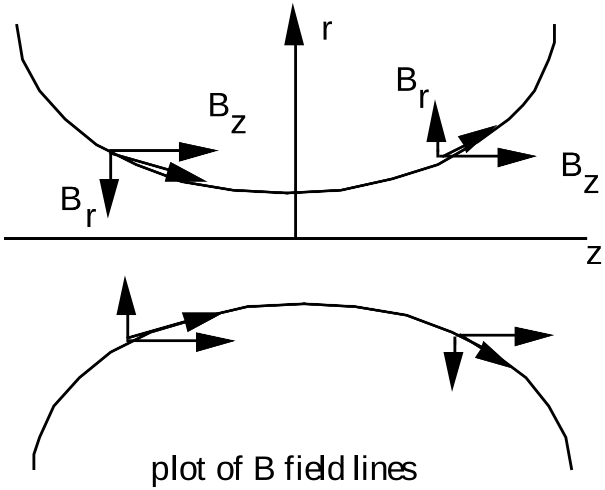

plot of B field lines

The axial and radial magnetic fields vary along the lens axis; roughly sketched as the following:

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