Presentation

on

Electron Sources

Chapter 5

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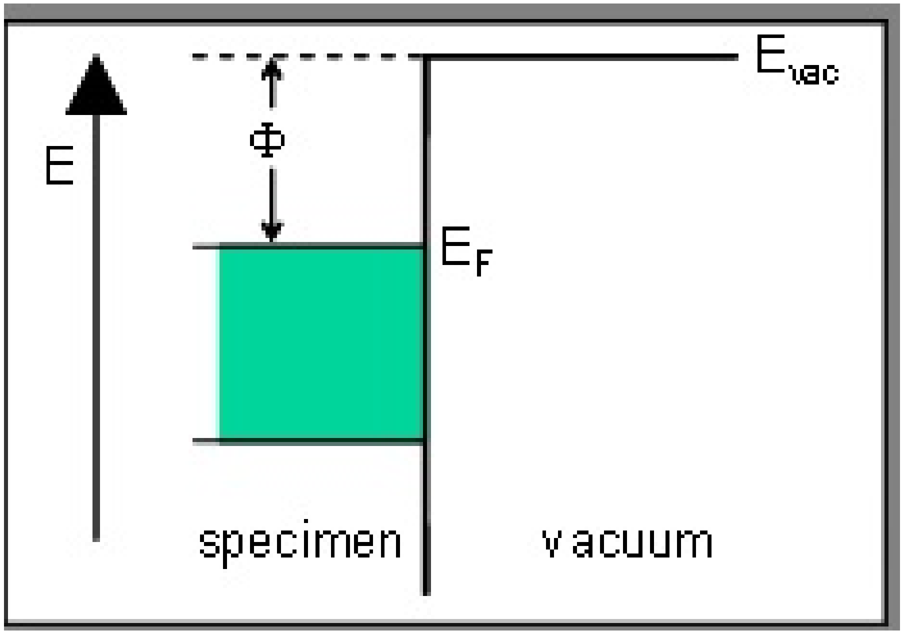
Two Types of Electron Sources

1. Thermionic source

Physics of Thermionic Source

WORK FUNCTION

- **The work function is the minimum energy needed to remove an electron from a solid to a point immediately outside the solid surface.**
- **For Tungsten $\Phi_w = 4.5$ eV**



Richardson's Law

- The emitted current density J (A/m^2) is related to temperature T by the equation:

$$J = AT^2 e^{\frac{-W}{kT}}$$

W is work function
A Richardson's constant

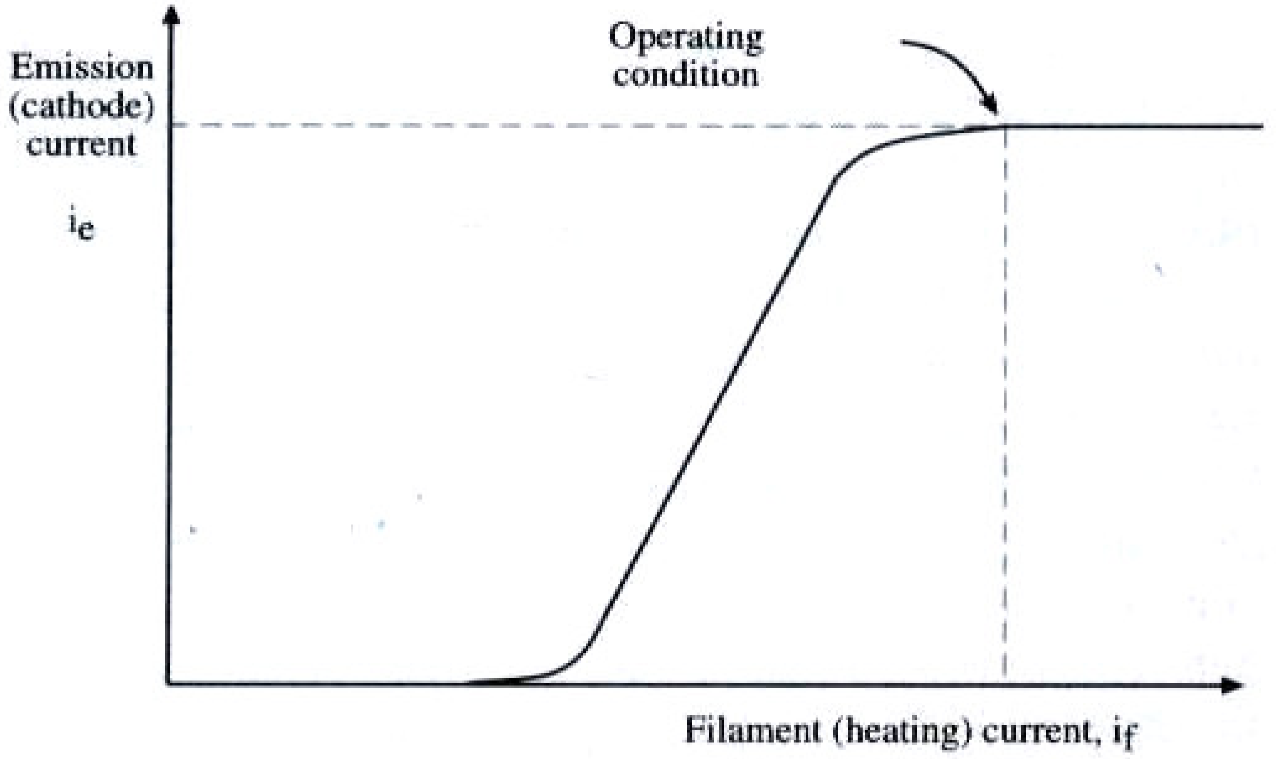
$$A = \frac{4\pi m k^2 e}{h^3} = 1.20173 \times 10^6$$ A m^{-2} K^{-2}

Tungsten = 4.5 eV
LaB$_6$ = 2.4 eV

- High temperature heating give higher J but shorten the source life through evaporation/ oxidation.

- Operation at compromising temperature: “Saturation Condition”

Saturation Condition

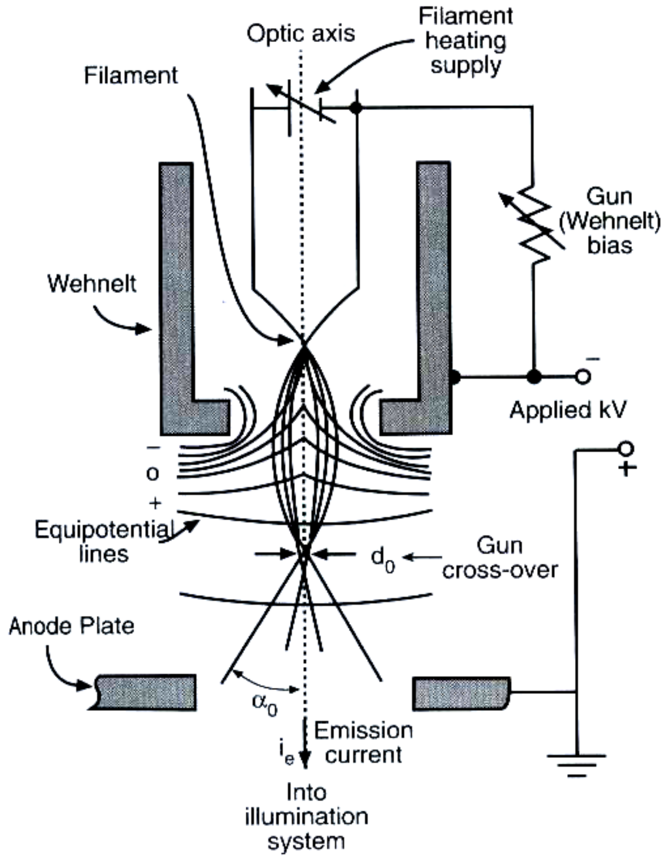


Less than saturation decreases the intensity of the signals

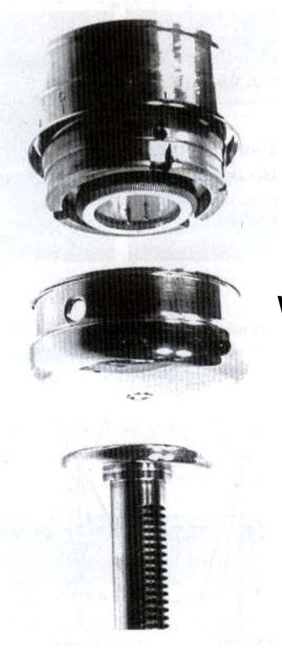
Higher than saturation decreases the life of filament

1. Thermionic source (function)

- **An positive electrical potential is applied to the anode**
- **The filament (cathode) is heated until a stream of electrons is produced**
- **The electrons are then accelerated by the positive potential down the column**
- **A negative electrical potential (~500 V) is applied to the Whenelt Cap**
- **As the electrons move toward the anode any ones emitted from the filament's side are repelled by the Whenelt Cap toward the optic axis (horizontal center)**
- **A collection of electrons occurs in the space between the filament tip and Wehnelt Cap. This collection is called a space charge**
- **Those electrons at the bottom of the space charge (nearest to the anode) can exit the gun area through the small (<1 mm) hole in the Whenelt Cap**
- **These electrons then move down the column to be later used in imaging**



Thermionic Gun



Cathode

Wehlnet cup

Anode

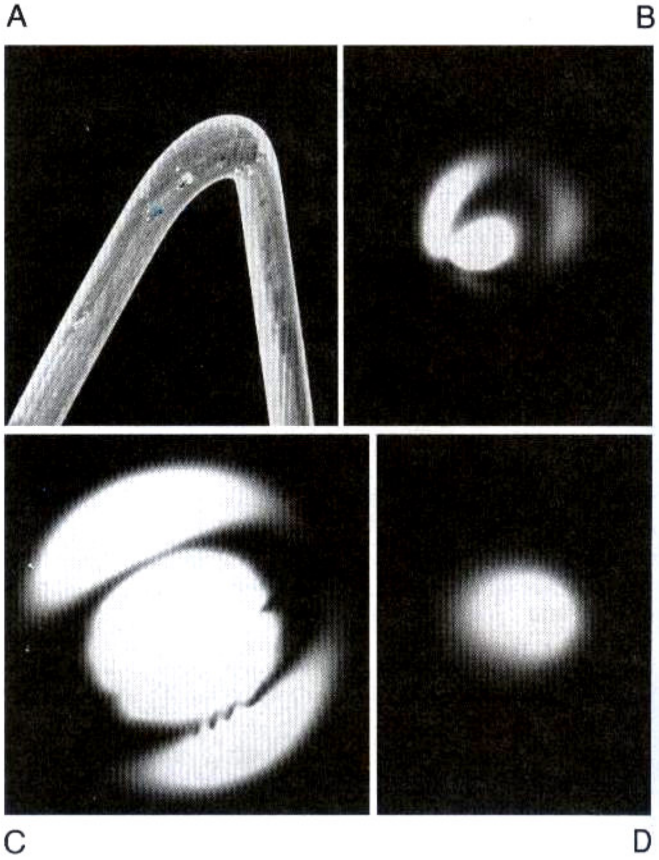


Figure 5.5. (A) The tip of a tungsten hairpin filament and the distribution of electrons when the filament is (B) undersaturated and misaligned, (C) undersaturated and aligned, and (D) saturated.

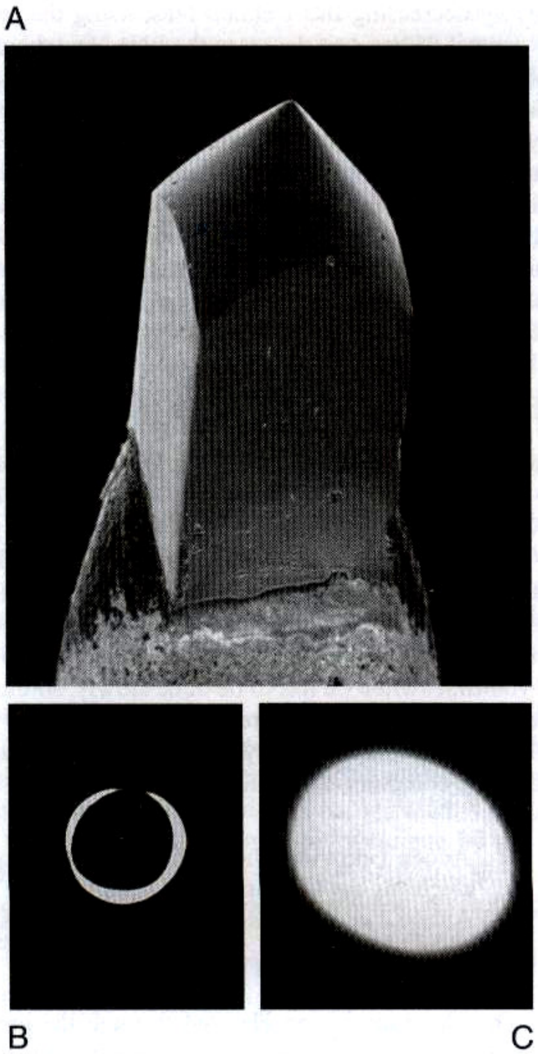


Figure 5.6. (A) An LaB$_6$ crystal and the electron distribution wh source is (B) undersaturated and aligned and (C) saturated.

Achieving Optimum Beam Current

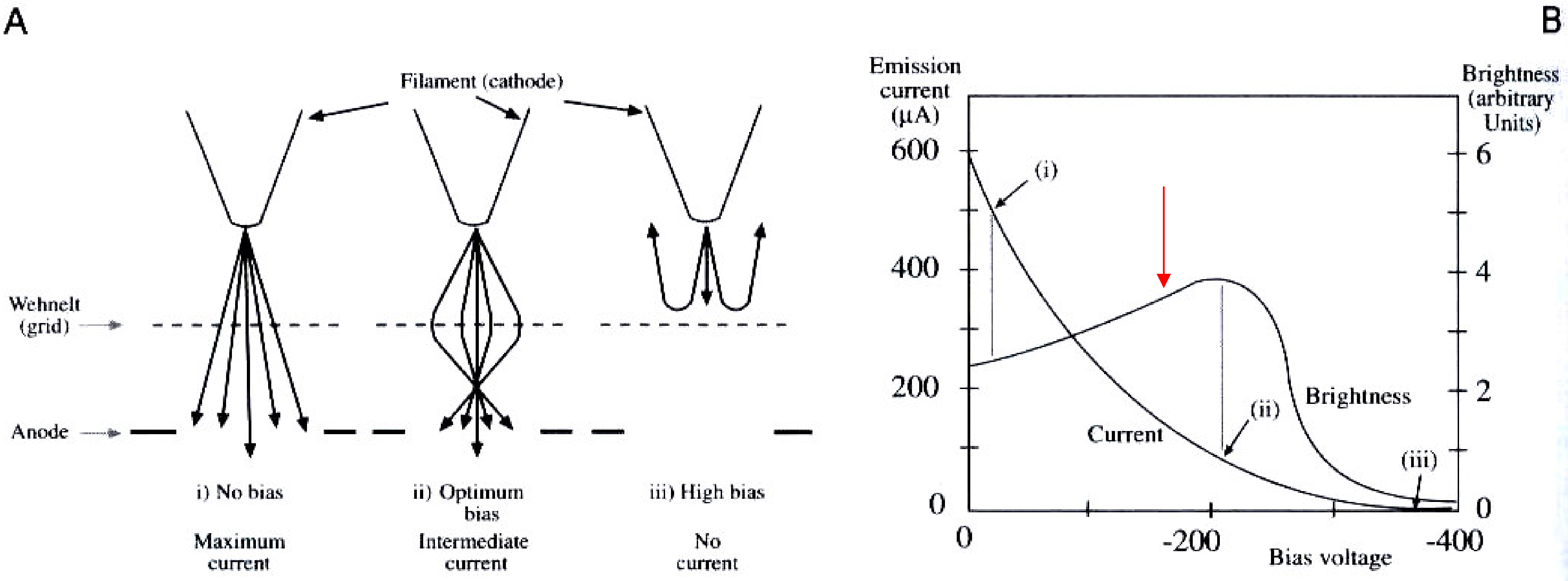


Figure 5.4. (A) The effect of increasing Wehnelt bias (i–iii) on the distribution of electrons coming through the anode. (B) The relationship between the bias and the emission current/gun brightness. Maximum brightness is achieved at an intermediate Wehnelt bias, and an intermediate emission current [condition (ii) in A].

In general beam dia < 0.1 micron

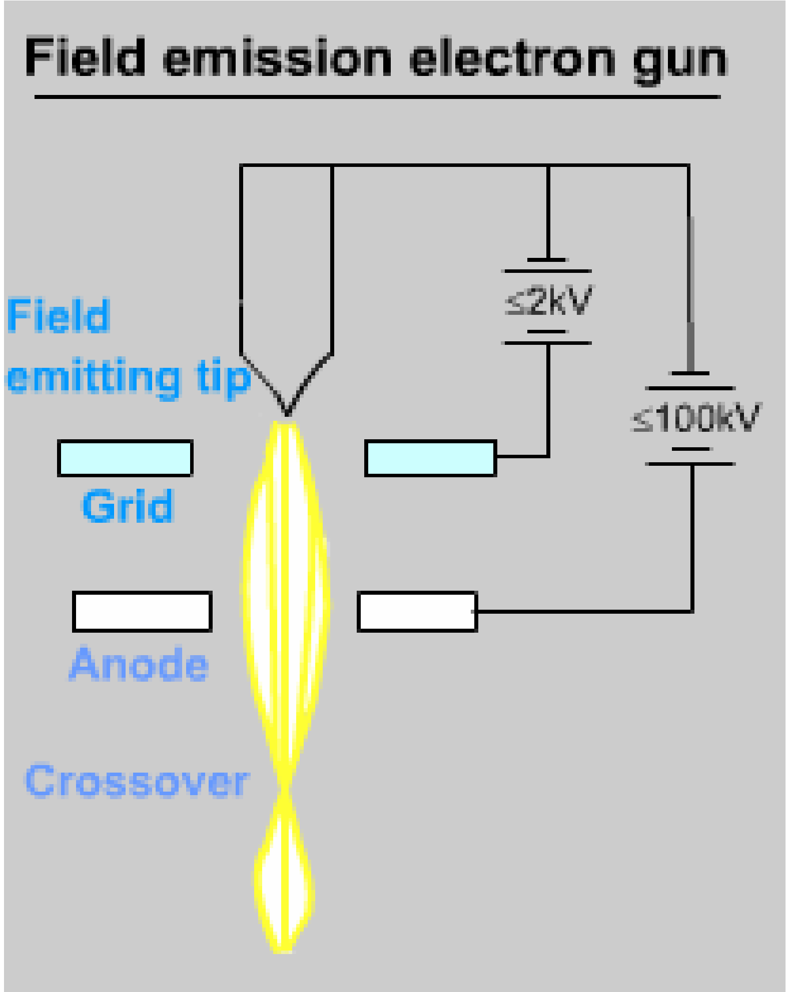
In SEM > we need small probe> no Wehnelt control is not provided
In TEM> we may need brighter image> Wehnelt control is not provided

Field Emission Sources

History of field emission

- The basic mechanism of field emission was discovered in 1897 by Wood, who found that a high voltage applied between a pointed cathode and a plate anode caused a current to flow.
- Hibi first suggested in 1954 that a heated tungsten point, rather than a bent tungsten wire, might produce a smaller source size and higher brightness.
- In 1954, Cosslett and Haine proposed the use of a field emission cathode for electron microscopy. But due to the requirement for an extremely high vacuum (~ 10^{-9} Torr), no practical use was made.
- Until 1966, Crewe managed to build a usable system.

Field Emission Gun



Grid (First anode):

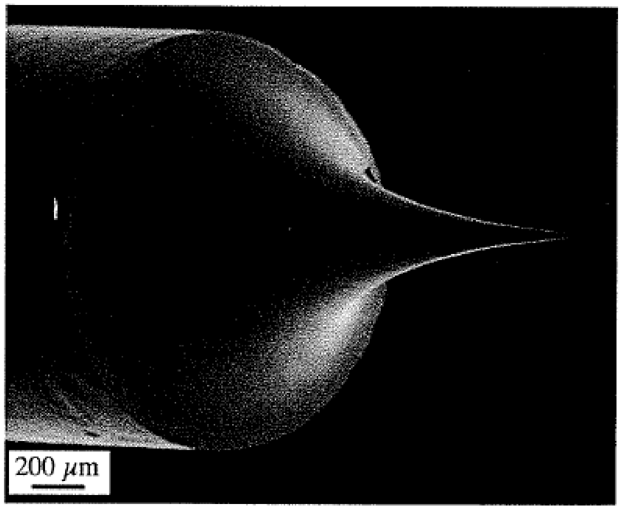
provides the extraction voltage to pull electrons out of the tip.

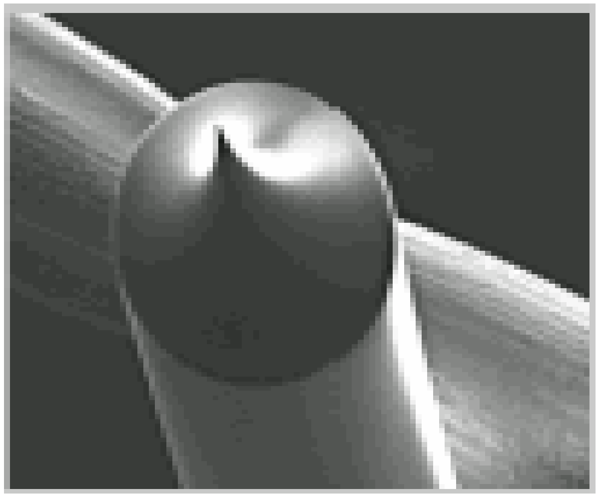
Anode (Second anode): accelerates the electrons to 100 kV or more.

Crossover: is the effective source of illumination for microscope.

Field emission tip

- **In order to obtain high filed strength with low voltages, the field emitting tip has a strong curvature.**
- **By etching a single crystal tungsten wire to a needle point.**
- **<310> orientation is found to be the best for emission.**
- **Emitting region can be less than 10 nm.**
- **E=V/r If 1kV at tip, E~10^{10} V/m**





Cold & Thermal Field Emission

- By operating in UHV ($<10^{-11}$ Torr), the tungsten tip is operated at ambient temperature.---------Cold field emission
- UHV can reduce contamination and oxide.
- If the cathode incorporates both thermionic and field emissions at a poorer vacuum, the thermal energy assists the electron emission.---------Thermal field emission.
- 'Schottky' emitter. Normally use ZrO_2 to treat the surface.

Advantages of Field Emission Gun

- Low operating temperature (~300K)
- High brightness (10^{13} A/m^{2}sr)
- High current density (10^{10} A/m^2)
- Small source size < 0.01 um
- Highly spatially coherent, small energy spread
- Long life time

Disadvantages of Field Emission Gun

- Small source size → Not good for large area specimen, easy lose current density
- The emission current is not as stable as Thermionic emission gun
- Need UHV

Comparison of electron guns

Characteristics of Electron Beam

Brightness

Current density per unit solid angle

$$\beta = \frac{i_e}{\pi\left(\frac{d_0}{2}\right)^2 \pi(\alpha_0)^2} = \frac{4\, i_e}{(\pi\, d_0\, \alpha_0)^2}$$

Units of β is A.cm^{-2}sr^{-1}

More is β, more is no of electrons/area

More beam damage

Important with fine beams, as in AEM

TEM uses defocused beam

Measured by inserting a Faraday cup

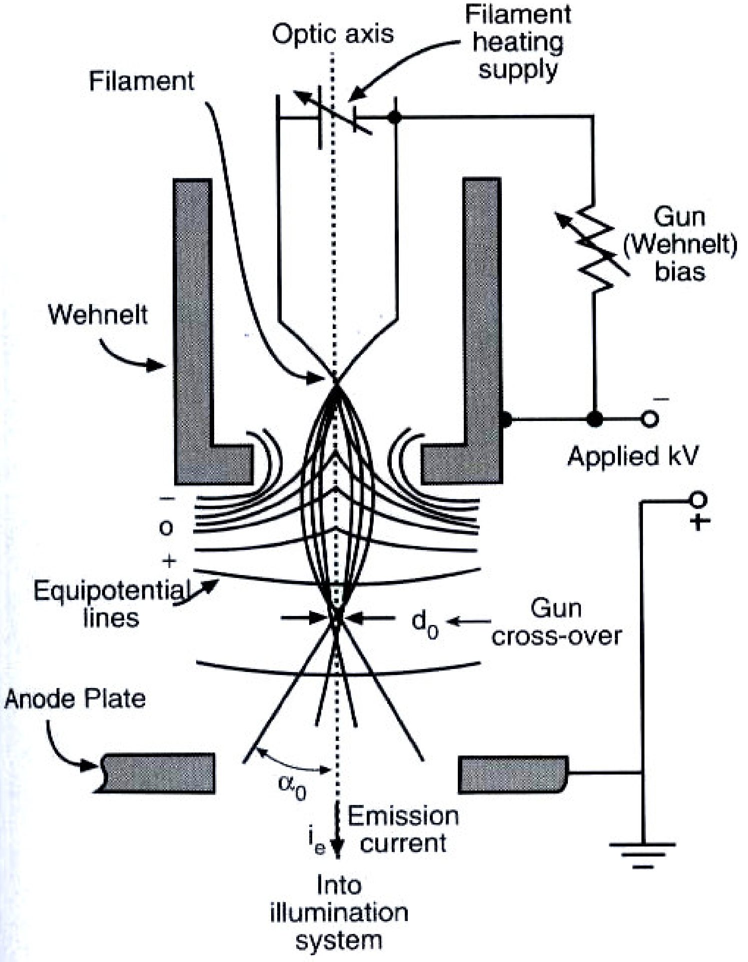


Figure 5.1. Schematic diagram of a thermionic electron gun. A high voltage is placed between the filament and the anode, modified by a potential on the Wehnelt which acts to focus the electrons into a crossover, with diameter d_0 and convergence/divergence angle α_0.

Temporal Coherency and Energy Spread

Monochromatic – 1 wavelength

Temporal coherency – measure of similarity of wave packets.

Coherence length

$$\lambda_c = \frac{vh}{\Delta E}$$

where h is Planck's constant, v is velocity of the electrons and ΔE is the energy spread of the beam

ΔE related to stability of accelerating voltage

Typical ΔE values are 0.1 – 3eV. Electron energies are up to 400keV

Not much important for imaging

Important in spectroscopy, EELS

ΔE measured using an electron spectrometer

ΔE is taken as the FWHM of the Gaussian peak obtained

Spatial Coherency

Related to the size of the source

Perfect source – electron emanating from same point

Effective source size for coherent illumination

$$d_c \prec\prec \frac{\lambda}{2\alpha}$$

where λ is the Wavelength and α is angle subtended by source at specimen

d_c should be as large as possible

α is limited by source size or aperture size

Small beams are more spatially coherent

Required for good phase contrast and diffraction patterns

Convergence Angle Determination

$$2\alpha = 2\theta_B \frac{a}{b}$$

α Important in Brightness calculation, CBED, STEM and EELS

α controlled by final aperture

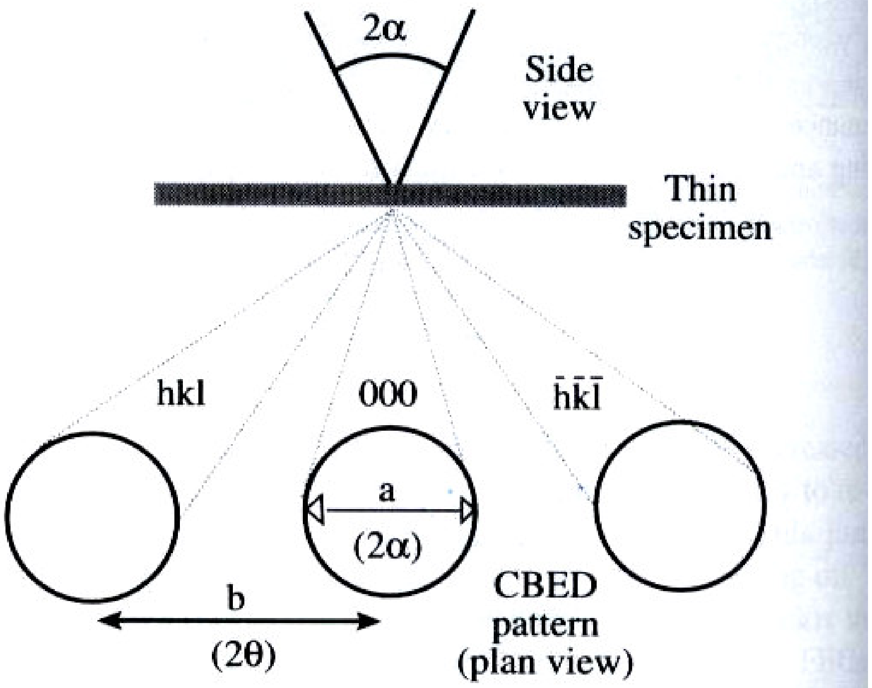


Figure 5.8. The distances on a convergent-beam diffraction pattern from which you can measure the beam-convergence semiangle, α, which is proportional to the width of the diffraction disk.

Calculating the Beam Diameter

$$d_t = \left(d_g^2 + d_s^2 + d_d^2\right)^{1/2}$$

$$d_g = \frac{2}{\pi}\left(\frac{i}{\beta}\right)^2 \frac{1}{\alpha}$$

$$d_s = 0.5 C_s \alpha^3$$

$$d_d = 1.22\frac{\lambda}{\alpha}$$

d_t = calculated beam diameter

d_s = broadening due to spherical aberration

d_d = broadening due to diffraction

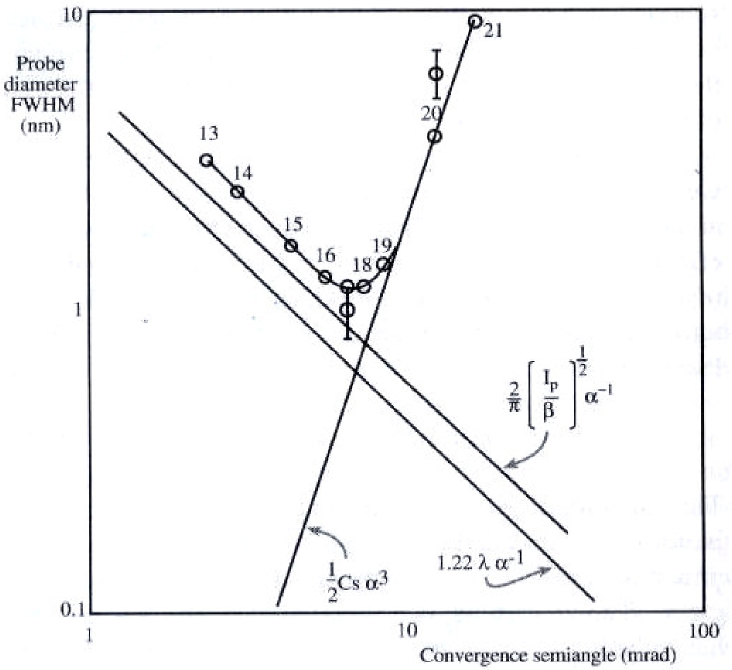


Figure 5.10. Calculations of the three contributions to the probe size as a function of the convergence semiangle α in an FEG STEM with a probe current I_p of 0.85 × 10^{-8} A. Two experimental measurements are shown, at condenser 1 lens settings 17 and 20. The minimum probe dimension is ~1 nm with α < 10 mrads.

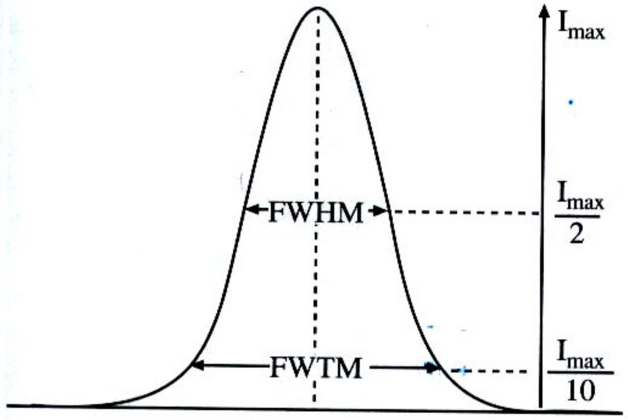


Figure 5.9. The definition of the full width at half maximum (FWHM) and the full width at tenth maximum (FWTM) of a Gaussian intensity distribution which is typical of a well-aligned beam.

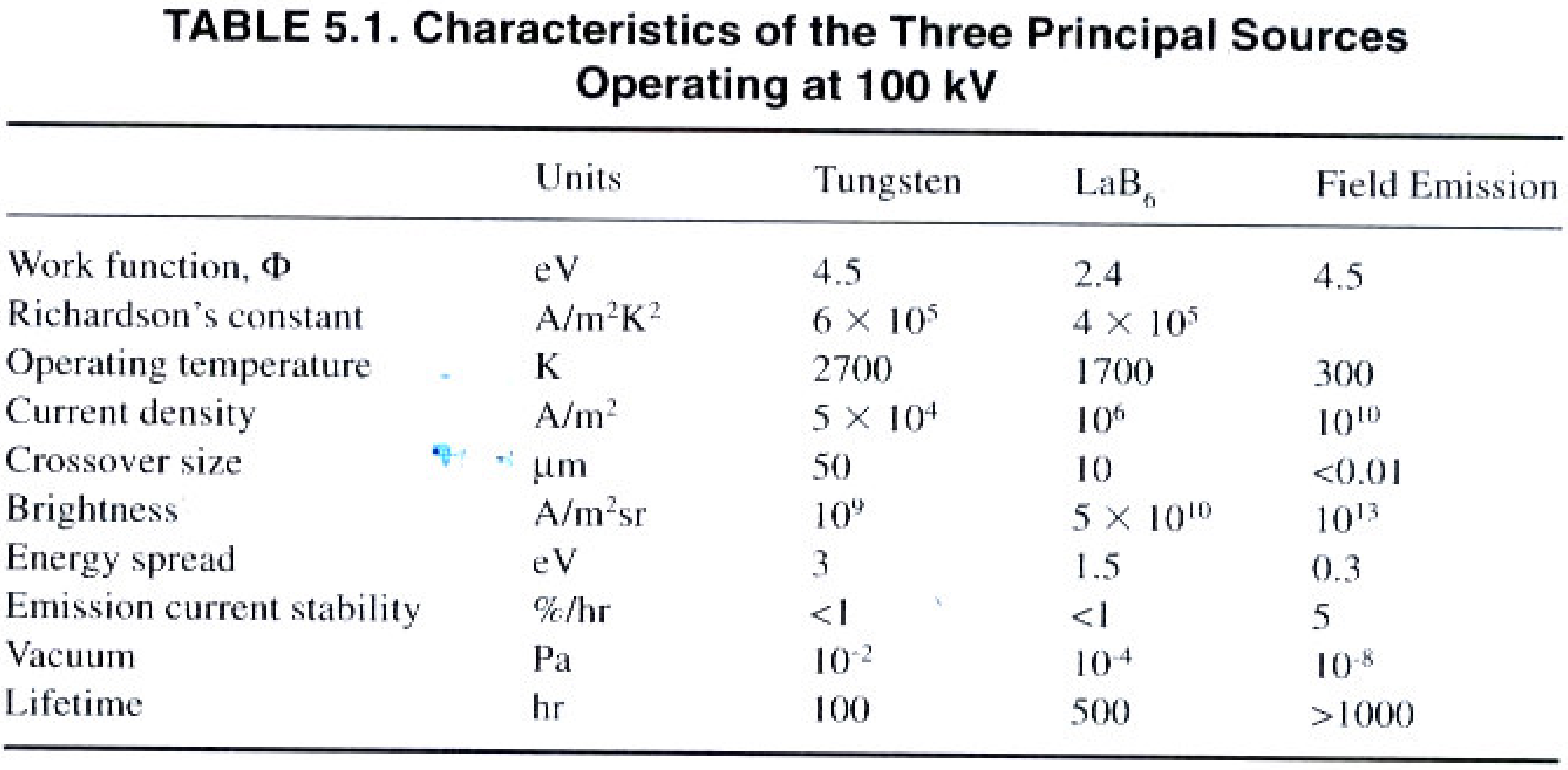


TABLE 5.1. Characteristics of the Three Principal Sources Operating at 100 kV

	Units	Tungsten	LaB_6	Field Emission
Work function, Φ	eV	4.5	2.4	4.5
Richardson's constant	A/m^2K^2	6×10^5	4×10^5	
Operating temperature	K	2700	1700	300
Current density	A/m^2	5×10^4	10^6	10^{10}
Crossover size	μm	50	10	<0.01
Brightness	A/m^2sr	10^9	5×10^{10}	10^{13}
Energy spread	eV	3	1.5	0.3
Emission current stability	%/hr	<1	<1	5
Vacuum	Pa	10^{-2}	10^{-4}	10^{-8}
Lifetime	hr	100	500	>1000

Tungsten hairpin filament – Robust, Cheap, Easily replaceable

LaB_6 :– Lower work function, More brightness, More coherent, Lower energy spread

Costly, High vacuum required, should be heated and cooled slowly

FEG :- Extremely high Current density, high brightness, small beam size

Large areas cannot be viewed, UHV required