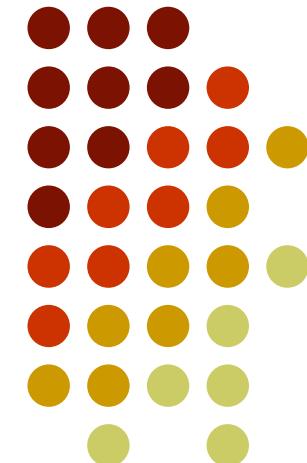
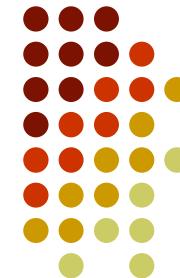


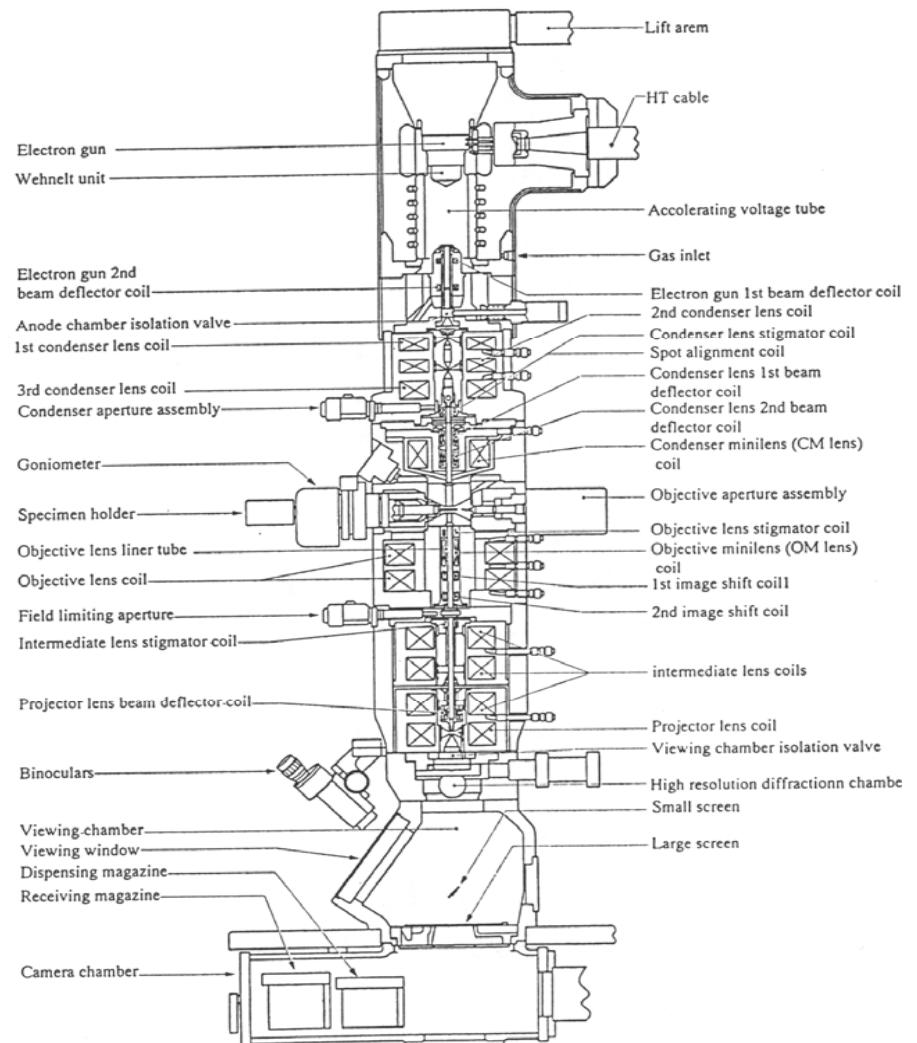
Canhões de Elétrons

André Luiz Pinto, DC
Chefe do Laboratório de
Microscopia Eletrônica do IME





Jeol





Canhão de Elétrons

ZrO/W(100) Schottky
Type Electron Gun

- ◆ Higher brightness, 100 times greater than LaB6 gun
- ◆ Higher coherency
- ◆ Higher energy resolution, 0.7 to 0.8eV
- ◆ Higher stability over a cold FEG
- ◆ Longer life time 1.5 to 3 years (guarantied time: 5,000 hours)



O que desejamos em um canhão?



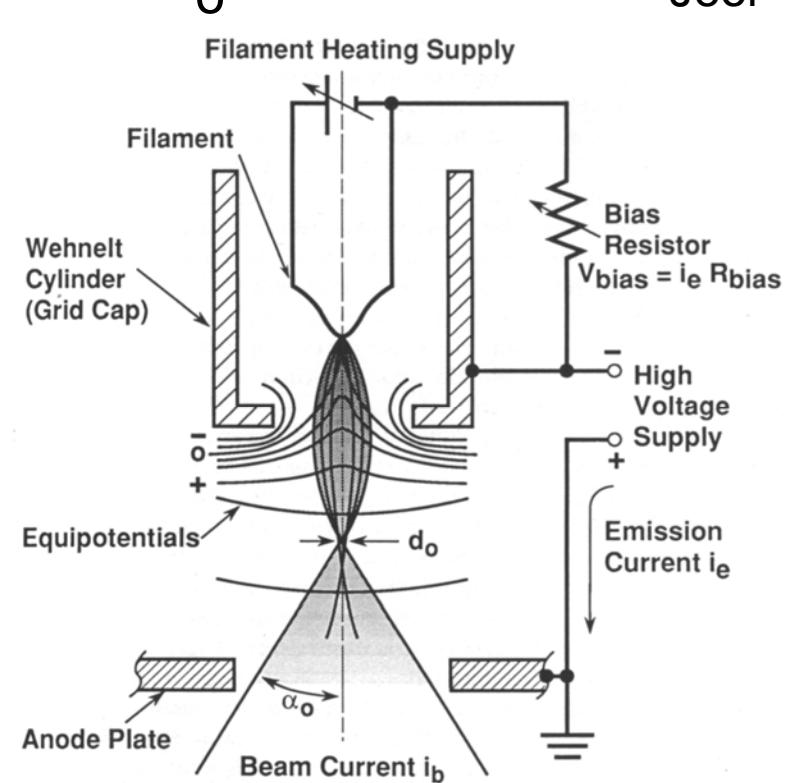
- Alto brilho
- Fonte de dimensões reduzidas
- Estabilidade
- Energia Controlável
- Coerência

Brilho



- Definimos o brilho como a densidade de corrente (corrente, i_e , por unidade de área) emitido em um ângulo sólido α_o .
Unidade: $\text{A/m}^2\text{sr}$

$$\beta = \frac{i_e}{\pi \left(\frac{d_o}{2} \right)^2 \pi (\alpha_o)^2}$$





Energia dos Elétrons

- Através do Princípio da Dualidade Onda-Partícula de de Broglie podemos associar o momento da partícula ao seu comprimento de onda

$$\lambda = \frac{h}{p}$$

- Energia cinética do elétron a partir do seu potencial de aceleração

$$eV = \frac{m_o v^2}{2} \Rightarrow p = m_o v = \sqrt{2m_o eV}$$



Energia dos Elétrons

- Comprimento de onda

$$\lambda = \frac{h}{\sqrt{2m_o eV}}$$

- Correção relativística

$$\lambda = \frac{h}{\sqrt{2m_o eV \left(1 + \frac{eV}{2m_o c^2}\right)}}$$



Fontes Termiônicas

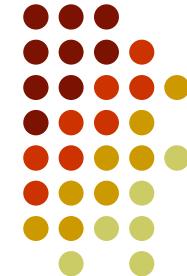
- Lei de Richardson para a densidade de corrente

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

A- Cte de Richardson

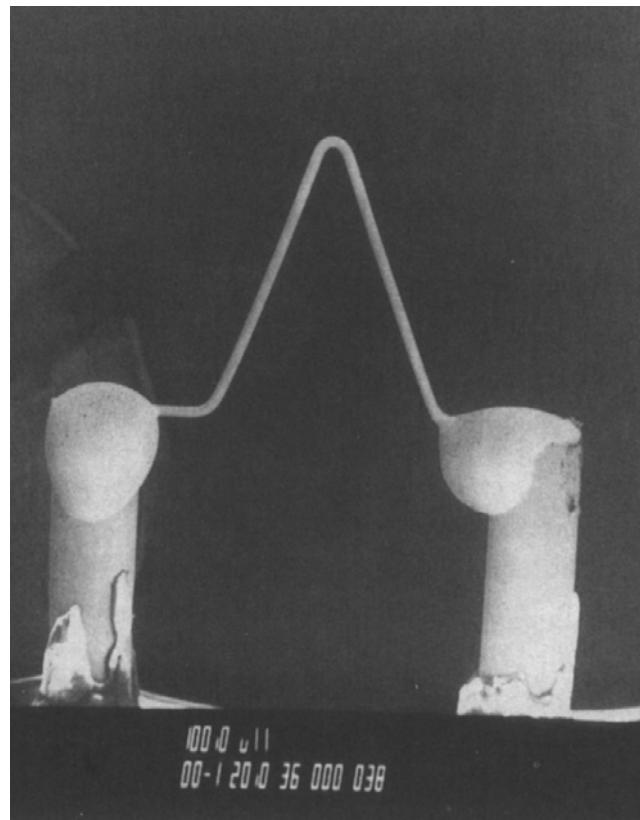
Φ - Função Trabalho

K – Cte de Boltzmann

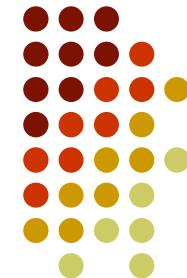


Filamento de W

- Baixo custo (~ US\$ 90)
- Baixa vida (~ 100 h)
- Baixo brilho

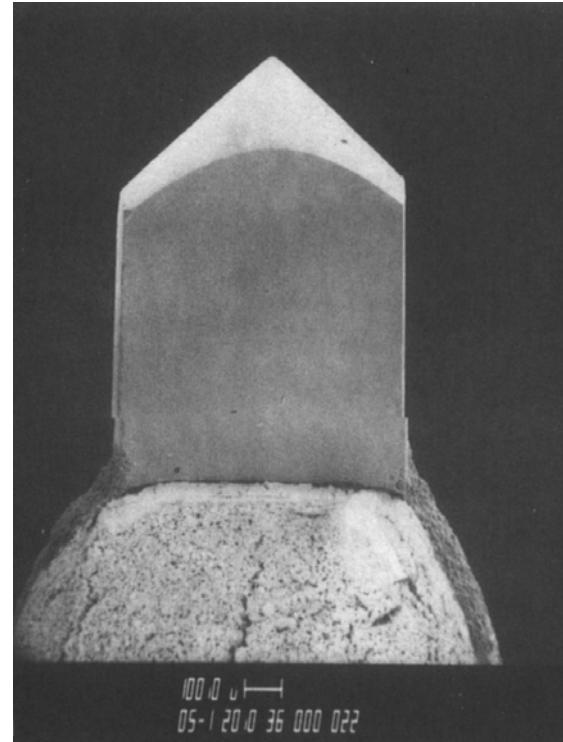


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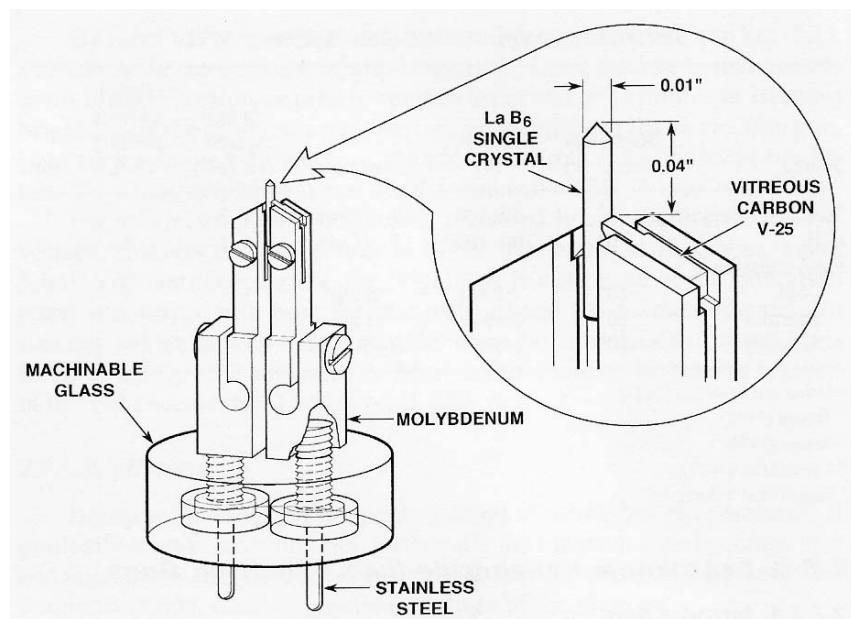


Filamento de LaB₆

- Maior custo (~US\$ 1-3k)
- Maior vida (~500 h)
- Maior brilho
- Monocristal <100>
- Suporte resistivo de grafite ou rênio
- Sujeito a choque térmico
- Altamente reativo
- Podem ter efeito Schottky (ponta com $r \sim 1-10 \mu\text{m}$ dobra o brilho)

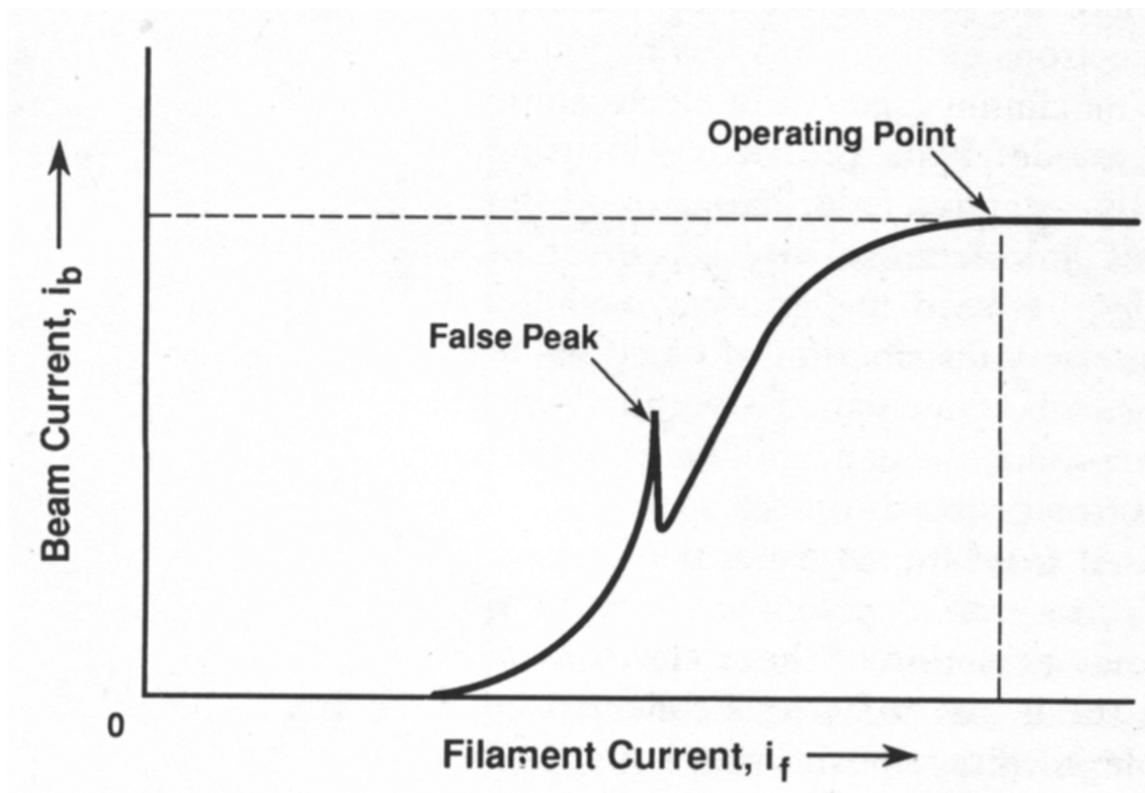


Williams e Carter

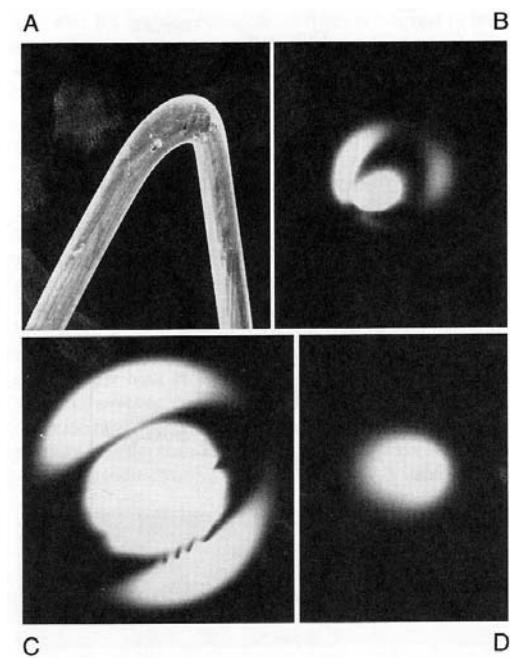


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Saturação



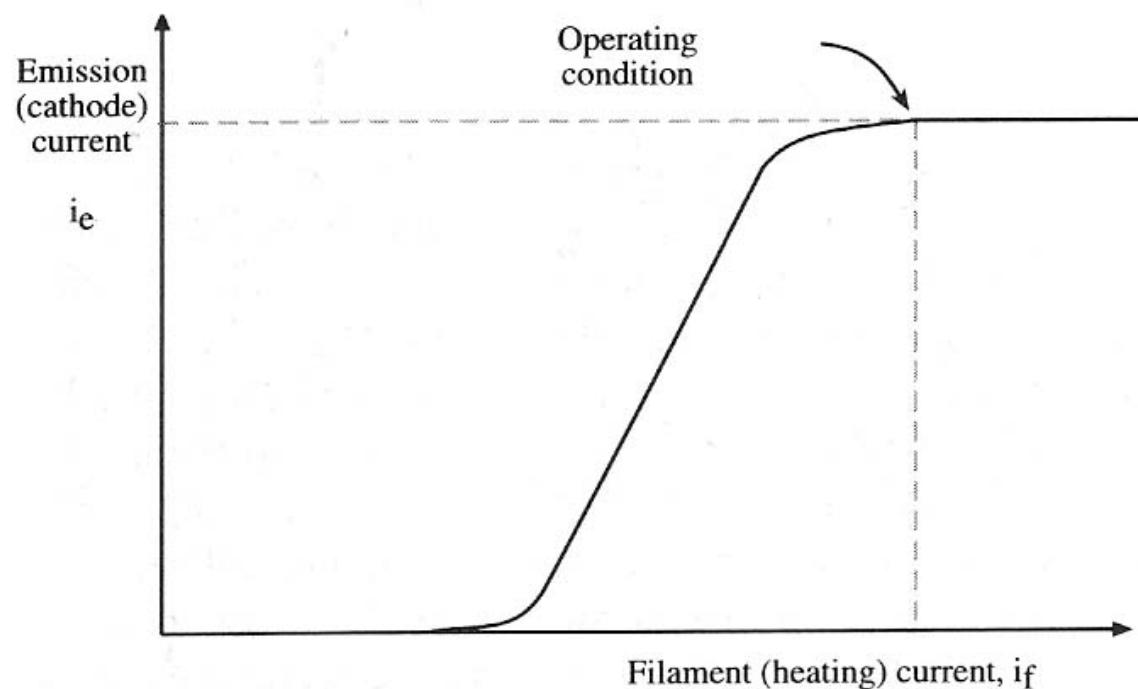
Jeol



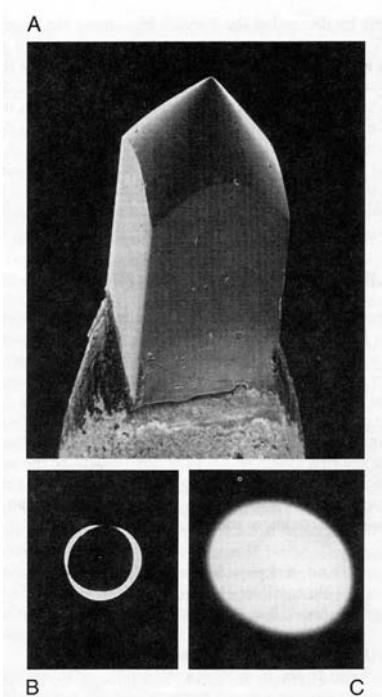
Williams e Carter



Saturação



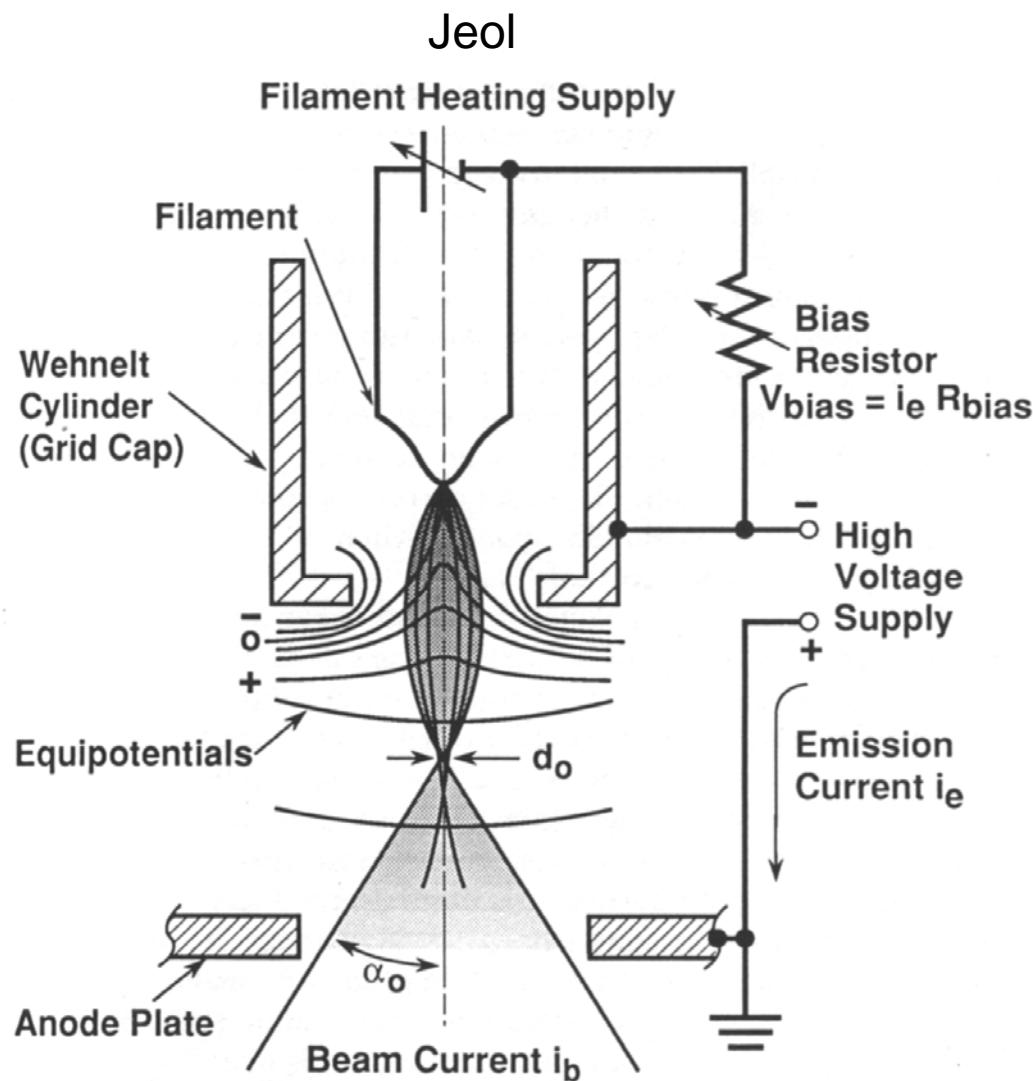
Jeol



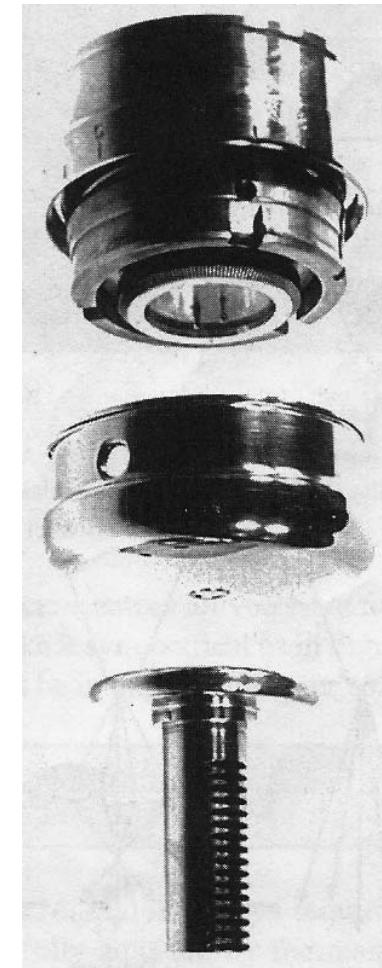
Williams e Carter



Canhão de Elétrons - Wehnelt



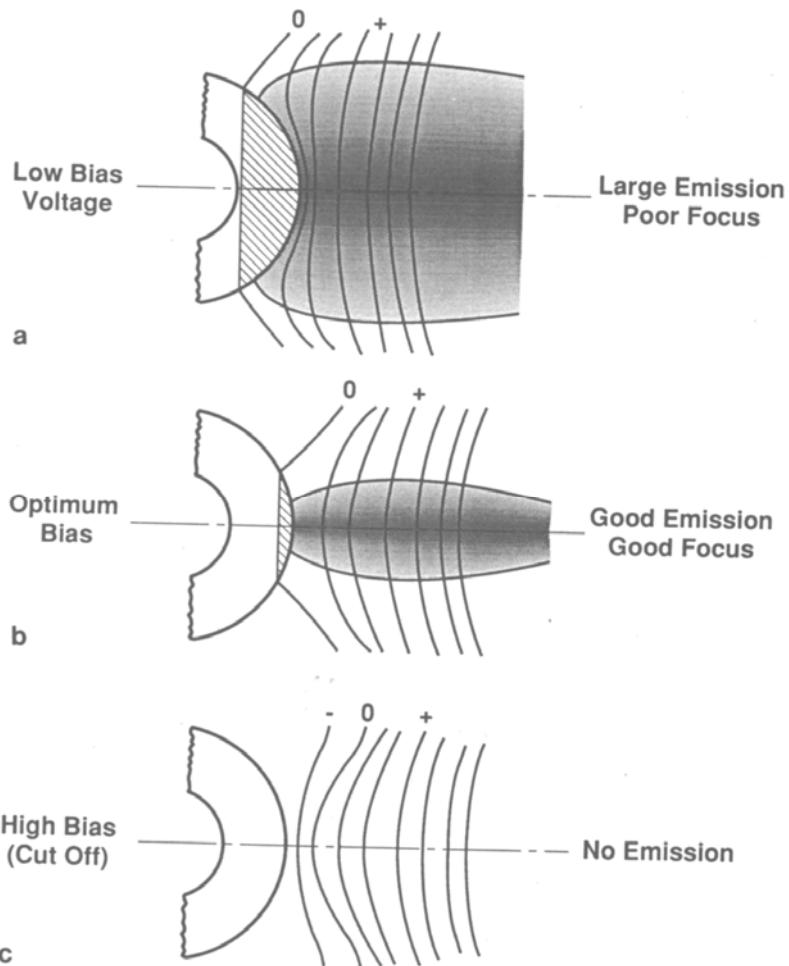
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Controle do Bias

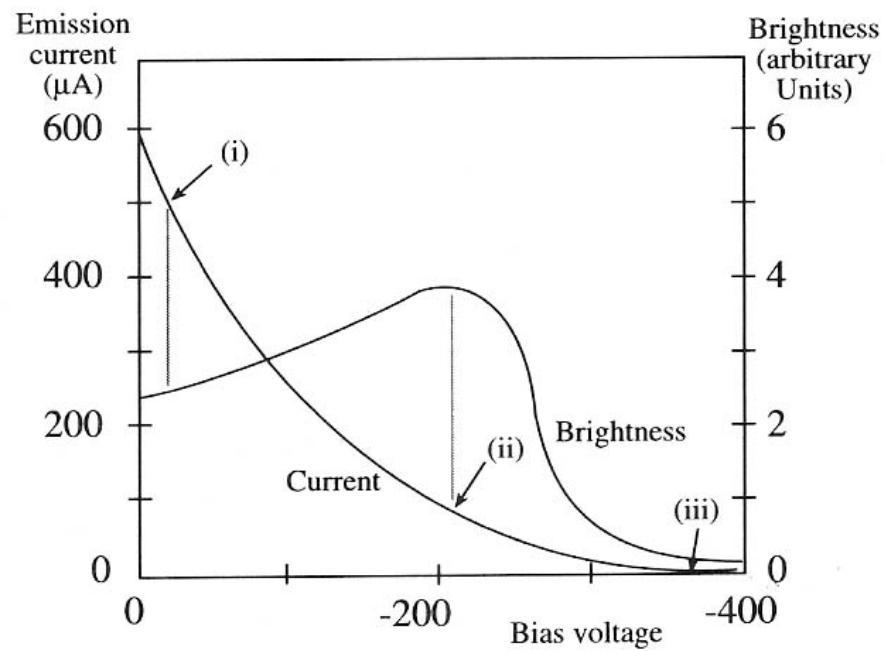


Jeol



Williams e Carter

B



Problemas das Fontes Termiônicas



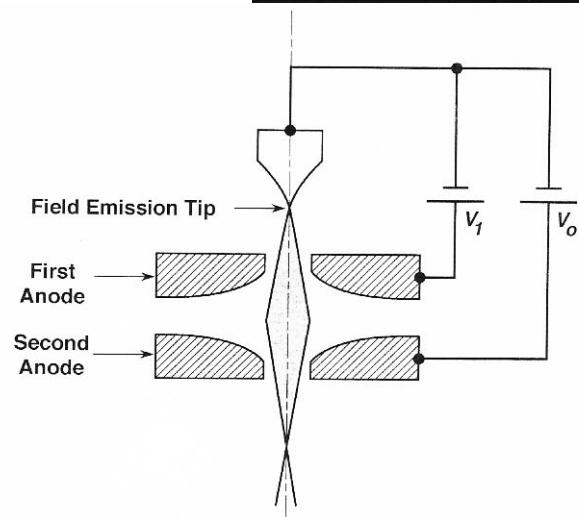
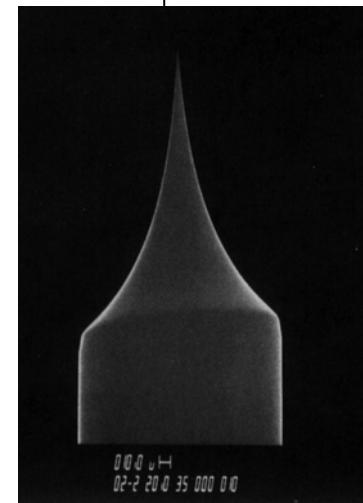
- Evaporação do catodo
- “Thermal drift”
- Baixo brilho
 - Brilho máximo

$$\beta_{Max} = \frac{J_c e V_o}{\pi k T}$$

Canhão de Emissão por Campo (Field Emission Gun - FEG)

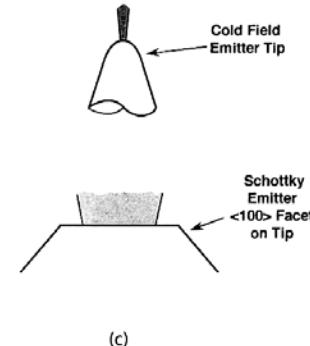
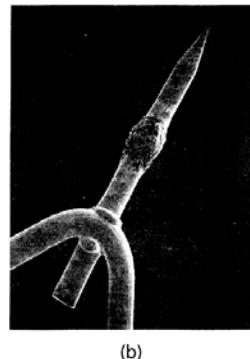
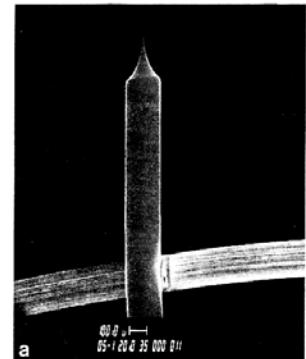


- Monocristal <310> com ponta afiada ($r < 100 \text{ nm}$)
- Menor raio concentra o campo elétrico e diminui a necessidade de T
- V_1 – voltagem de extração (3-5 kV)
- V_2 – voltagem de aceleração
- Brilho máximo $\beta_{Max} = \frac{J_c e V_o}{\pi \Delta E}$



Williams e Carter

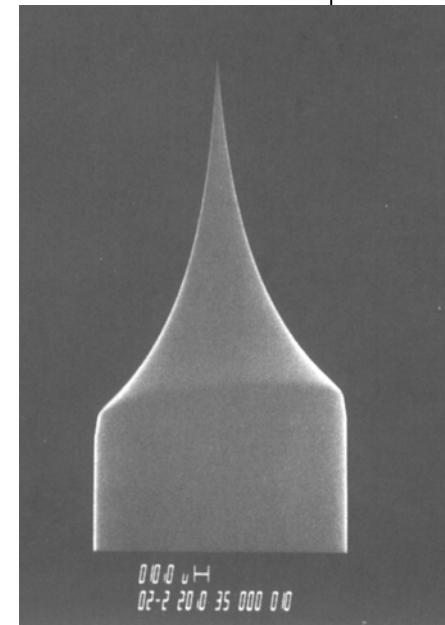
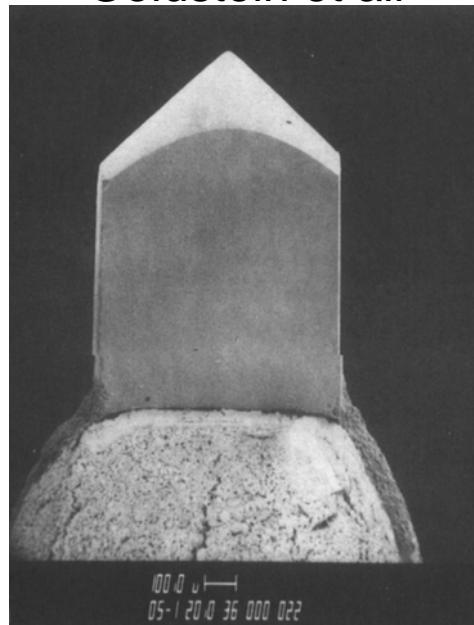
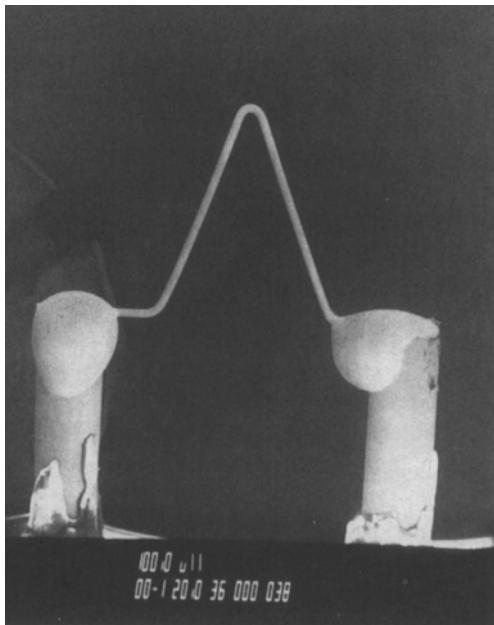
Canhão de Emissão por Campo (Field Emission Gun - FEG)



Goldstein et all

- 3 tipos básicos
 - Frio
 - Térmico
 - Schottky
- Crossover
 - Frio - $< 5 \text{ nm}$
 - Térmico - $< 5 \text{ nm}$
 - Schottky - $< 15-30 \text{ nm}$
- Variação da Energia (ΔE)
 - Frio – 0,3 eV
 - Térmico – 1 eV
 - Schottky – 0,3 - 1 eV
- Estabilidade
 - Frio – 5%/h
 - Térmico – 5%/h
 - Schottky – 2%/h

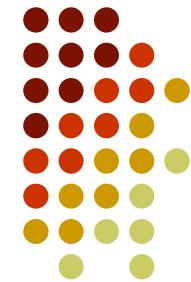
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**TABLE 5.1. Characteristics of the Three Principal Sources
Operating at 100 kV**

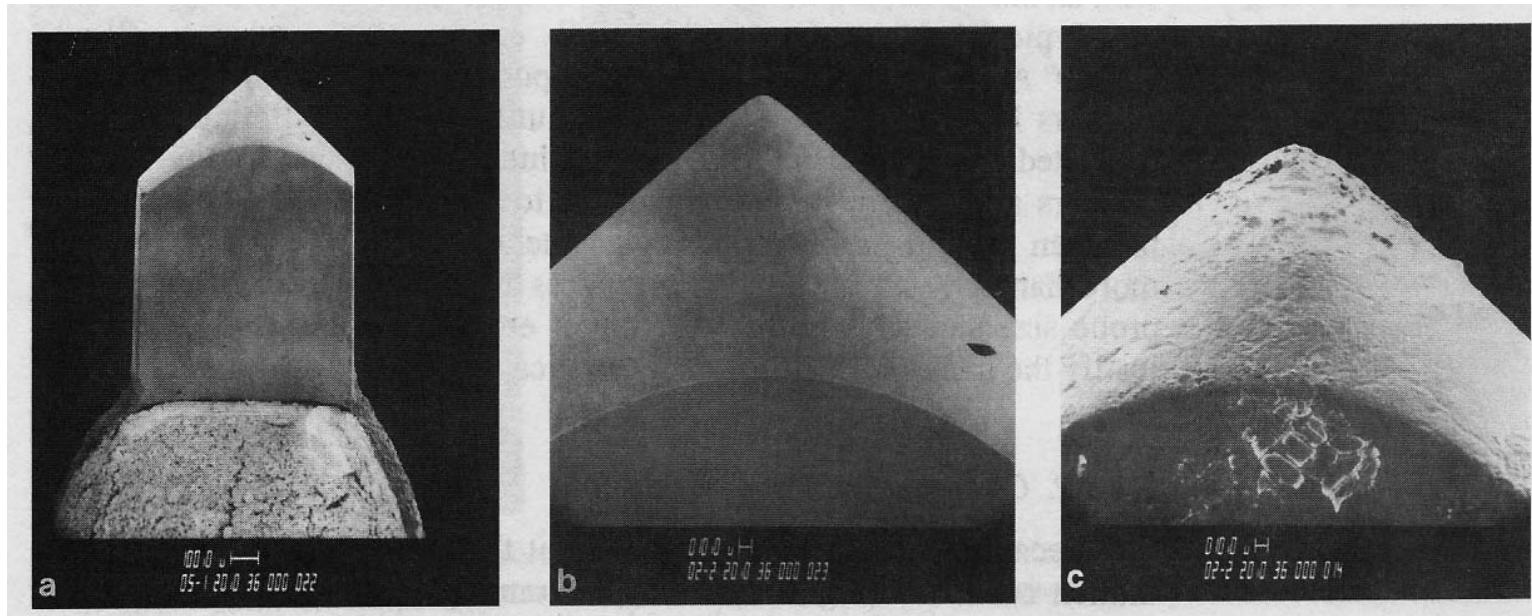
	Units	Tungsten	LaB_6	Field Emission
Work function, Φ	eV	4.5	2.4	4.5
Richardson's constant	$\text{A/m}^2\text{K}^2$	6×10^5	4×10^5	
Operating temperature	K	2700	1700	300
Current density	A/m^2	5×10^4	10^6	10^{10}
Crossover size	μm	50	10	<0.01
Brightness	$\text{A/m}^2\text{sr}$	10^9	5×10^{10}	10^{13}
Energy 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

Williams
e Carter



Degradação da Fonte

Goldstein et all





Coerência

- Coerência avalia quão “em fase” estão as ondas de elétrons
- Coerência temporal
- Coerência Espacial
- FEG possui grande coerência temporal e espacial

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

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



Diâmetro do Feixe

- O diâmetro final, d_t , é resultado do diâmetro do “crossover” alargado pela aberração esférica da lente objetiva, d_s , e a difração pela última abertura, d_d .

$$d_t = \sqrt{d_g^2 + d_s^2 + d_d^2}$$

$$d_g = \frac{2}{\pi} \left(\frac{i}{\beta} \right)^2 \frac{1}{\alpha} \quad d_s = 0,5 C_s \alpha^3 \quad d_d = 1,22 \frac{\lambda}{\alpha}$$



Referências

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“Transmission Electron Microscopy”, Ed.
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- Apresentação da Jeol – Jeol 2100F