Fundamentals and Applications of Vacuum Microelectronics

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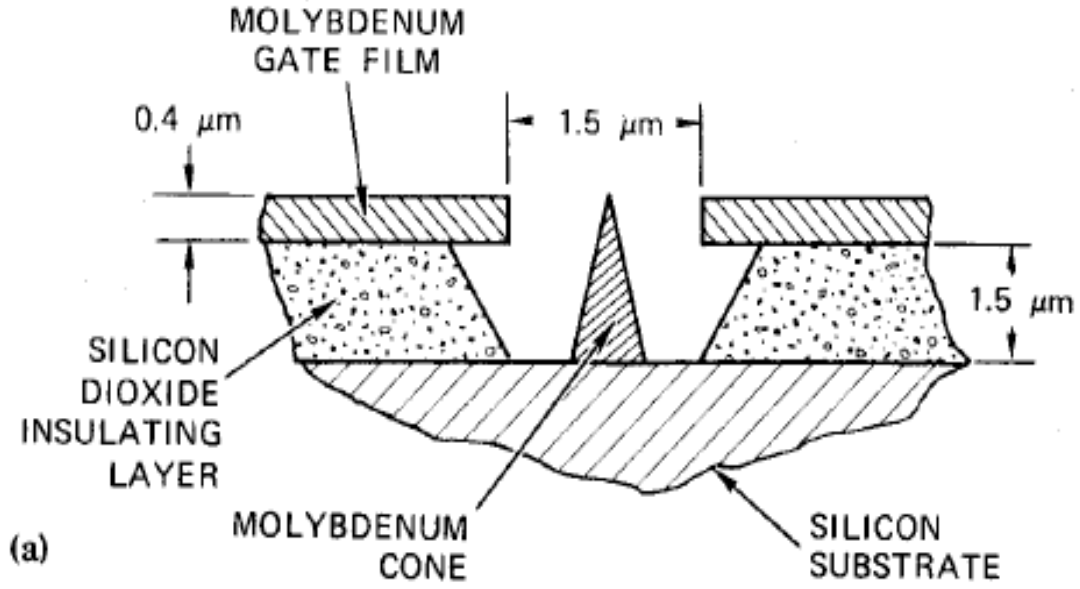
EE 698A

Outline

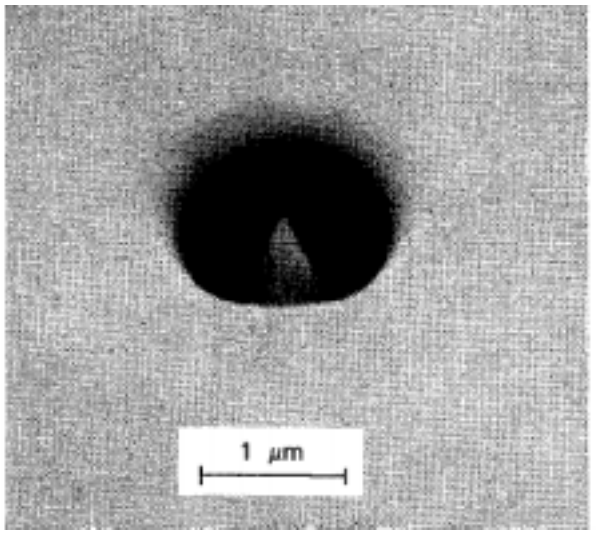
- Introduction
- Field emission basics
- Spindt emitters and arrays
- Beyond Spindt emitters
- Field emission display
- Summary

Introduction (I)

- What is vacuum microelectronics



[Ref. 1]

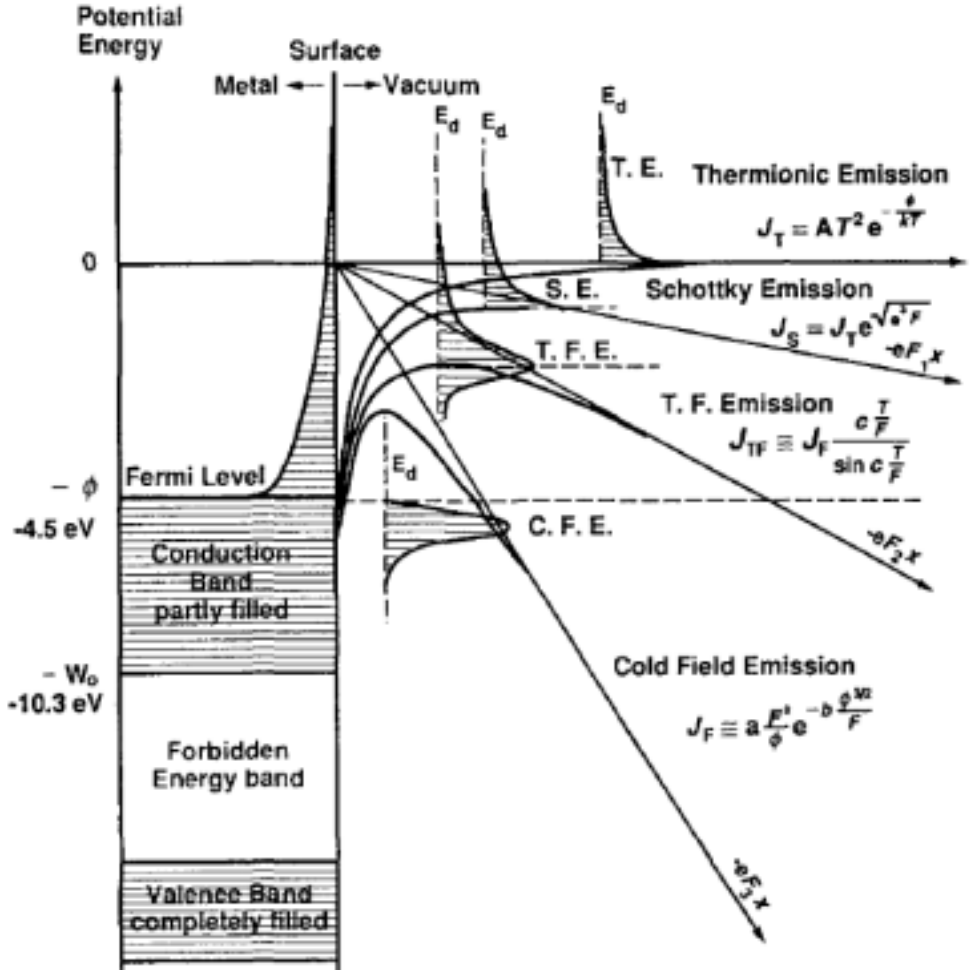


[Ref. 1]

Introduction (II)

- Good
  - Power handling ability
  - Ballistic and coherent transport
  - Resistance to radiation-induced defects
- Bad
  - Fabrication difficulties
  - Packaging issues

Field emission basics



F-N equation [Ref. 2]

$$J(F,\phi) = a\frac{F^2}{\phi} e^{-b\frac{\phi^{3/2}}{F}}$$

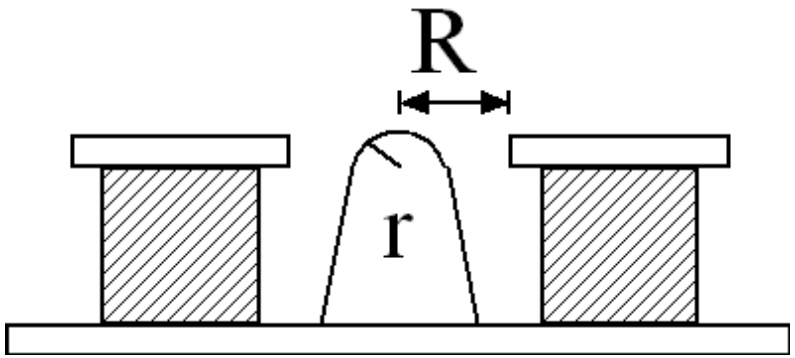
$$a \simeq 1.54 \times 10^{-6}$$

$$b = 6.83 \times 10^{7}\, f(y)$$

F	$f(y)$
4.5×10^7	0.61
6.4×10^7	0.49
10.5×10^7	0.25

When $\phi = 4.5$ eV

Spindt emitters and arrays (I)



$E = \beta V$

E: electric field (V/m)

V: applied voltage (V)

$\beta = R / (k\, r\, (R - r)) \sim 1/ (k\, r)$

when $r << R$ [Ref . 3]

k: const. $1 < k < 5$

Assuming field emission onset

$E \sim 1 \times 10^7$ V/cm

Classical processing:

R = 1mm , r = 2000Å

$\beta = 5 \times 10^4 / k$ cm^{-1}

→ V = 1000 V

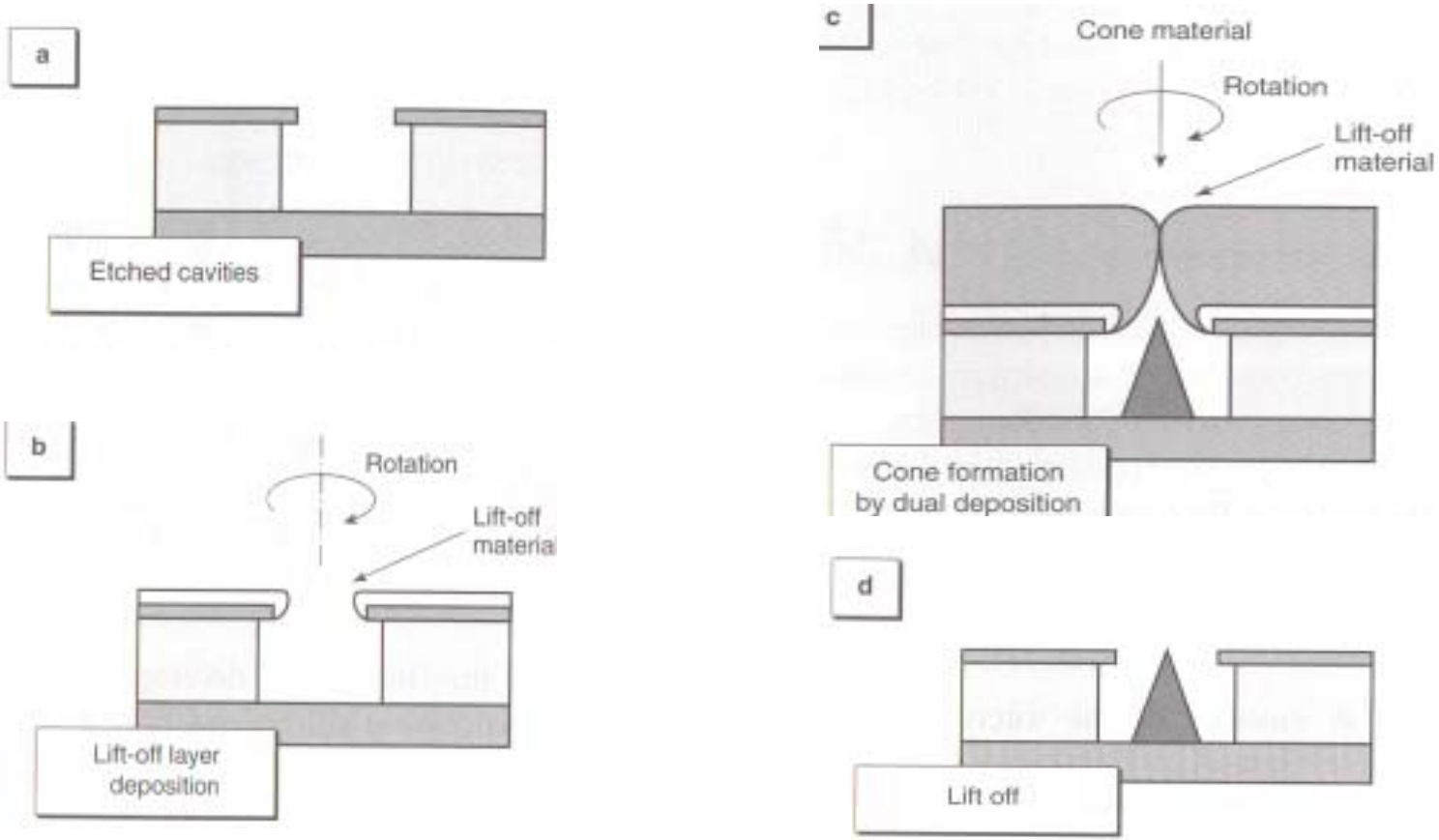
Micro-fabrication:

R = 5000Å, r = 250Å

$\beta = 4 \times 10^5 / k$ cm^{-1}

→ V = 100 V

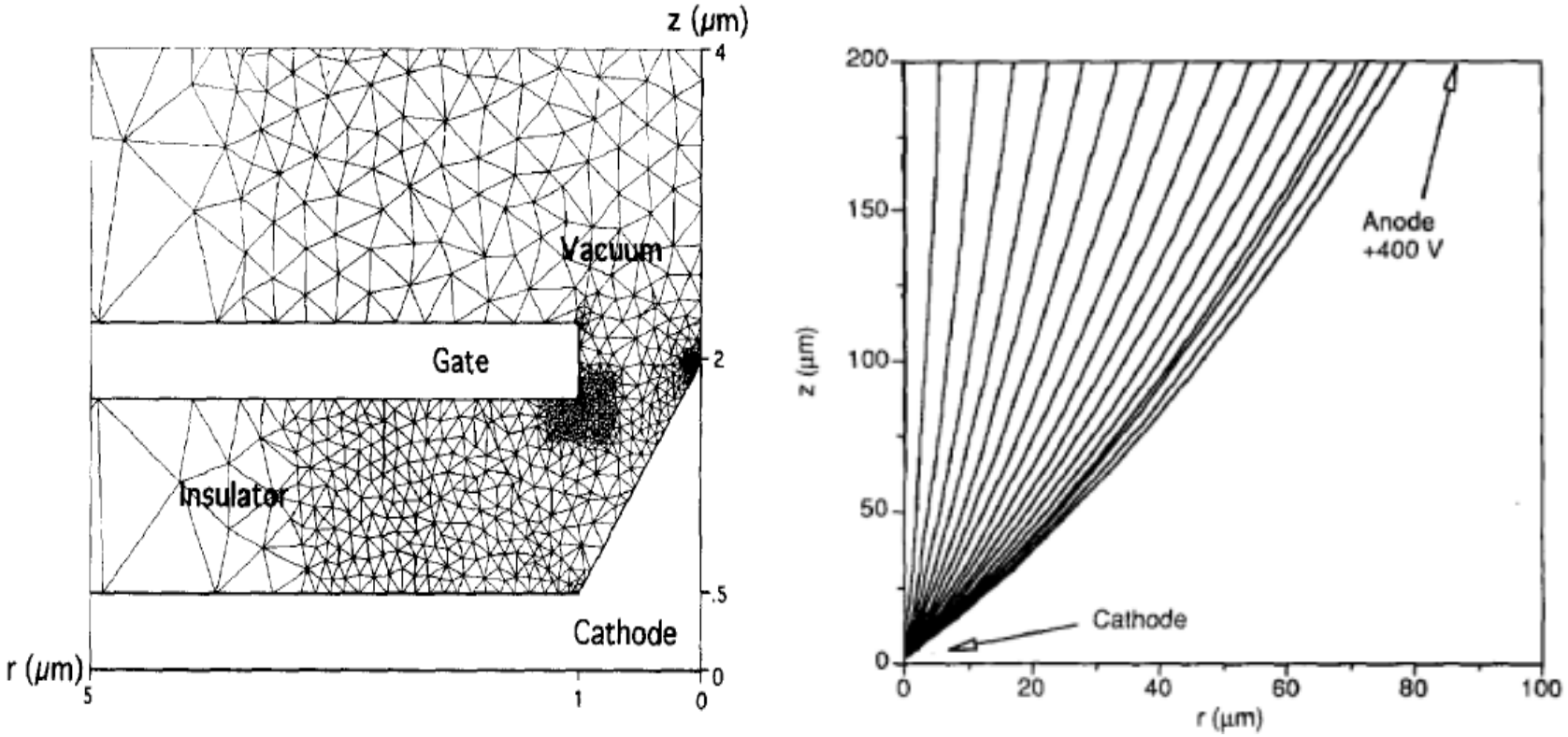
Spindt emitters and arrays (II)



[Ref. 3]

Spindt emitters and arrays (III)

- Fields of a triode structure [Ref. 4]



Spindt emitters and arrays (IV)

- Structure parameter dependence [Ref. 5]

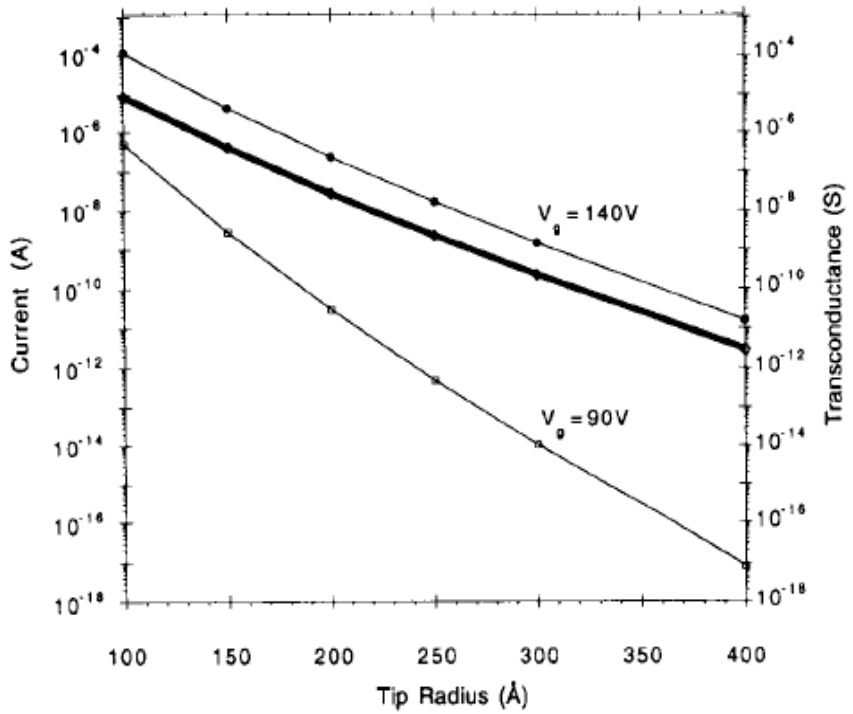


Fig. 4. Emitted current as a function of tip radius at 90 V (lower curve) and 140 V (upper curve). Transconductance at 140 V is indicated in bold.

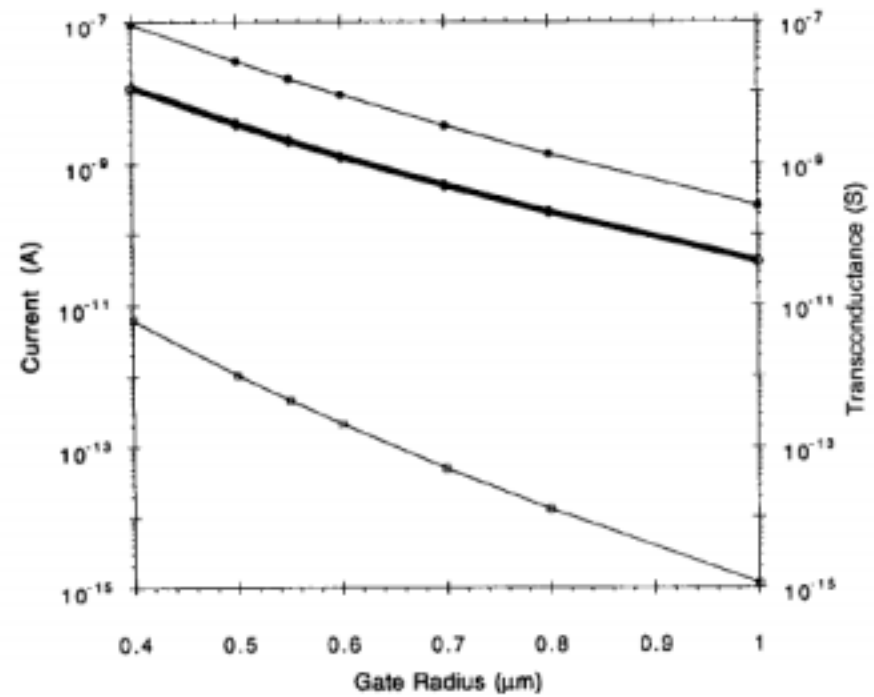
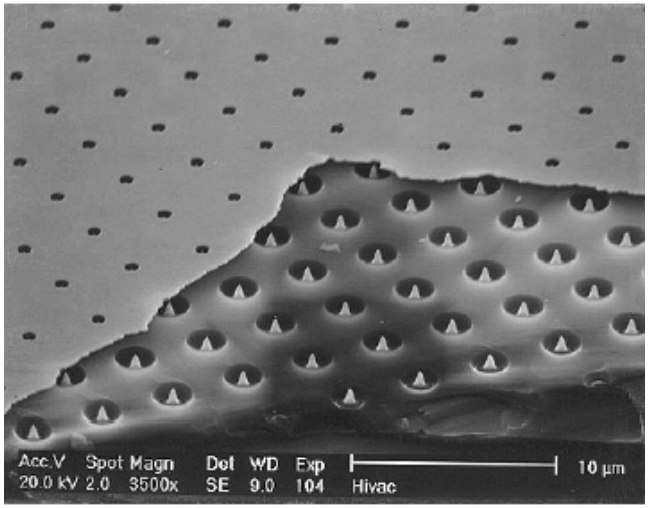
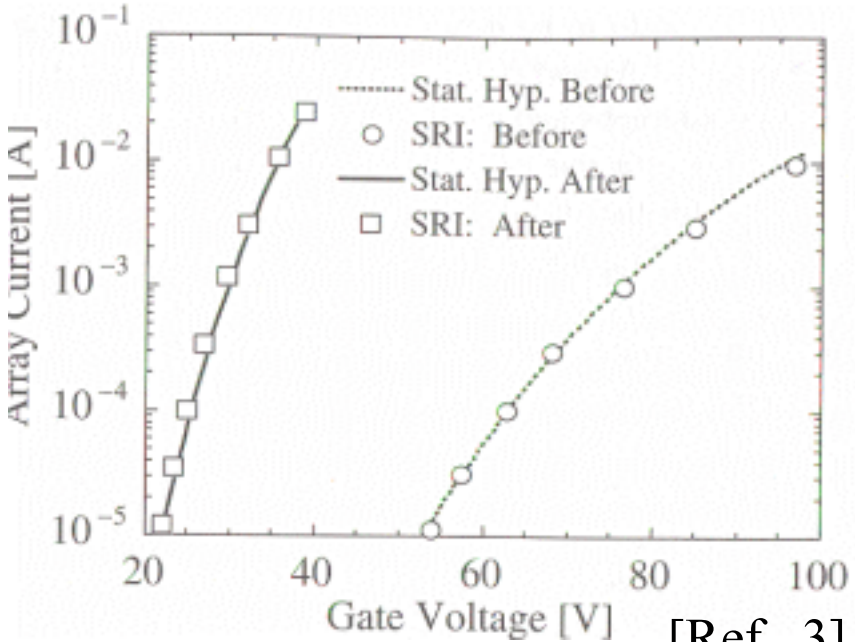


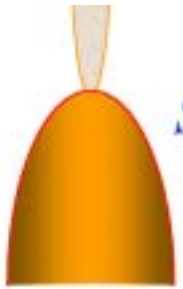
Fig. 8. Emitted current as a function of gate hole radius at 90 V (lower curve) and 140 V (upper curve). Transconductance at 140 V is indicated in bold.

Spindt emitters and arrays (V)





[Ref . 3]



SHOULD

IS

[Ref . 6]

Before:

$\Delta\Phi = 1$ eV $\Sigma \sim 0.1\%$

After:

$\Delta\Phi = 0.2$ eV $\Sigma \sim 20\text{-}40\%$

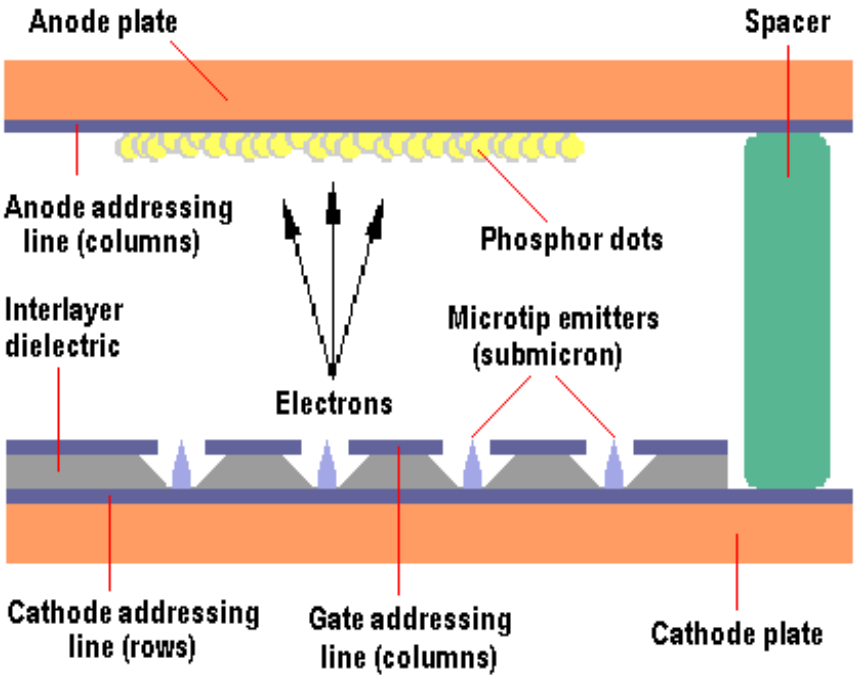
Beyond Spindt emitters (I)

- Problems with simple Spindt emitters
  - Contamination
  - Focusing
  - Uniformity of array fabrication
  - Power consumption

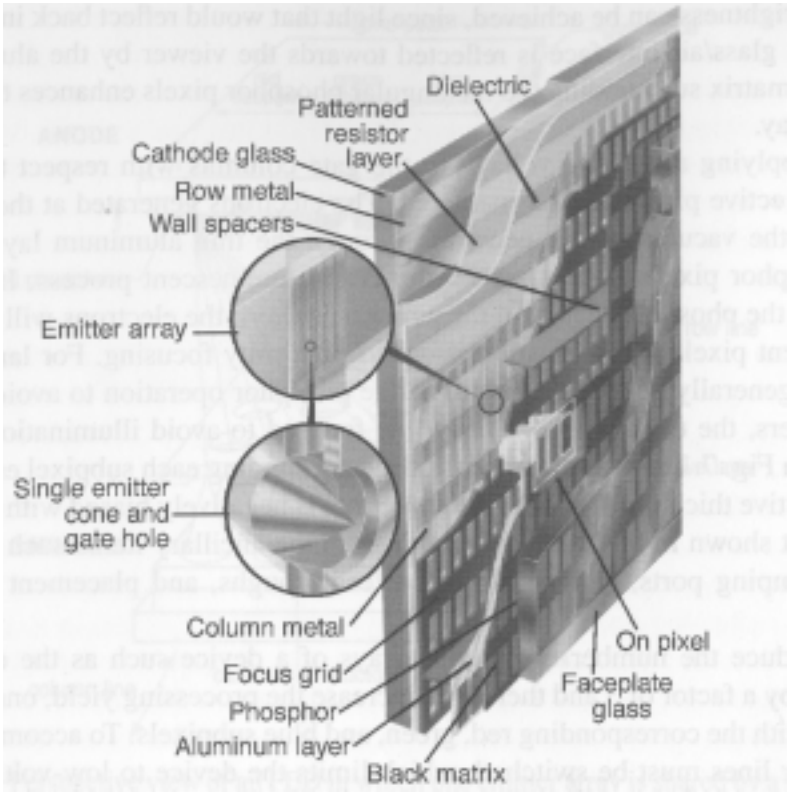
Beyond Spindt emitters (II)

- Solutions
  - Metal-Insulator-Metal (MIM) emitters
  - Surface Conduction Emitters (SCE)
  - Diamond-coated emitters
  - Carbon nanotube emitters

Field emission display (I)



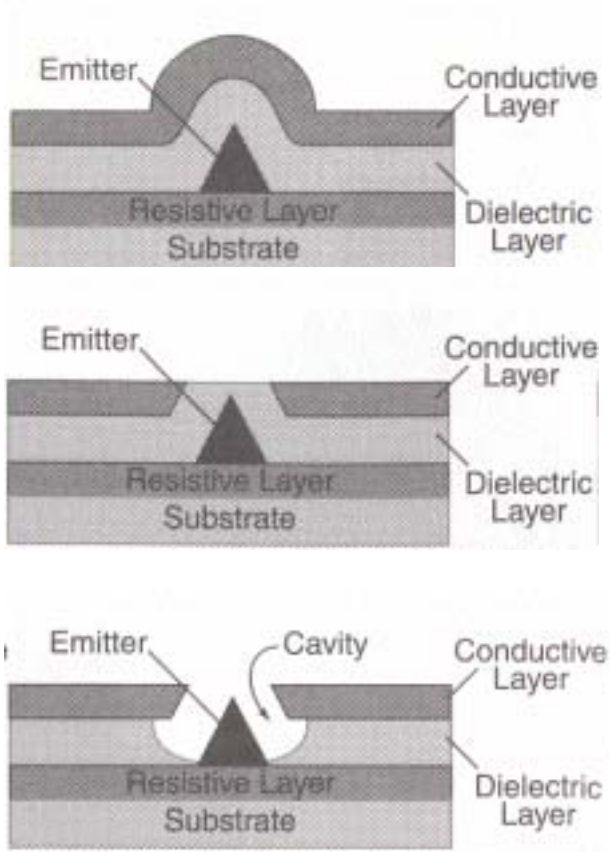
[Ref. 7]



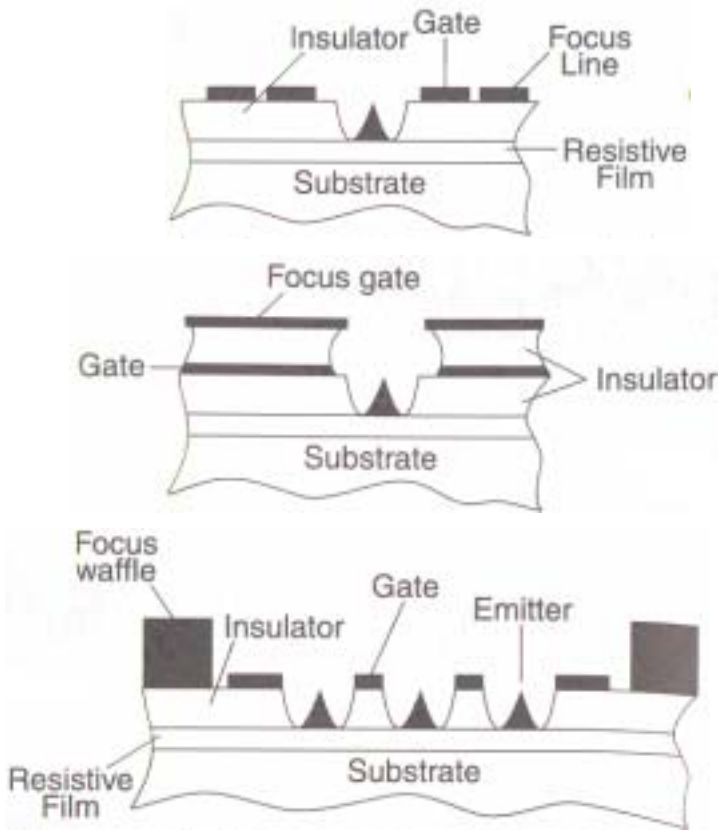
[Ref. 8]

Field emission display (II)

- Large array [Ref. 9]

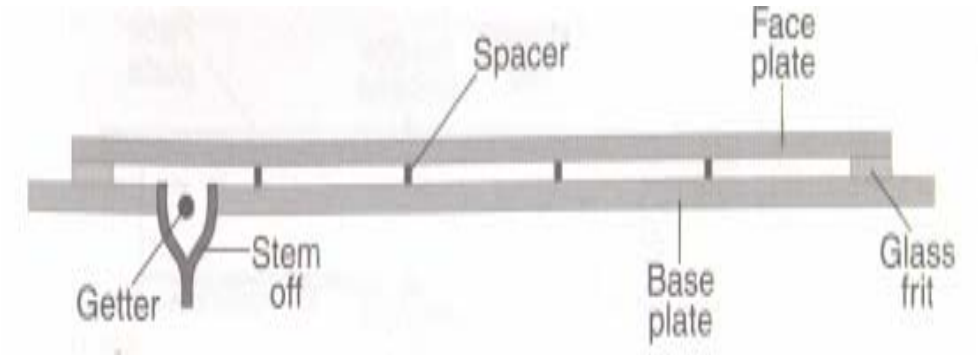


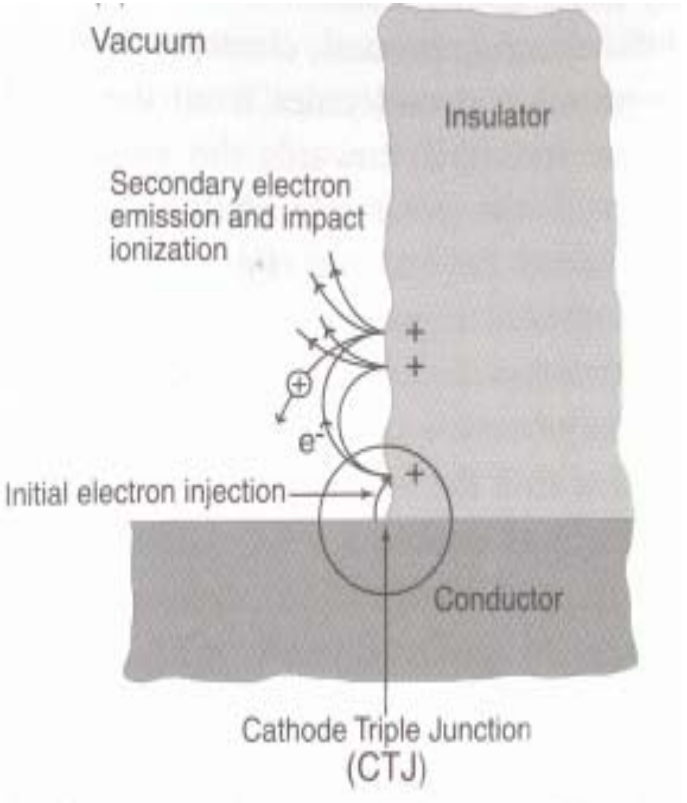
- Beam focusing [Ref. 3]



Field emission display (III)

- Spacers breakdown [Ref. 3]
- Getters [Ref. 3]





Field emission display (IV)

Feature	Thin Film Transistor LCD	Electro-luminescent Display	FED	Plasma Display Panels	OLED Display
Brightness (cd/m^2)	200	100	150 (low-V) >600 (high-V)	300	300
Viewing angle (degrees)	±40	±80	±80	±80	±80
Emission efficacy (lm/W)	3–4	0.5–2	1.5–3 (low-V) 10–15 (high-V)	1.0	10–15
Response time (ms)	30–60	<1	0.01–0.03	1–10	<0.001
Contrast ratio (intrinsic)	>100:1	50:1	300:1	100:1	100:1

[Ref. 3]

Field emission display (V)

Feature	Thin Film Transistor LCD	Electro-luminescent Display	FED	Plasma Display Panels	OLED Display
Number of pixels	1024 × 768	640 × 480	800 × 600	852 × 480	640 × 480
Resolution (mm in pitch)	0.31	0.31	0.27	1.08	0.012
Power consumption (W)	3 (25.4)[a]	6 (25.4)	2 (25.4)	200 (106.7)	6 (15.2)
Maximum screen size in diagonal (cm)	55.9 (22)[b]	25.4 (10)	35.6 (14)	106.7 (42)	15.2 (6)
Panel thickness (mm)	8	10	10	75–100	3

[Ref. 3]

Summary

- An interesting device family
- Special design/fabrication considerations
- Complementary to conventional solid-state devices
- Important applications

References

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[2] F. Charbonnier, *Appl. Surf. Sci.*, 94/95 (1996) 26

[3] W. Zhu, *Vacuum Microelectronics*, John Wiley & Sons, 2001

[4] W.Dawson et al., *J. Vac. Sci. Tech. B*, 11(2),(1993) 518

[5] E. G. Zaidman, *Trans. Electron Dev.*, May 1993, 1009-1016

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[8] T. S. Fahlen, *Proc. IVMC*, 1999, p. 56

[9] T. T. Doan et al., *US patent* 5229331, 1993