3. LES CATHODES FROIDES SSE :

Une nouvelle approche avec des couches ultra-minces

Motivation: cathodes froides pour des applications industrielles

Objectif: une miniaturisation poussée de systèmes basés
sur des faisceaux d'électrons

Développements:
* écrans plats à émission de champ
* générateurs de rayons X miniaturisés
* microcanon pour lithographie électronique
* réfrigérateur local par effet Nottingham
* spectromètres miniatures, ……….

LES CATHODES FROIDES SSE
en couches ultra-minces

Conditions requises pour un développement industriel

Trois principales:

✓ (1) source : froide / émission électronique à température ambiante

✓ (2) fabrication : faible coût et compatible avec une grande série

✓ (3) qualité requise: émission stable dans un vide médiocre

($100 A/cm^2$ - 10^{-7} Torr)

Deux nouvelles approches

Première approche avec de nouvelles techniques de fabrication :

* les nanotubes de C

* les nanoperles de C

(travail de sortie ~4 eV)

Seconde approche avec de nouvelles structures de surface:

Les cathodes SSE à couches ultra-minces

(travail de sortie ~0.3 eV)

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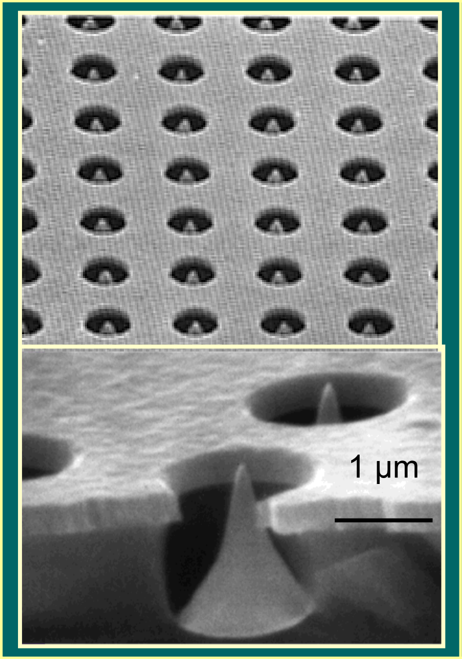
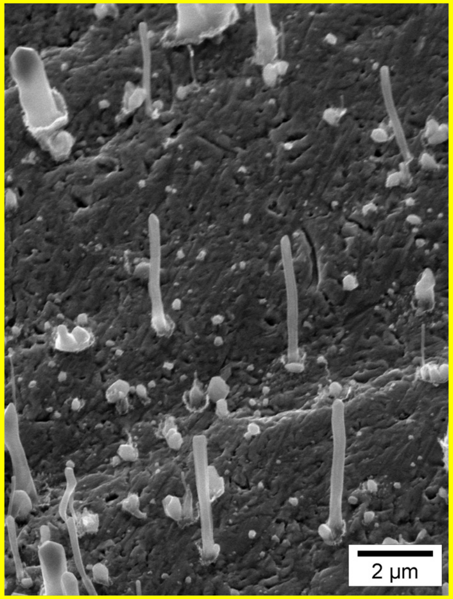
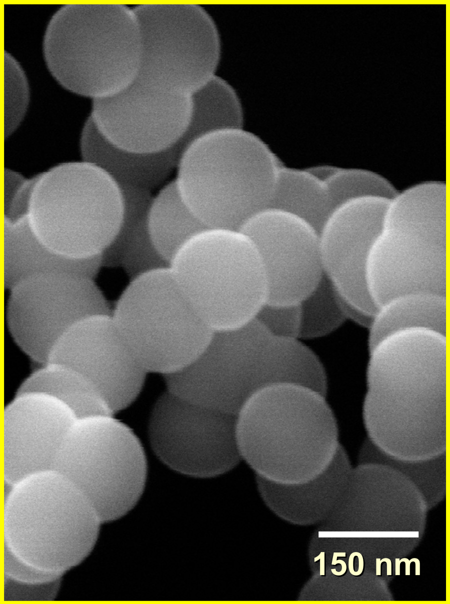
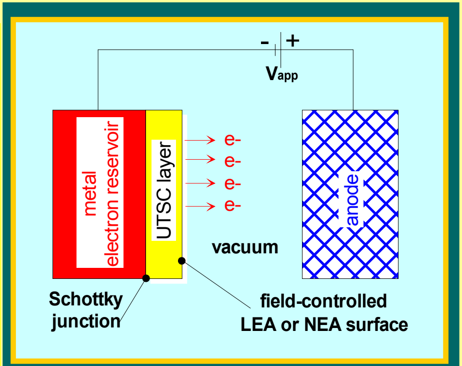
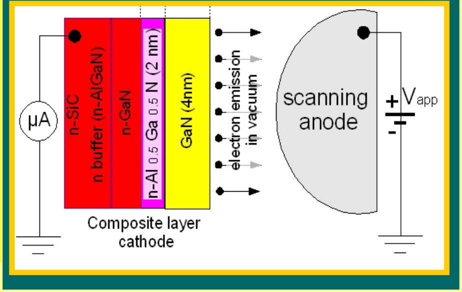
Pointes de Spindt (1968, 1980)	Nanotubes de C (1991, Lyon 1999)	Nanoperles de C (Lyon 2003)	Cathodes SSE (Lyon 1999,2003)
			 

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Conditions requises pour un développement industriel

Trois principales:

- ✓ (1) source : froide / émission électronique à température ambiante
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  (100A/cm^2 - 10^{-7} Torr)

Approach using
the solid-state field controlled emission (SSE) cathodes

(1) * Lowering of the effective work function until 0.1 to 0.5 eV

⬇

* Field emission for electric field ~1/100 of conventional FE field (~50 V/µm)
* Thermionic emission for temperatures ~ 300 K (RT)

(2)&(3) * Ultra-thin dielectric layers and thin film deposition process

Solid-state field-controlled emission (SSE) cathode

The challenge:

Question: Is there any possibility
to overcome the predominant role of the surface
in the definition of the barrier height ?

Possibilities:

* low adsorption rate surfaces, i.e. covalent surfaces
* control of the electron affinity by tuning the solid state electronic structure of the underneath layer

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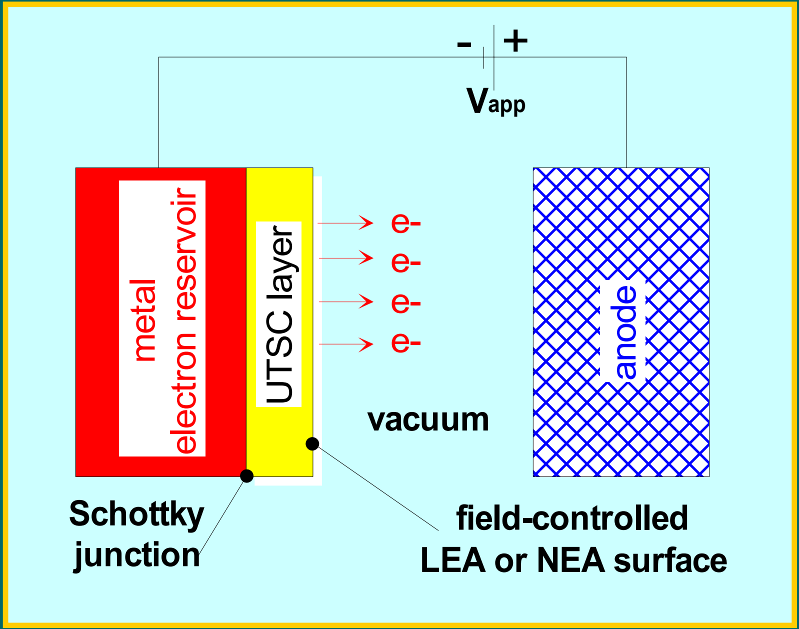
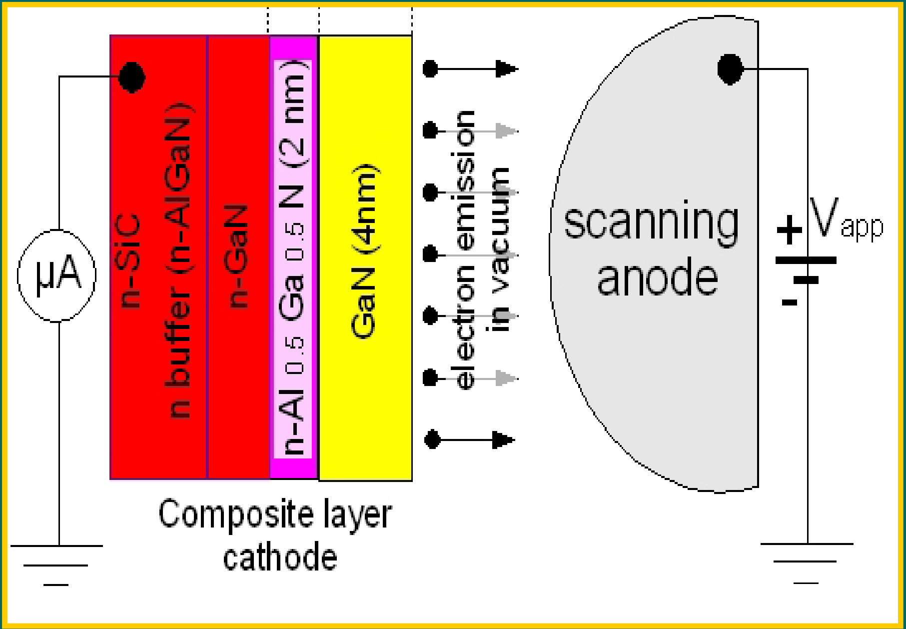
Solid-state field-controlled emission (SSE) cathode

Single layer SSE cathode, 1999



(collaboration: H. Birecki, HP, Palo-Alto)
Phys. Rev. Letters, 85, 864-867 (2000)

Composite layer SSE cathode, 2003



(collaboration: Ray Tsu, UNC Charlotte;
Asif Khan, USC Columbia)
Applied Phys. Letters, 84, 1937-1939 (2004)

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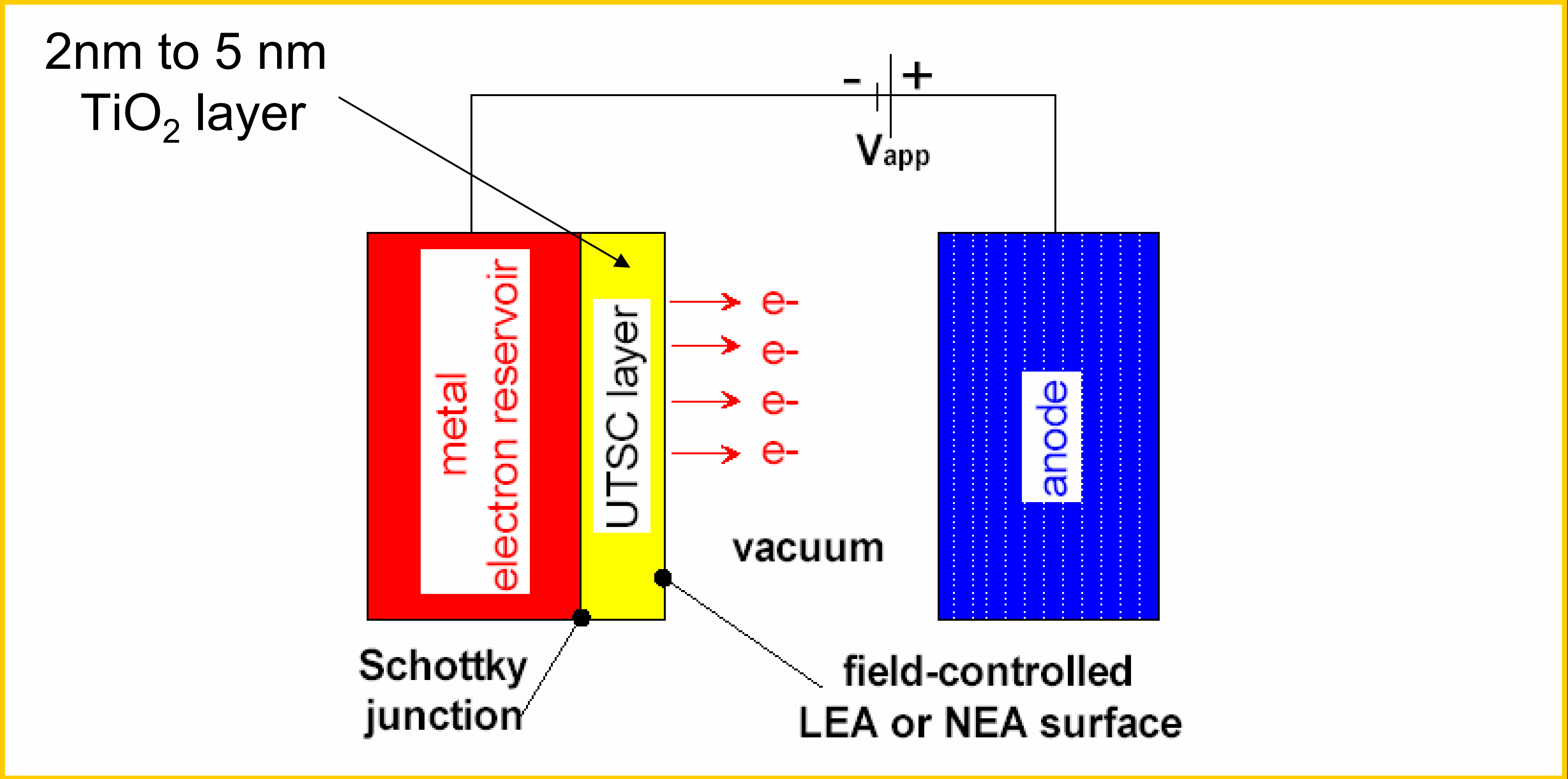
Single layer SSE cathode: the structure



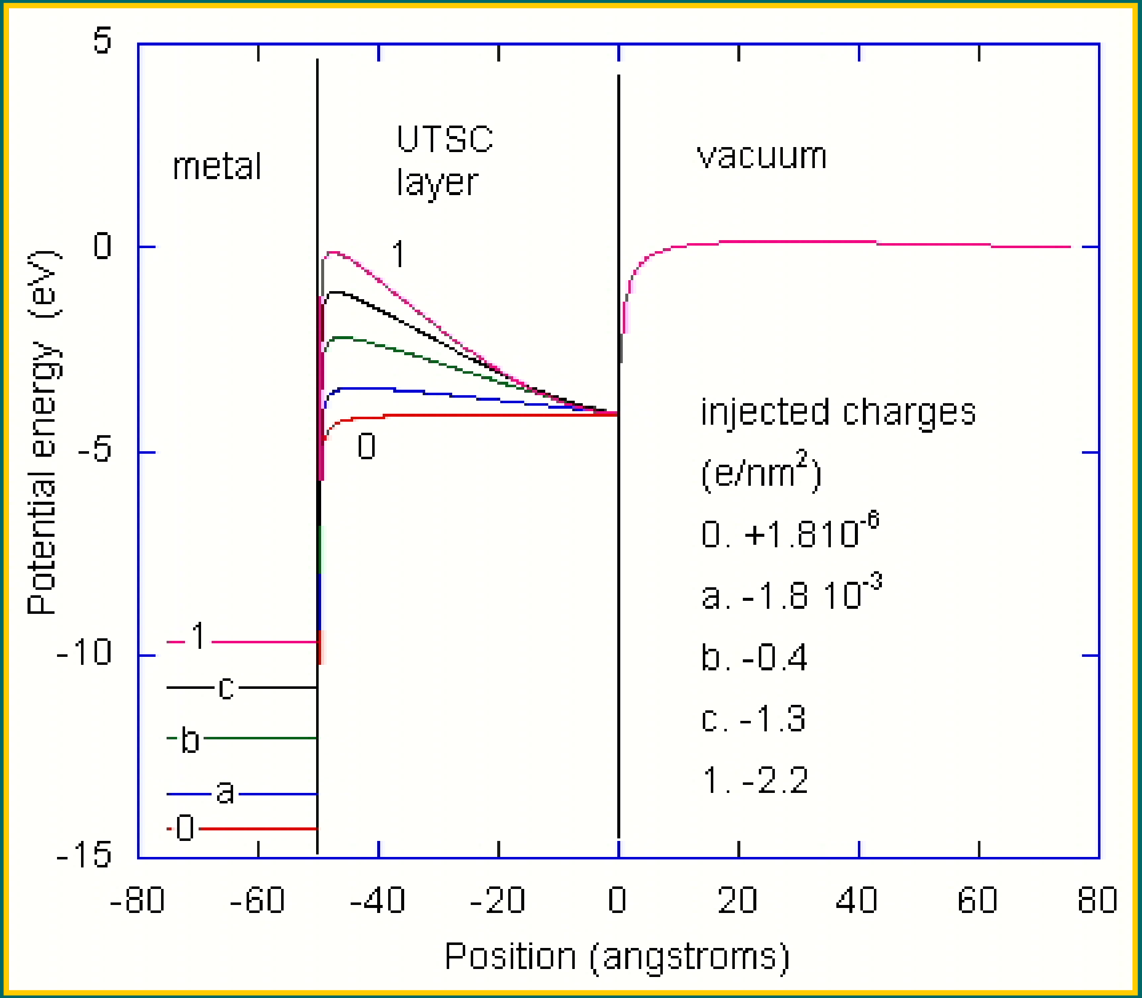
Single layer SSE cathode: the concept

The concept: serial two-step mechanism

- electronic injection from the Schottky junction to create an equilibrium space-charge inside an UTSC (ultra-thin wide band gap semiconductor) which controls the height of the emission barrier $\Delta\Phi_E$
- emission currents from the UTSC surface monitor by an applied field

The fabrication: thin-film deposition techniques

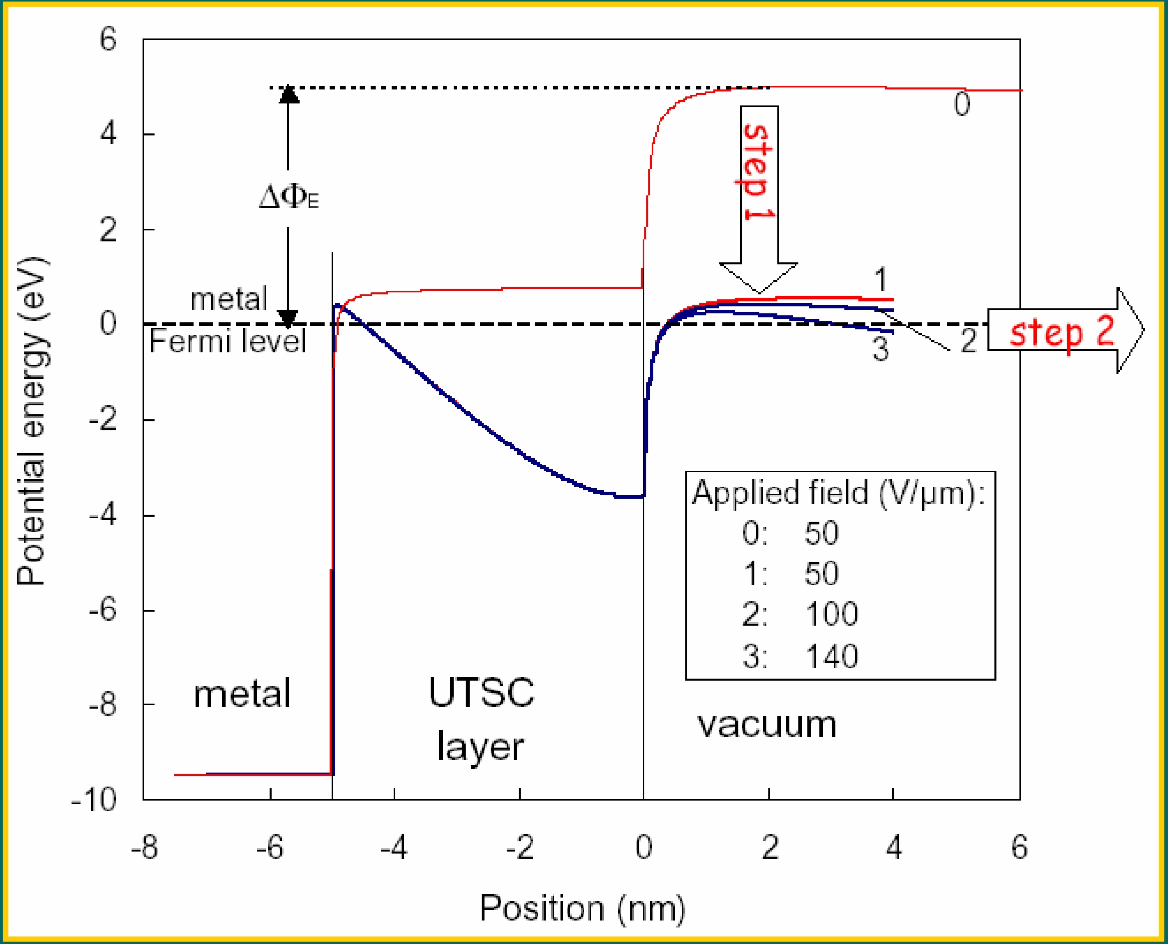
Single layer SSE cathode: the concept



Step1:

Space charge formation in the UTSC by electron injection through Schottky junction ➔ reduction of the effective emission barrier to a few tenth of eV

Single layer SSE cathode: the concept



Step1:

Space charge formation in the UTSC by electron injection through Schottky junction ➔ reduction of the effective emission barrier to a few tenth of eV

Step 2:

Electron emission through / over the field deformed reduced surface barrier

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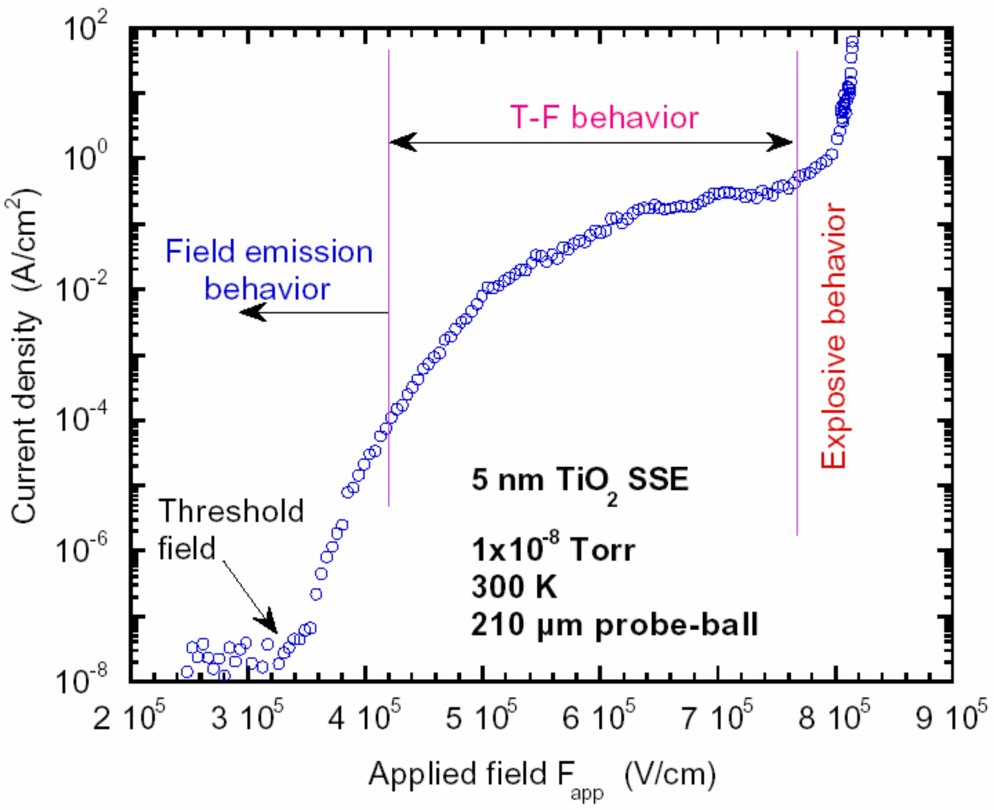
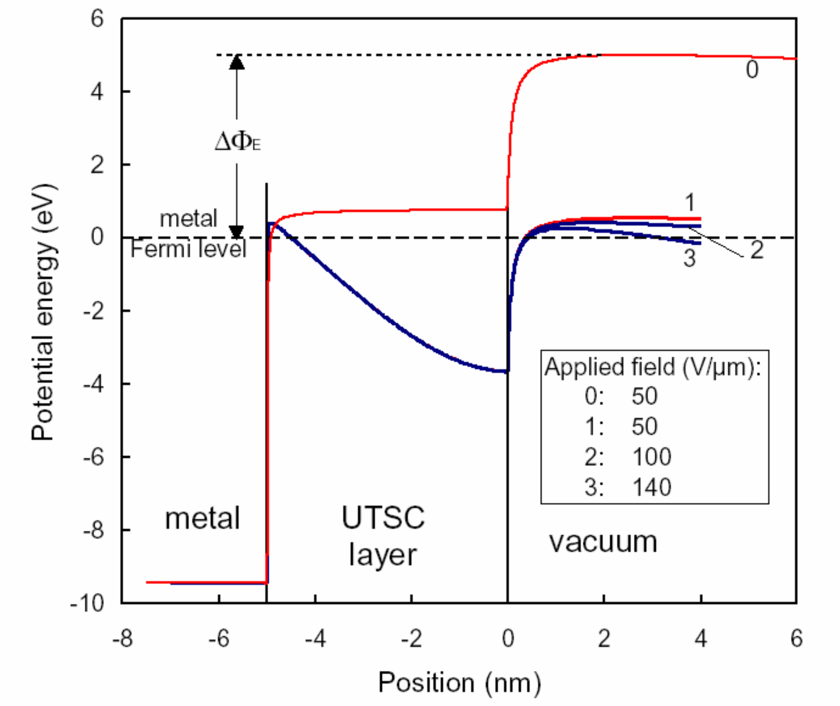
Single layer SSE cathode: field emission characteristics





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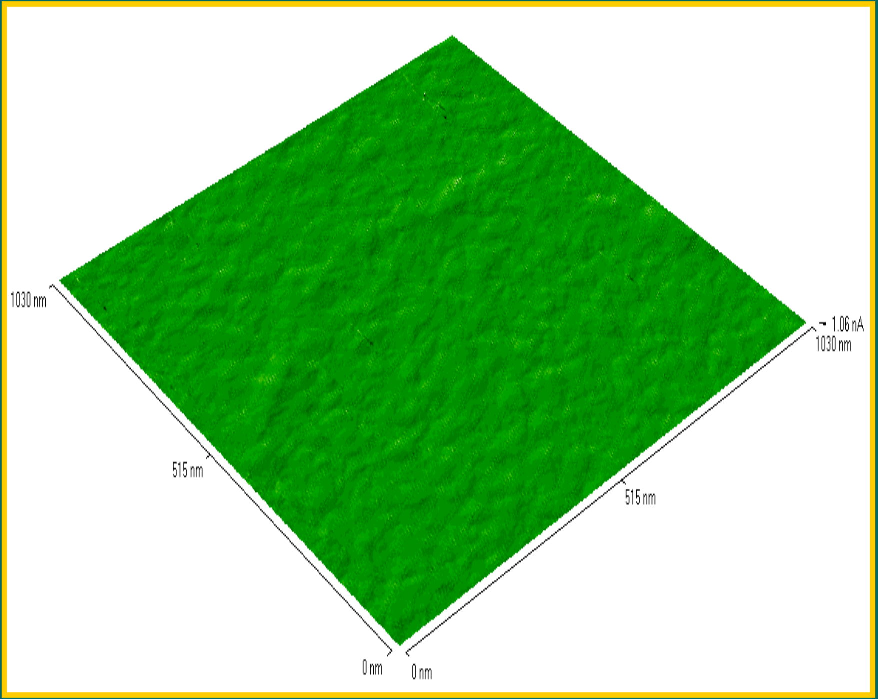
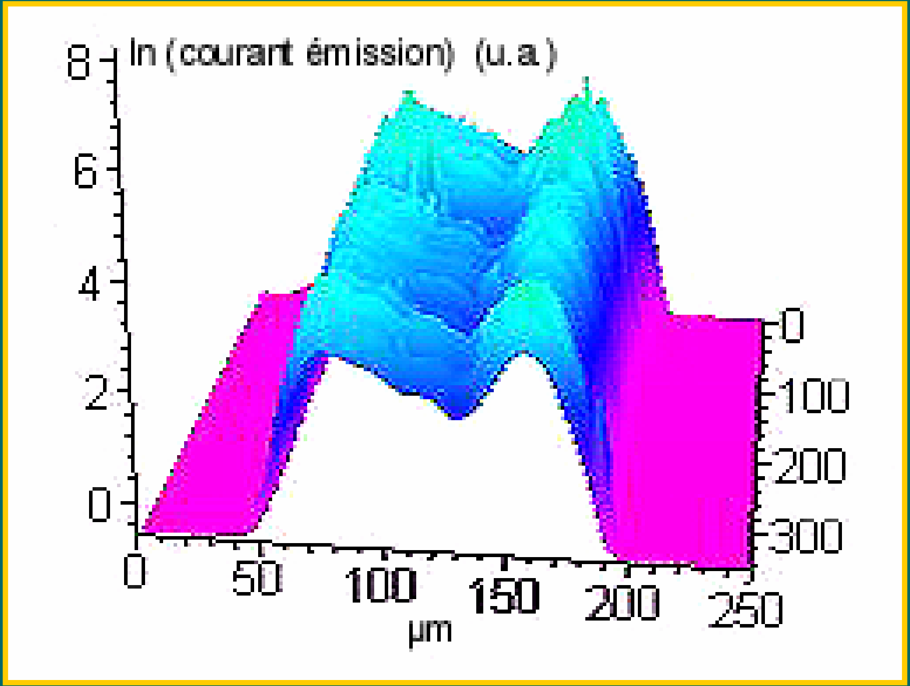
Single layer SSE cathode: field emission characteristics

AFM observation of the TiO_2 surface



1µmx1µm
Mean roughness ~7nm

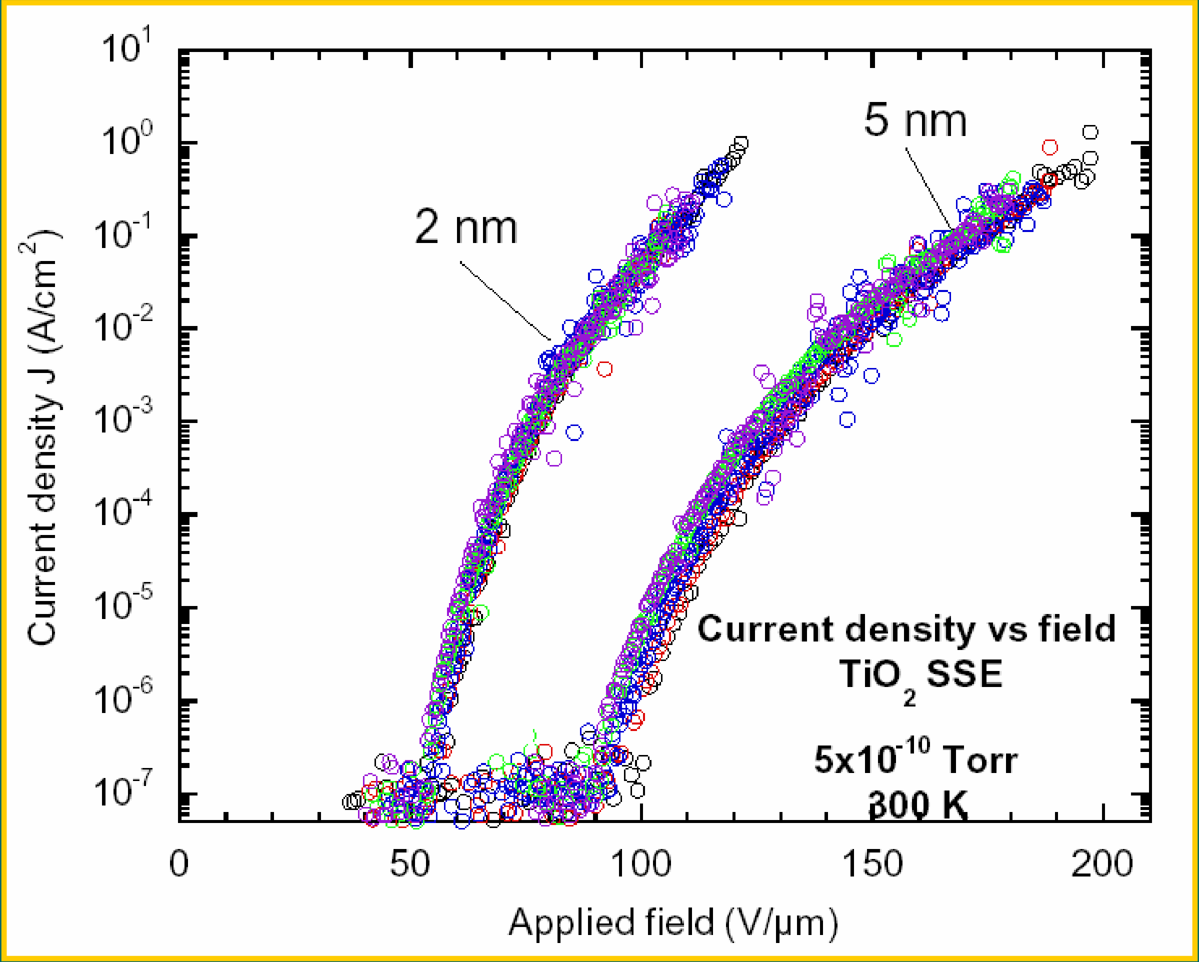
Scanning anode field emission pattern



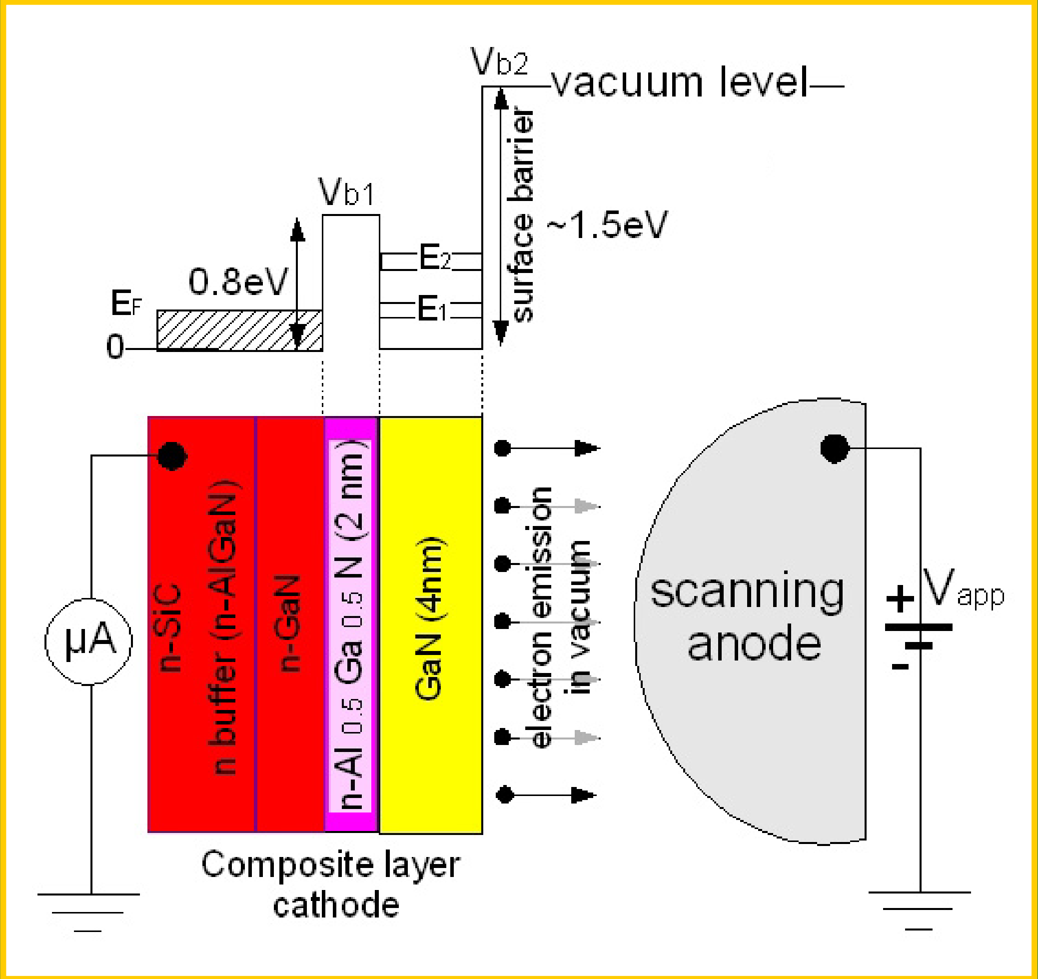
TiO_2 deposited along a 100 µm strip
The electron emission is strictly confined over this strip

Single layer SSE cathode: field emission characteristics

UTSC thickness dependence



Nanostructured SSE cathode : the structure



The role of the multilayer :

Presence of a quantum well at the surface layer

⬇

Formation of sub-bands at discrete energy levels E_1 , E_2

⬇

Controlled value for the space charge at the surface layer

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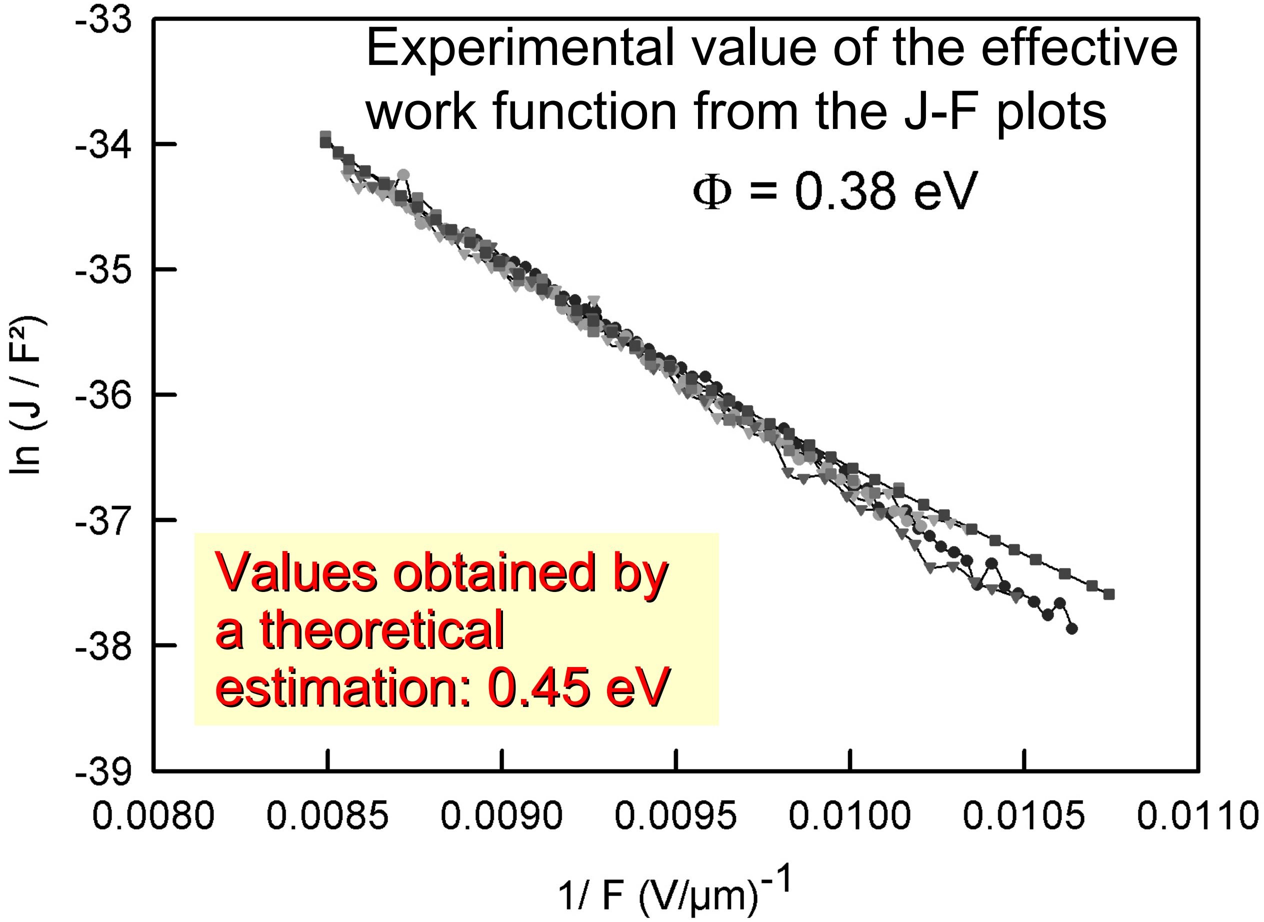
Nanostructured SSE cathode : field emission characteristics

The field emission barrier



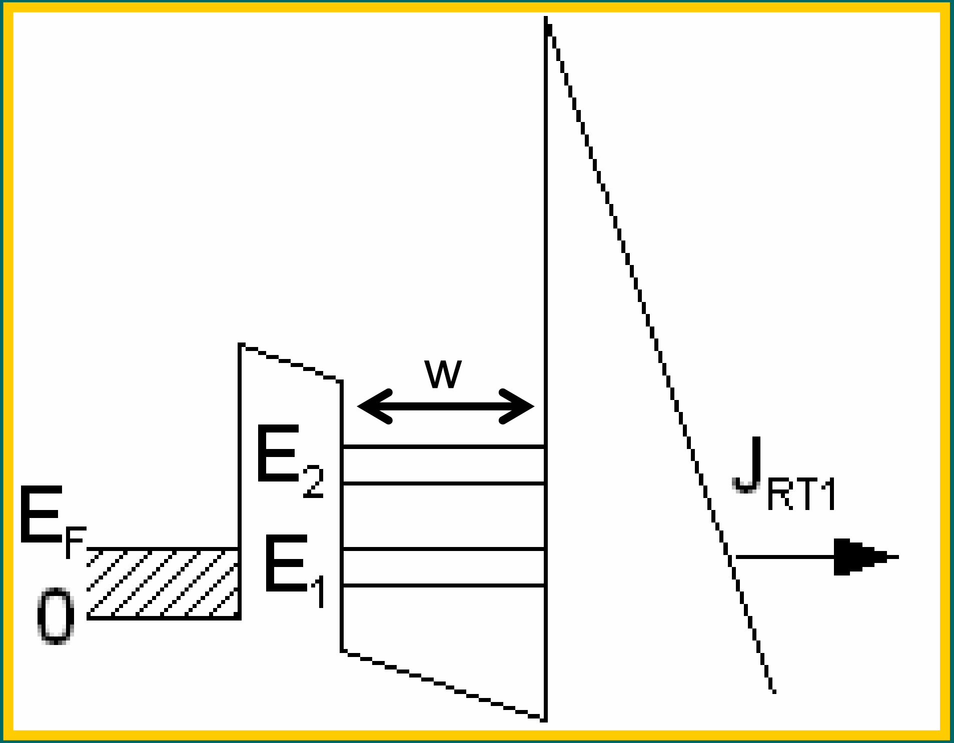
Experimental value of the effective work function from the J-F plots

$\Phi = 0.38$ eV

Values obtained by a theoretical estimation: 0.45 eV

Nanostructured SSE cathode : field emission mechanism

Resonant tunneling ?



Tsu, Esaki (APL, 1971)

Lowering of the effective work function only by a few tenths of eV

$\sim (E_1 + [V(w) - V(0)] /2)$

with $E_1 = 0.18$ eV

it cannot account for the very low values of * the threshold field for FE
* the surface barrier measured

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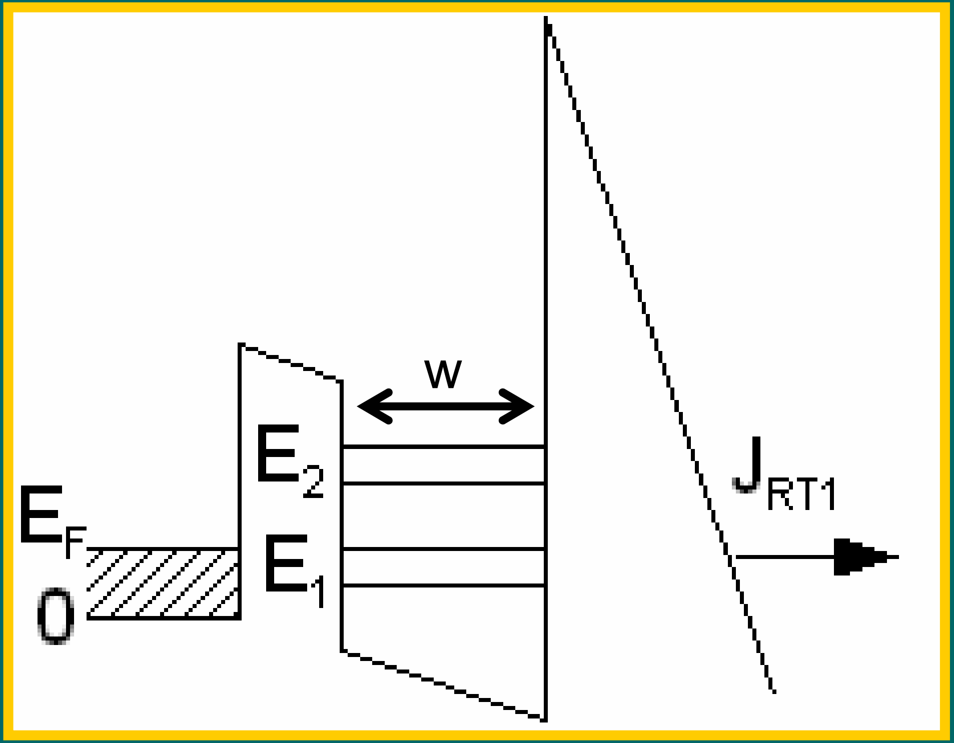
Nanostructured SSE cathode : field emission mechanism

Lowering of the work function due to space charge in the QW ?



Tsu, Esaki (APL, 1971)

The concept :

* when the 2D-like quantum state is occupied it creates a space charge in the QW

Nanostructured SSE cathode : field emission mechanism

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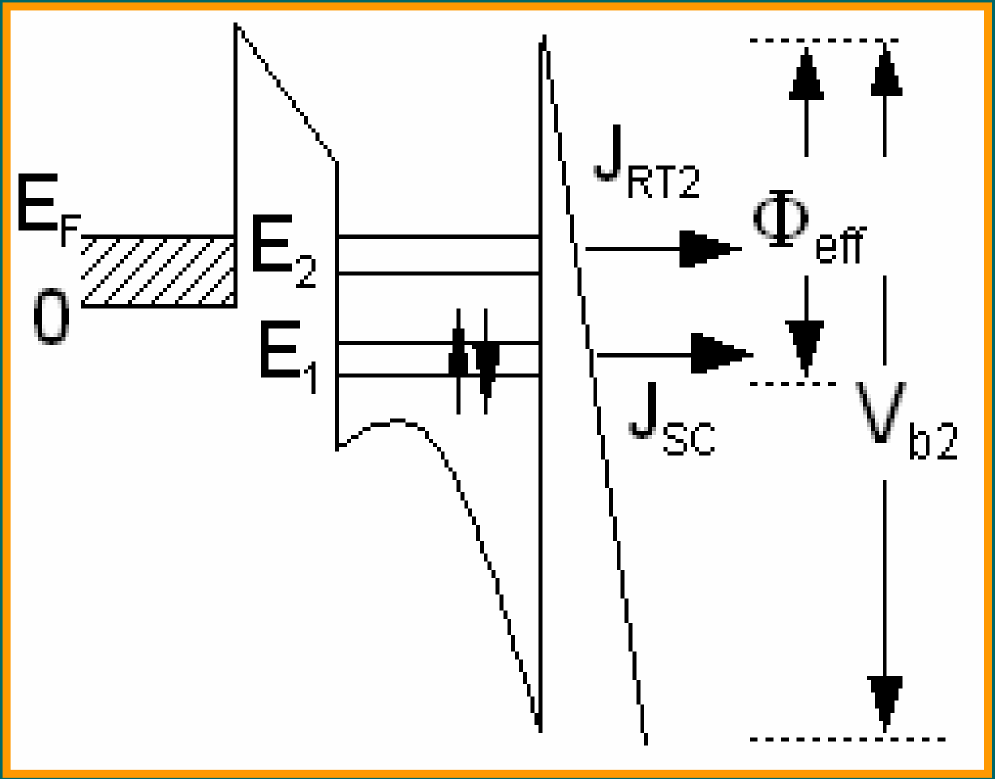


The concept :

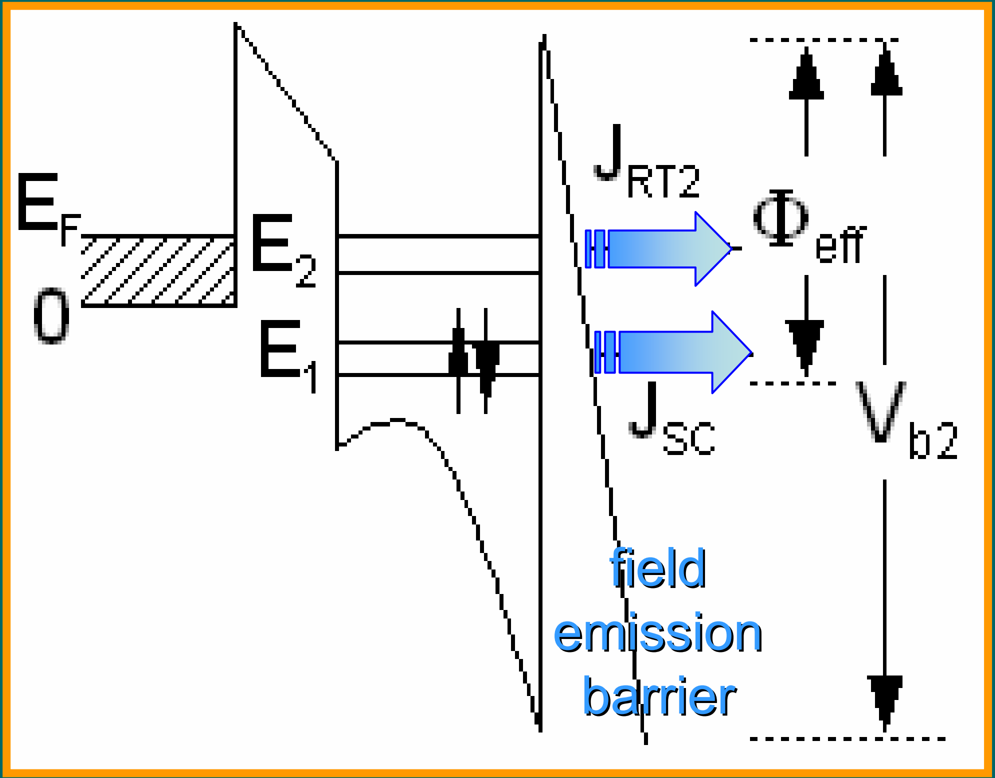
* when the 2D-like quantum state is occupied it creates a space charge in the QW

* resulting then in an effective lowering of the surface barrier

Nanostructured SSE cathode : field emission mechanism

Lowering of the work function due to space charge in the QW ?

$$\Delta\Phi \equiv V_{b2} - \Phi_{eff} = V_{SC}[av] + 0.5\times[V(w) - V(0)] + E_1$$



The estimation :

$m^* = 0.22\ m_o$, $\varepsilon = 8\varepsilon_o$
$V_{SC}[av] = 0.25eV$,
$0.5\times[V(w) - V(0)] = 0.62$ eV,
and $E_1 = 0.18$ eV & $V_{b2} = 1.5$ eV

$\Delta\Phi = 1.05$ eV

value of Φ_{eff} is then 0.45 eV

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Nanostructured SSE cathode : field emission mechanism

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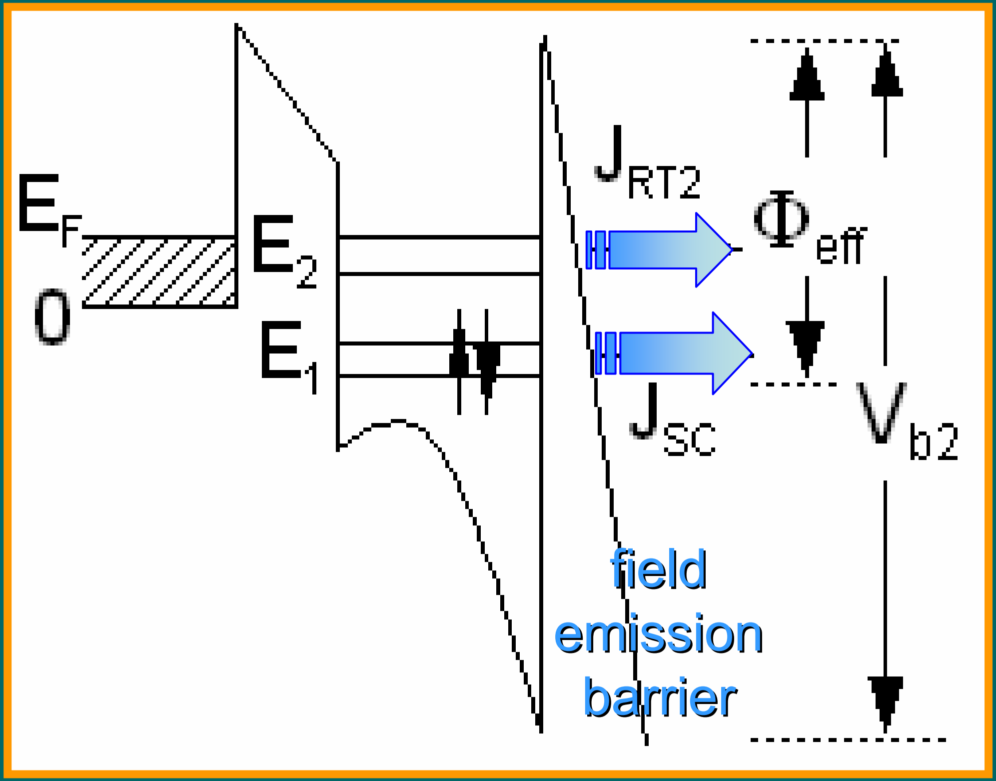

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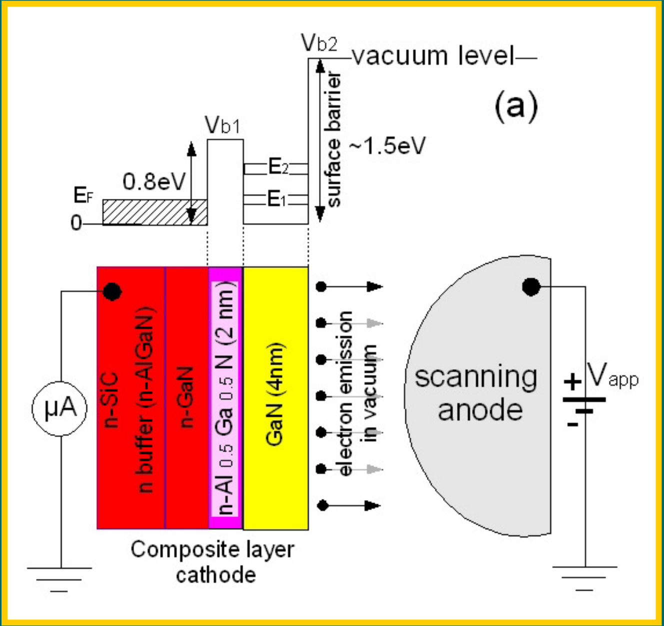
$\Phi_{FN} = (\ 0.53$ to 0.23 eV)

(experimental values)

Nanostructured SSE cathode : field emission mechanism



Two-step mechanism

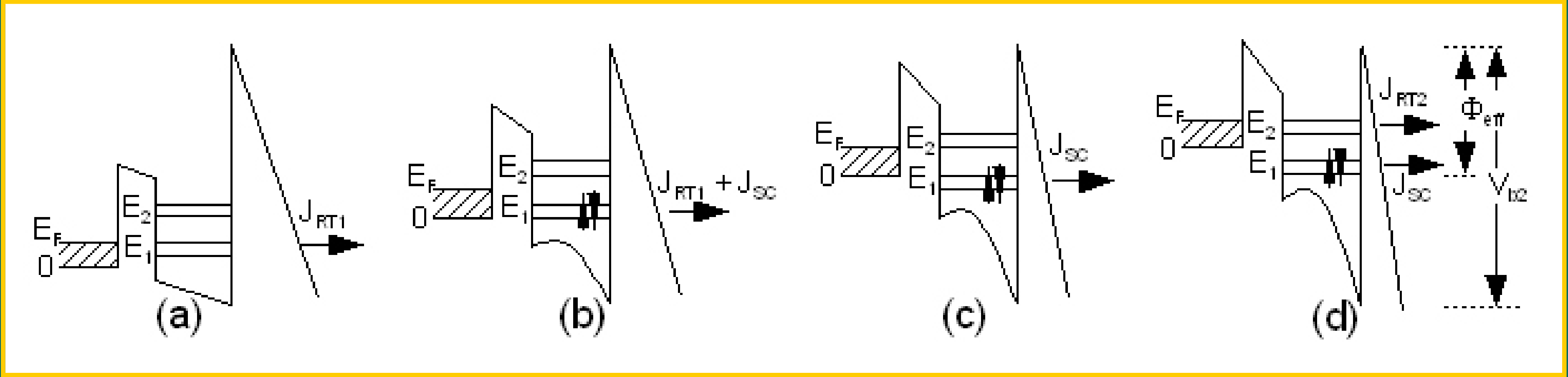
Step 1: Electron injection through the first barrier, the electrons will occupy the sub-bands if they are under the Fermi level

➔ space charge formation in the GaN layer

➔ lowering of the effective work-function

Step 2: Field emission through the surface barrier

➔ resonant & conventional tunnelling



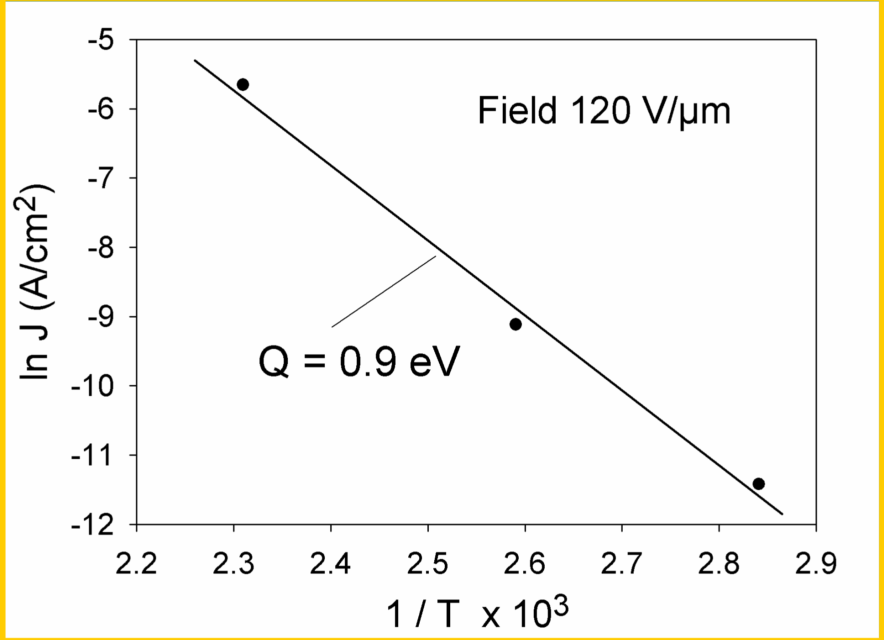
Nanostructured SSE cathode : field emission mechanism

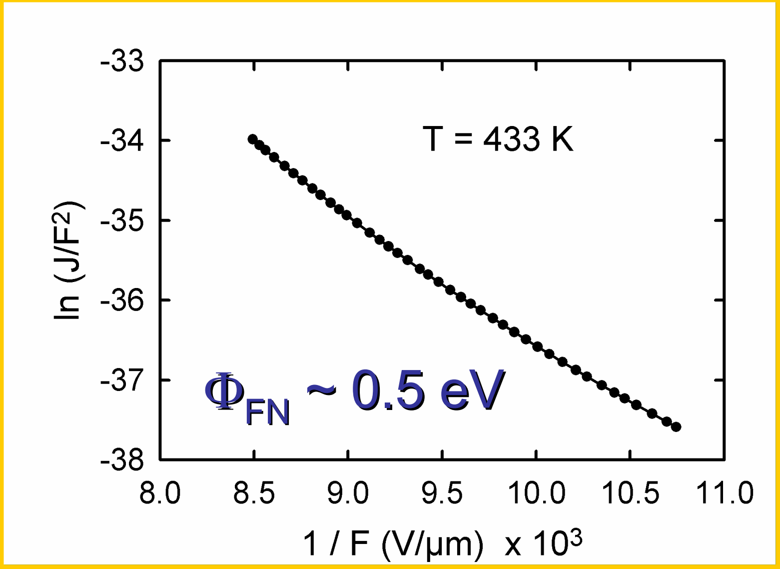
Field dependence for different temperatures

$$J_{FN} = A\,F^2 \exp\left(-\,B\Phi_{FN}^{3/2} / F\right)$$

Temperature dependence for a given field

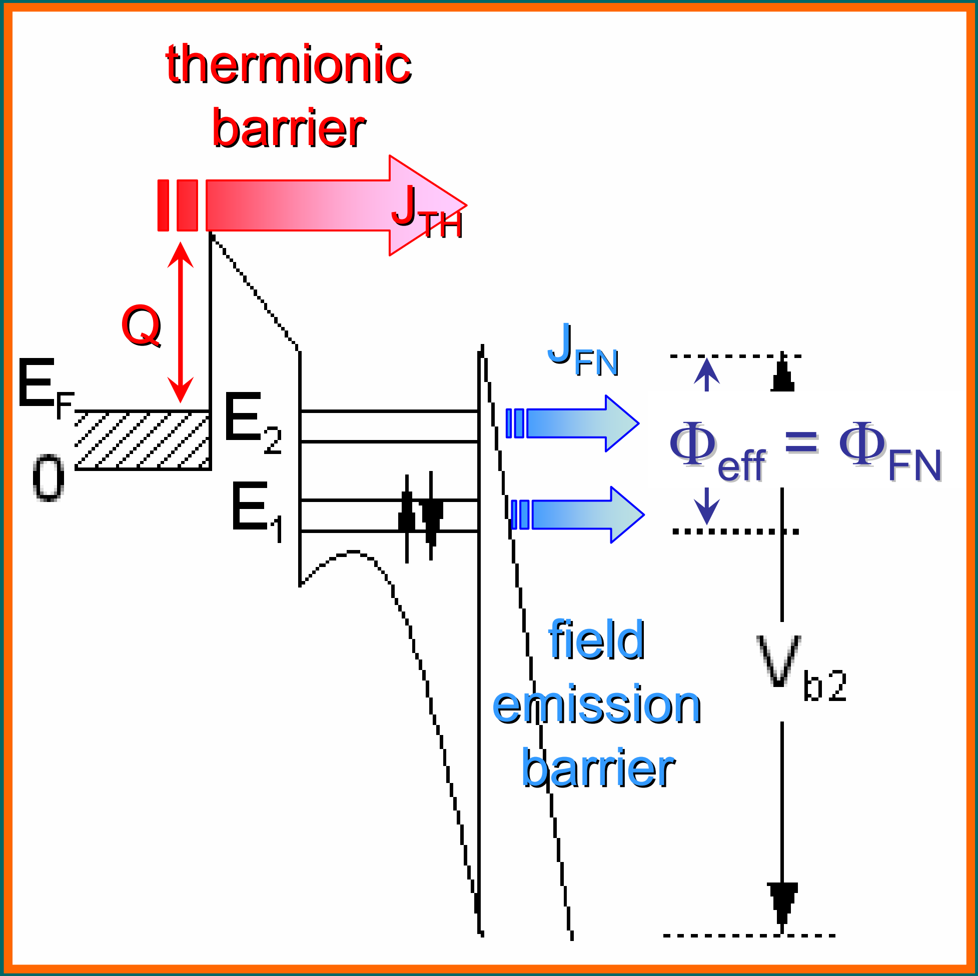
$$J_{TH} = A_2\,T^2 \exp\left(-\,Q / k_B T\right)$$





Emitting point 1				
T (K)	298	349	383	433
Φ_{FN}(eV)	0.24	0.30	0.27	0.23
Emitting point 2				
T (K)	352	383	433	463
Φ_{FN}(eV)	0.53	0.53	0.38	0.31

Nanostructured SSE cathode : dual-barrier model



Field dependence at different temperatures

$J_{FN} = A\, F^2 \exp(-B\Phi_{FN}^{3/2} / F)$

$\Phi_{FN} \sim 0.5$ eV

Temperature dependence at a given field

$J_{TH} = A_2\, T^2 \exp(-Q / k_B T)$

$Q \sim 0.9$ eV

In this dual-barrier model, the measured total emission current, J_{mes}, will be the sum of both contributions, $J_{mes} = J_{FN} + J_{TH}$

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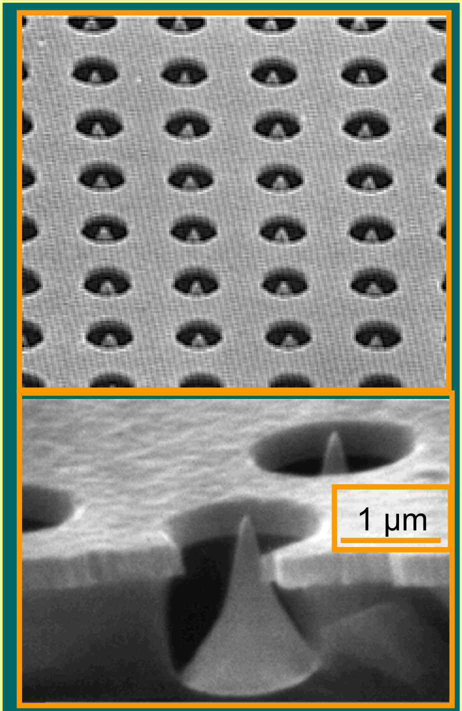
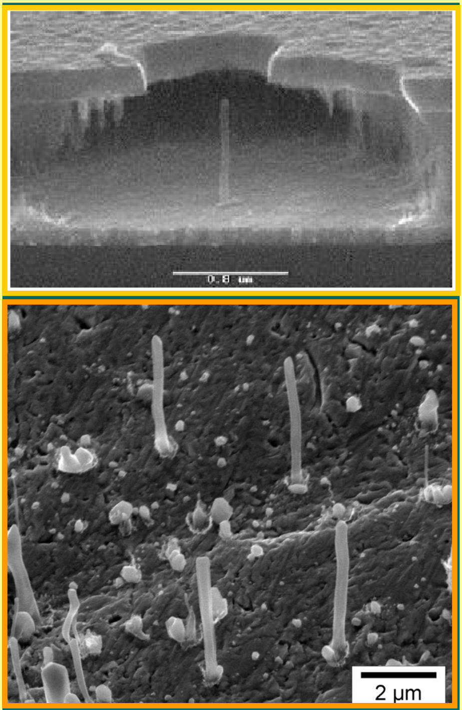
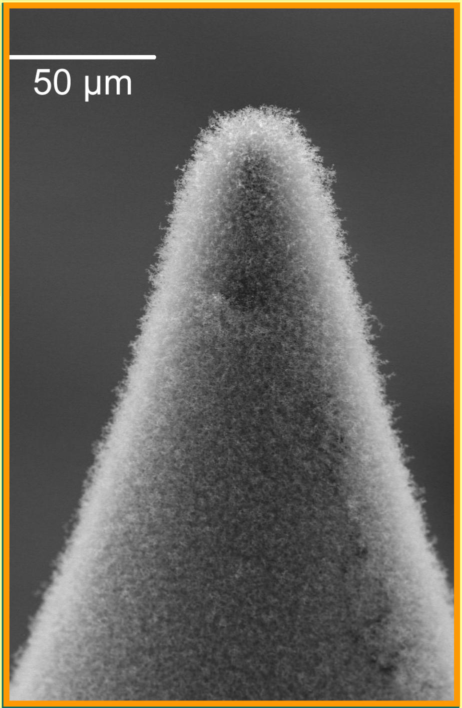
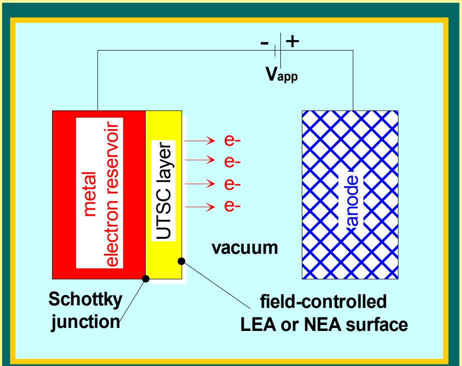
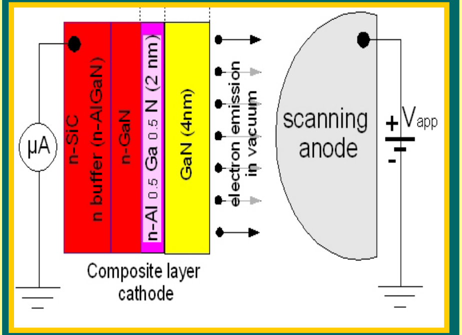
Conclusions and Applications

Spindt-type (1968,1980)	Carbon nanotubes (1991, Lyon 1999)	Carbon nanopearls (Lyon 2003)	SSE cathodes (Lyon 1999,2003)
			 
Small FED, thrusters, …….	µ-CRT, large FED, µ-X-rays tubes, (large consumer products), rf-sources, // e-beam lithography, e-gun, …….		Hard-working environment devices, local cooling, e-microscopy, …..

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Conclusions and Applications

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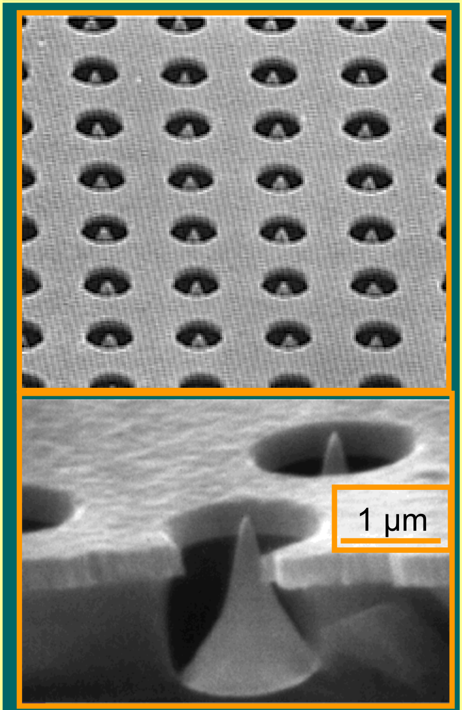
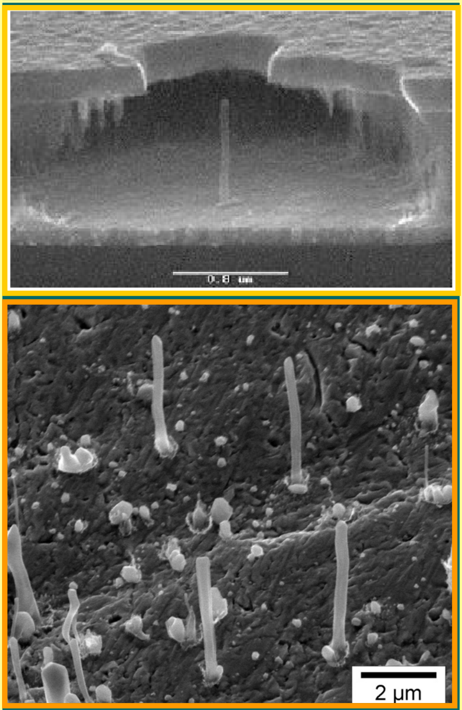
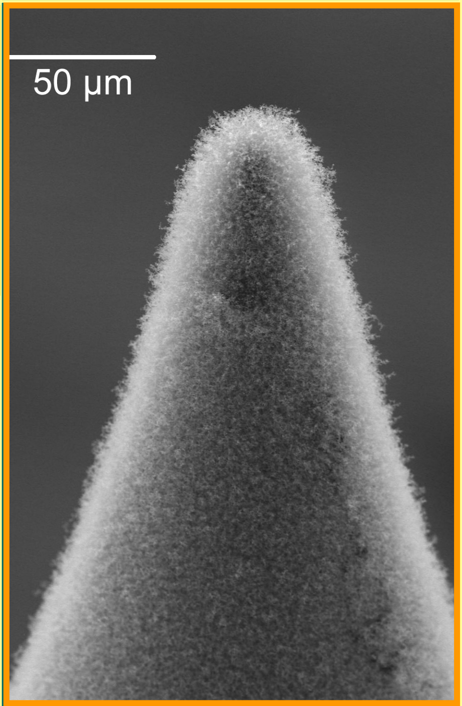
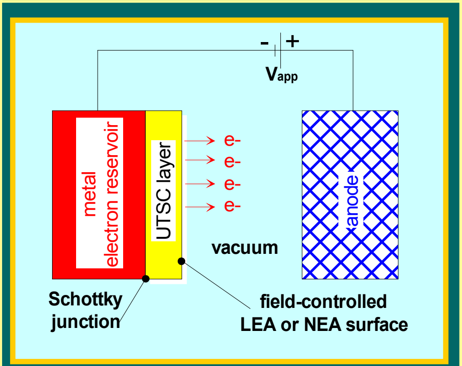
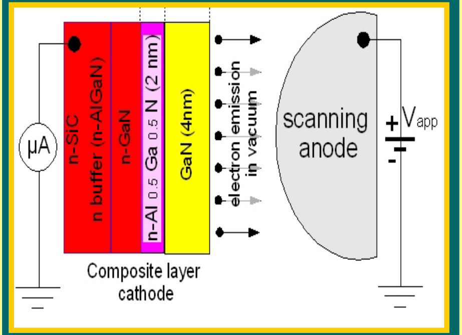










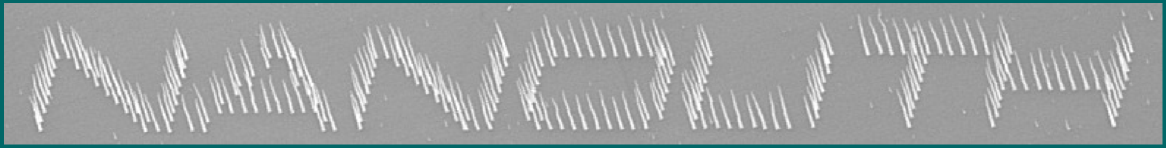
3-D lithography

CVD technology

2-D deposition technol.

Stable emission under medium or bad vacuum conditions

Remerciements



Arrays of microguns for parallel e-beam lithography

THALES

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Nanopage

6è PCRD

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SAES, TUB, FGH-IGE, FGH-IPA,
IMEC-Gent, IMEC-SPIN-OFF, BARCO, M-Sharp

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Merci de votre attention !