Electron sources based on the field emission properties of carbon nanotubes systems organized at micro- and meso-scopic scale

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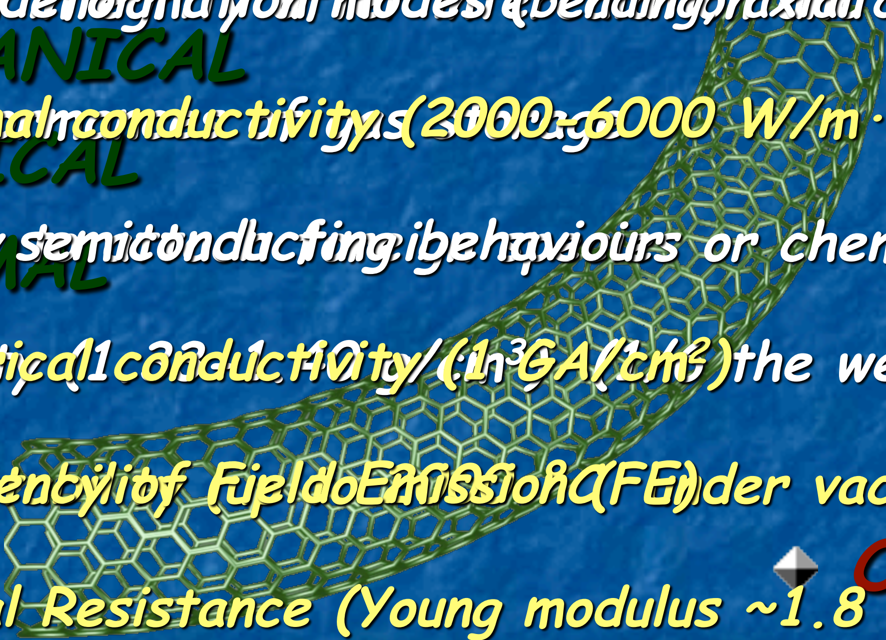
Carbon Nanotube (CNT) properties

- Breaking strength 13-50 GPa (at strain of 6%)
- ELECTRONIC
- Reversible deformation modes (bending, axial compression, torsion)
- MECHANICAL
- High thermal conductivity (2000-6000 W/m·K)
- CHEMICAL
- Metallic or semiconducting behaviours [illegible] or chemical groups
- THERMAL
- High electrical conductivity (10^{9} A/cm^{2}) [illegible] the weight of steel)
- High efficiency of Field Emission (FE) [illegible] under vacuum)
- Mechanical Resistance (Young modulus ~1.8 TPa)



- OPTICAL
- MAGNETIC
- SPINTRONICS

CNT Based Cold cathodes

- Room temperature
- No Ultra-High Vacuum (10^{-7} – 10^{-6} mbar)
- Low threshold electric fields
  - Potentials for miniaturization
  - Vacuum microelectronics (nanotriodes, nanoklystron)

- Fast response time
  - High-frequency applications (>1 THz)
  - Efficient electron beams bunching

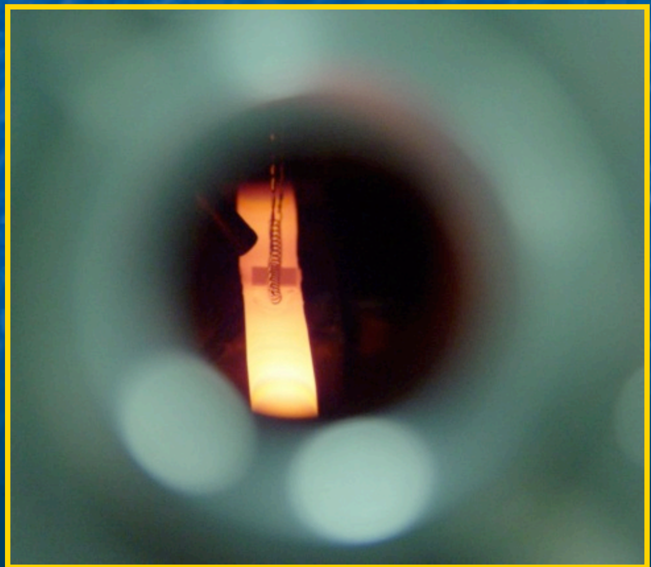
- Highly collimated beams
- Narrow Energy Spectrum of electrons
  - Electron microscopy
  - X-ray microscopy

- Covalent crystalline structure
- Chemical inertness
  - Harsh work conditions

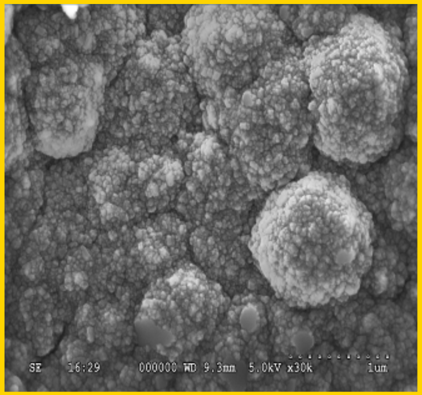
CVD Reactors (Chemical Vapour Deposition)

Hot Filament CVD (HFCVD)

MicroWave Plasma Enhanced CVD (MWPECVD)

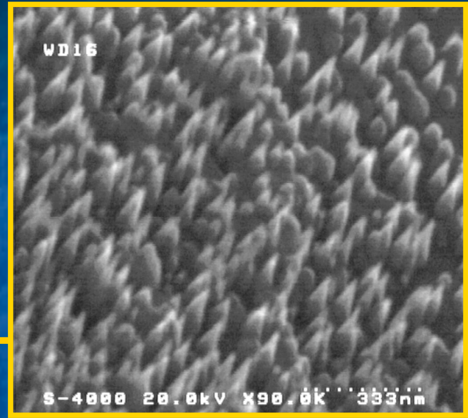


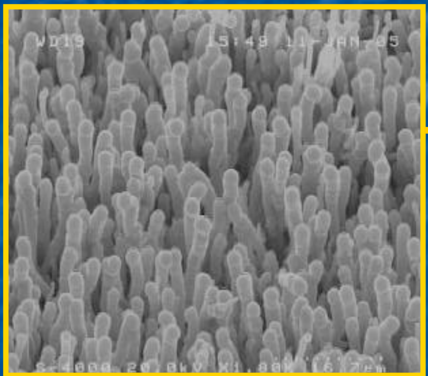
Nanomaterials synthesized



Doped diamond films

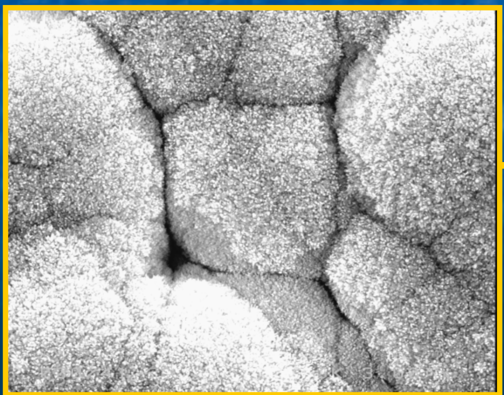
Diamond Nanocones





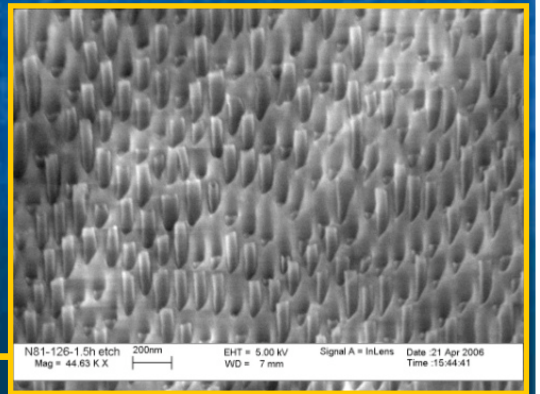
Carbon Nanotubes (CNT)

CNT + Nanodiamond



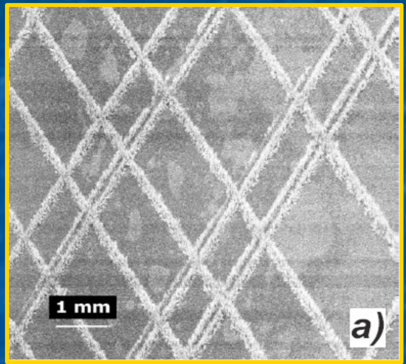
TiO_2 coated CNT

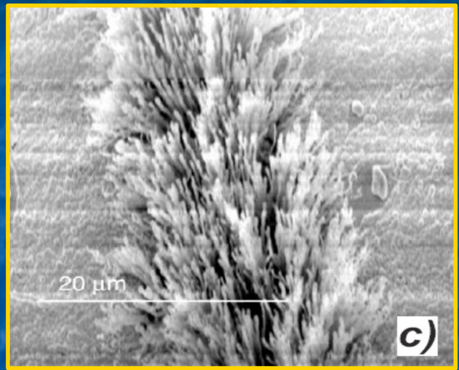
CNT in Al_2O_3 template

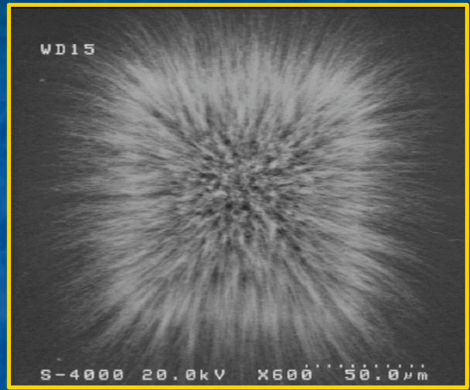


Single Wall Carbon Nanotubes (SWCNT)

Planar patterned substrates

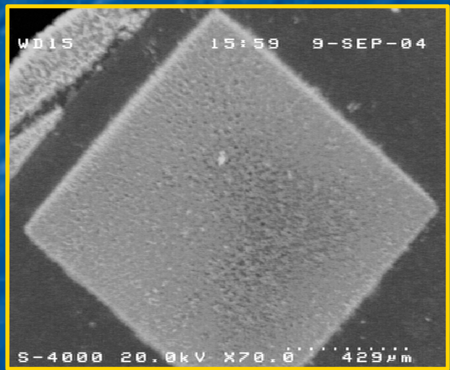


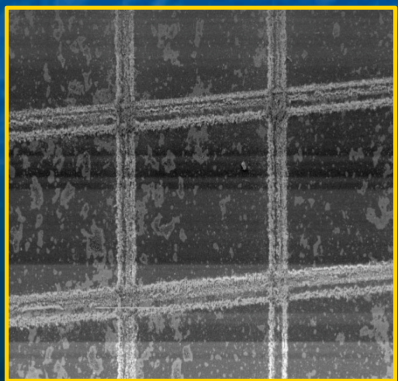


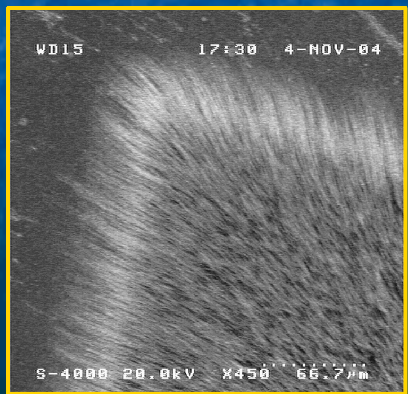


Substrate: Si/SiO_2

Catalyst: Fe/Ni

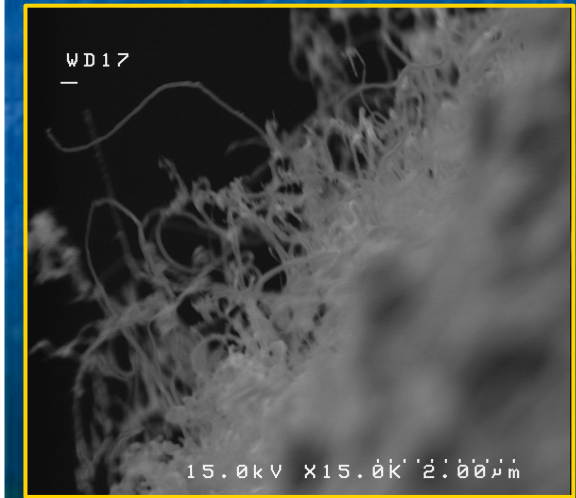




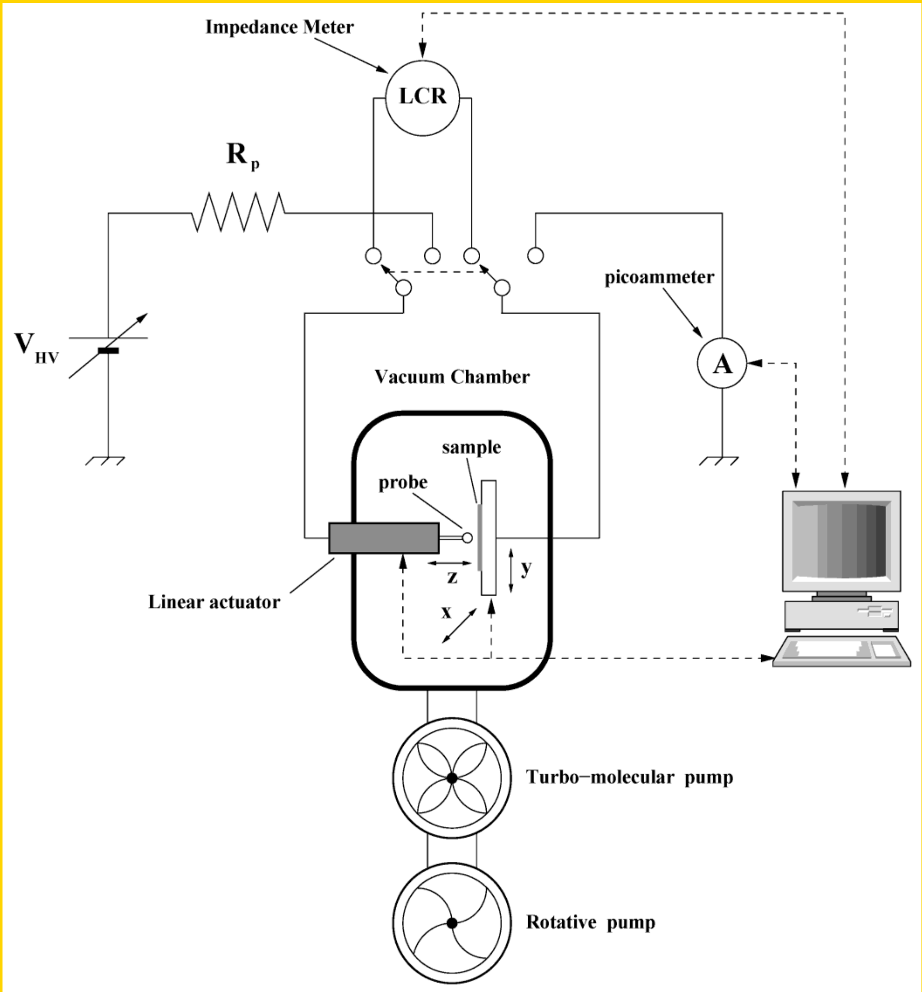


SWCNT coated wires and tips

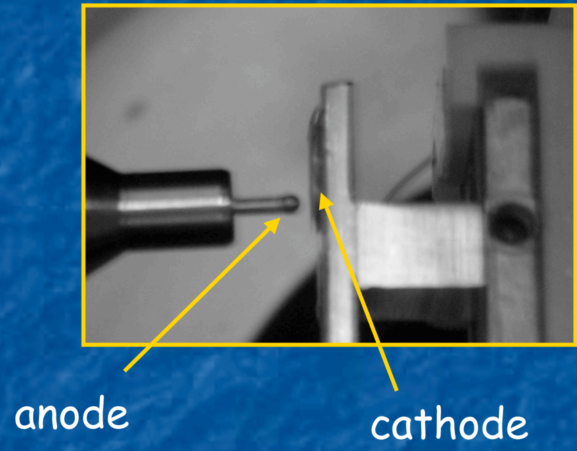
Wires of W (Ø = 300 µm), Ta (Ø = 300 µm), Steel (Ø = 300 µm)
W tips (Ø = 100 µm)



Field Emission set-up (1/2)



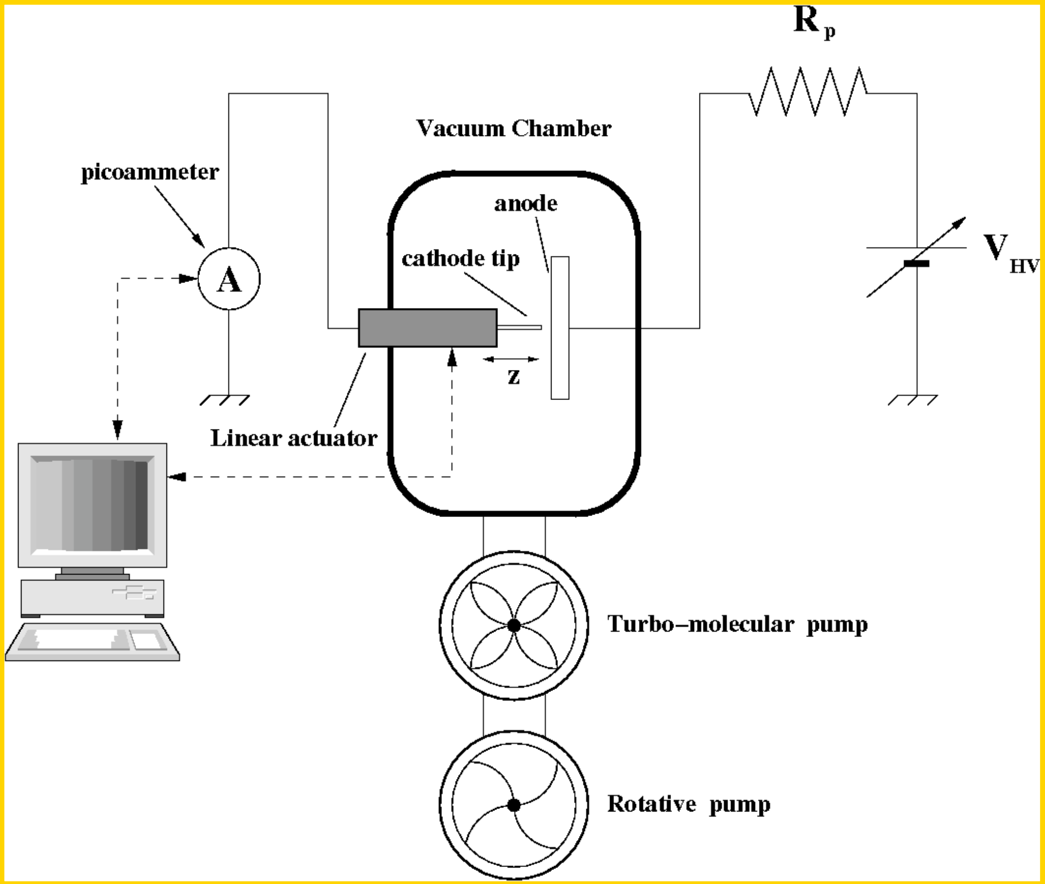
Spherical probe (anode)
Planar sample (cathode)

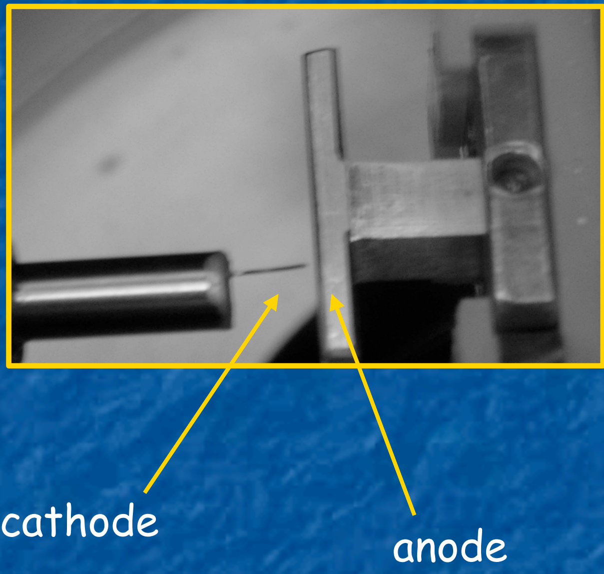


- Pressure 10^{-6} -10^{-8} mbar
- Max applied voltage: 2 kV
- Picoammeter Resolution : 10 fA
- Protection ballast resistor : 100 MΩ
- Linear actuator accuracy: 0.1 μm
- Distance measured by a capacimetric method

Field Emission set-up (2/2)

SWCNT coated wire/tip (cathode)
Planar anode

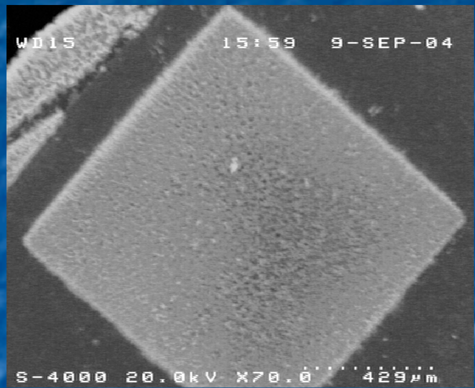


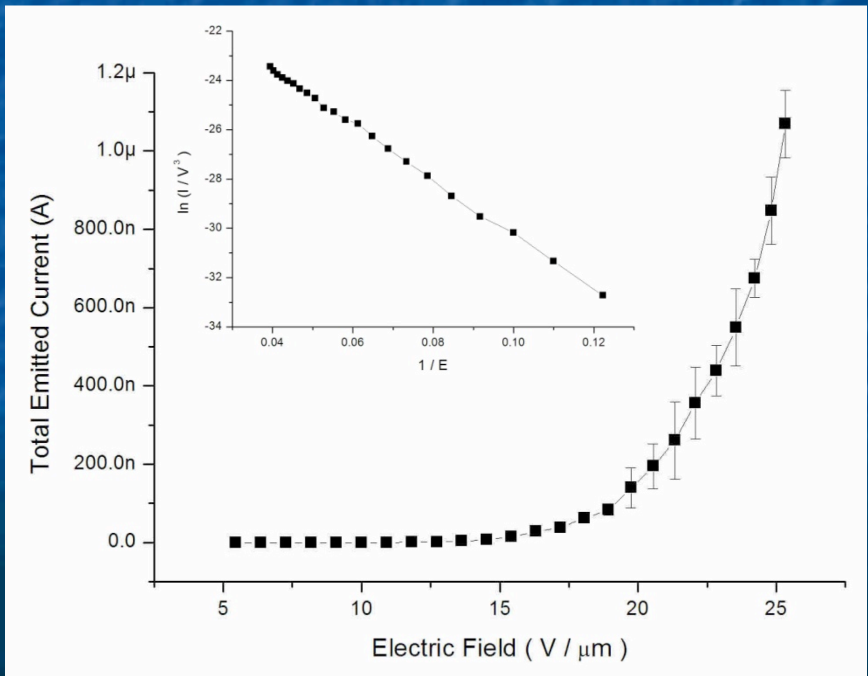


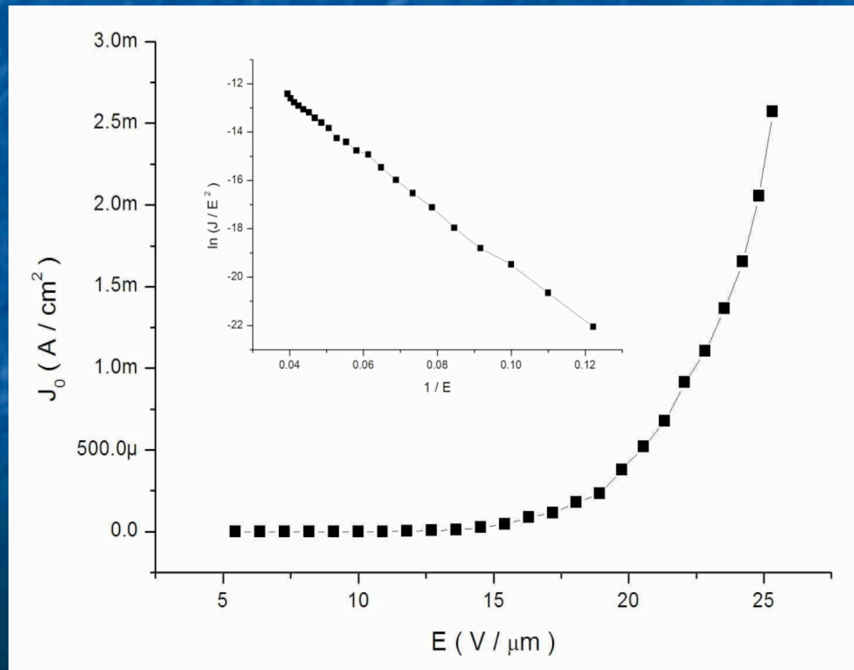
- Pressure: 10^{-6} - 10^{-8} mbar
- Max applied voltage: 2 kV
- Picoammeter Resolution : 10 fA
- Protection ballast resistor : 100 MΩ
- Distance: ~ 1 mm

Aligned SWCNT on planar substrates

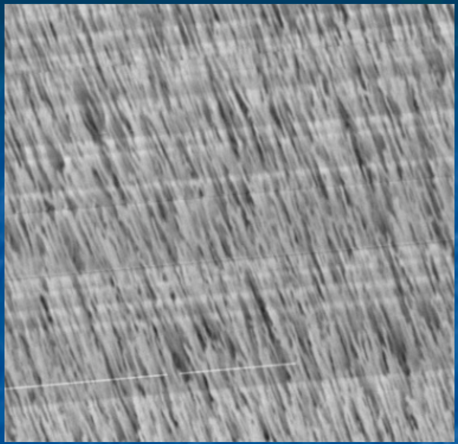
Threshold electric field E(I = 1 nA) = 12 V/μm







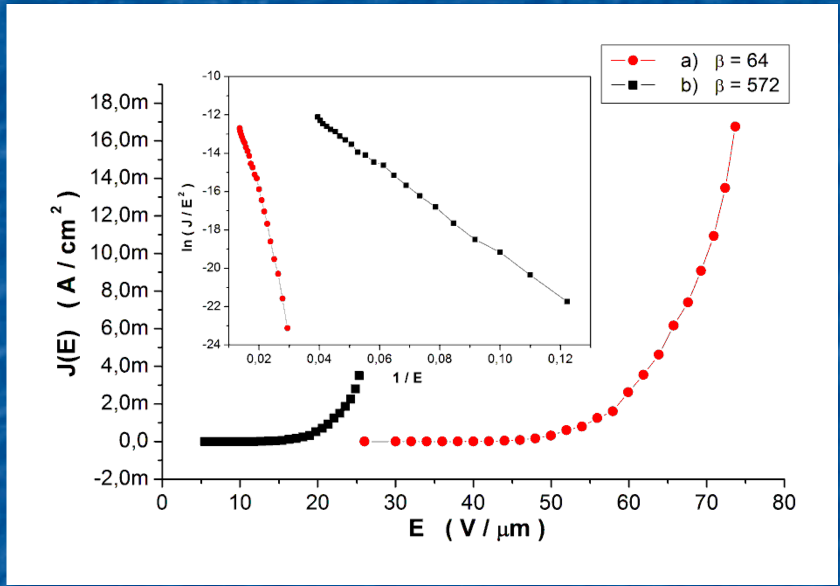
Dependence on morphology

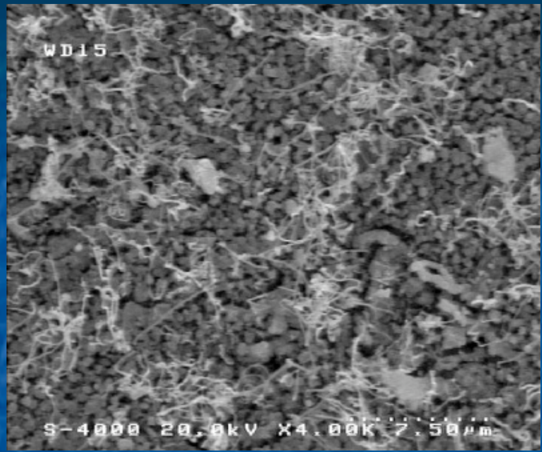


a) Dense, aligned SWCNT bundles

$\beta_a = 64$

$d_a = 25\ \mu m$





b) Sparse spaghetti-like SWCNT bundles

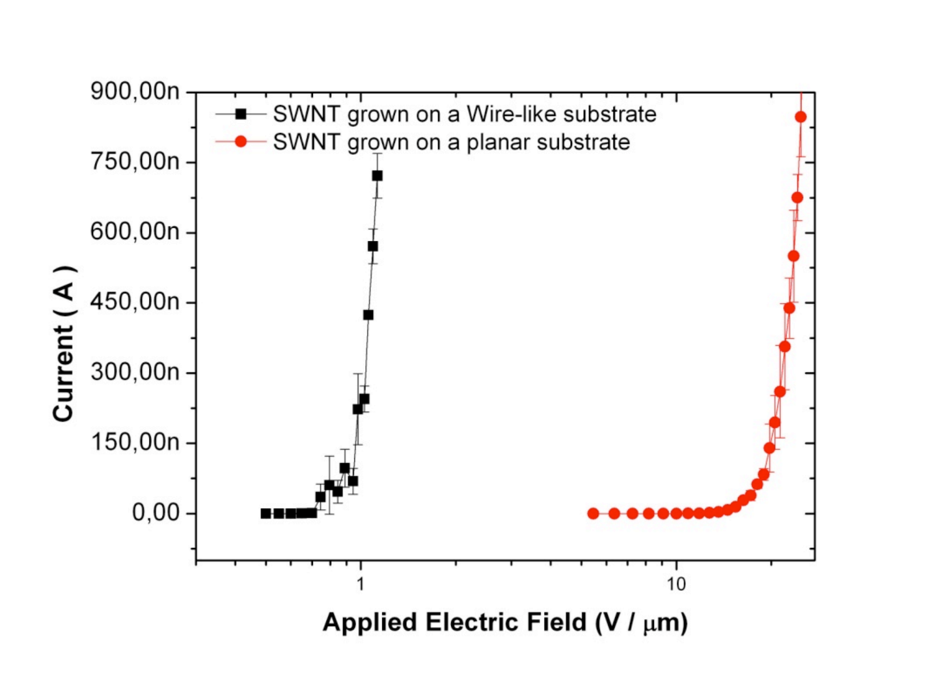
$\beta_b = 572$

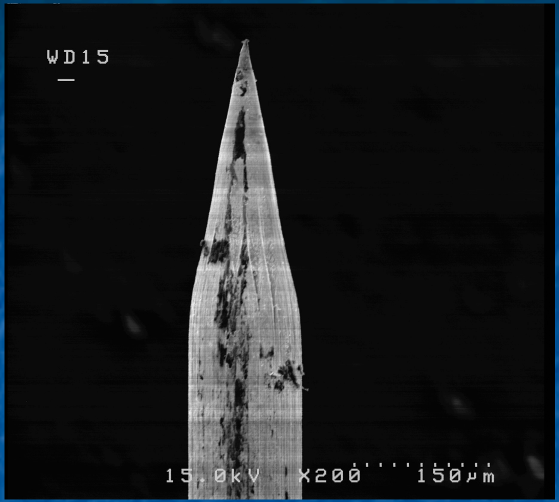
$d_b = 55\ \mu m$

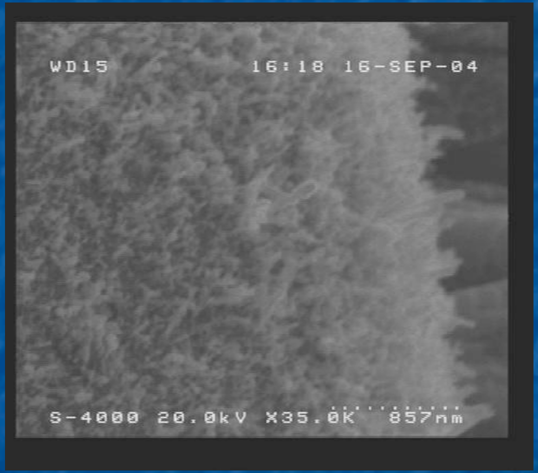
- Fowler-Nordheim behavior (slight deviation at highest fields)
- Threshold Electric fields (I = 1 nA) : 10 - 40 V/µm
- $\beta_b \cong 10\ \beta_a$ (screening effect)

Dependence on support geometry

Planar anode
Wires diameter: 100-300 μm

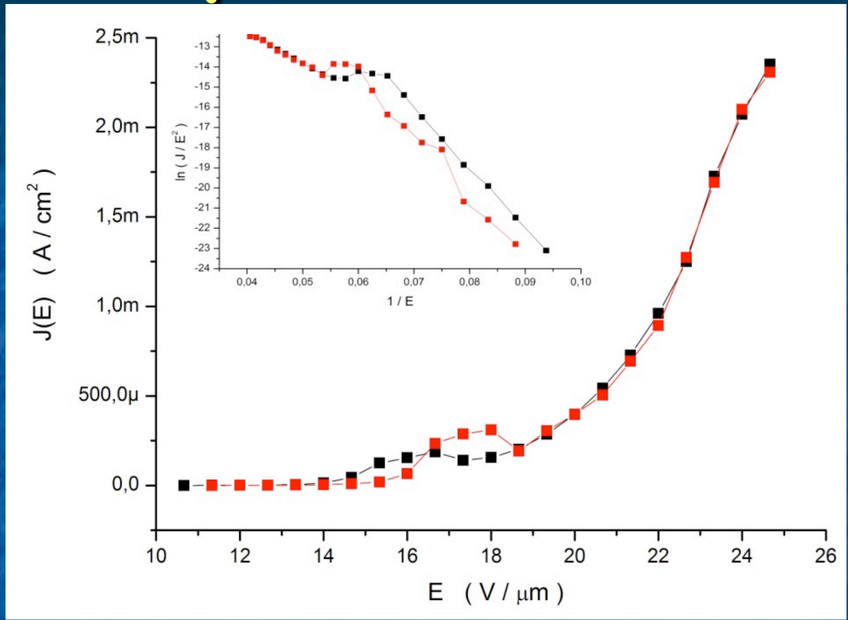


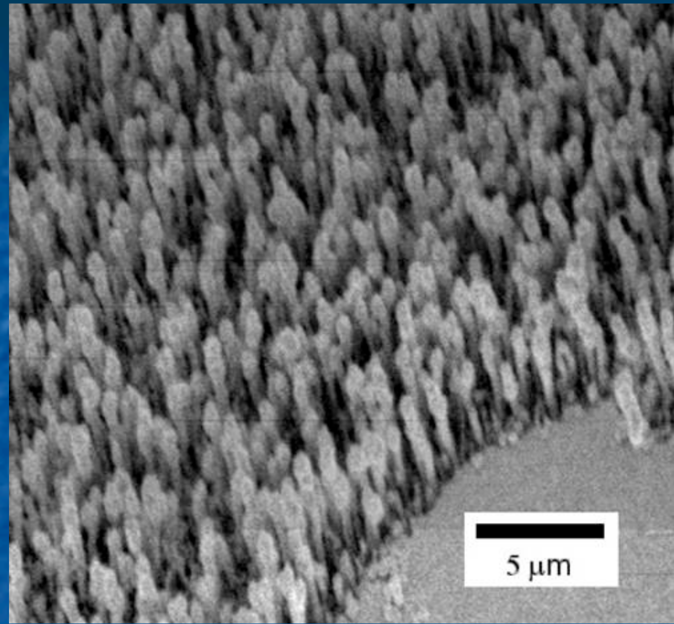


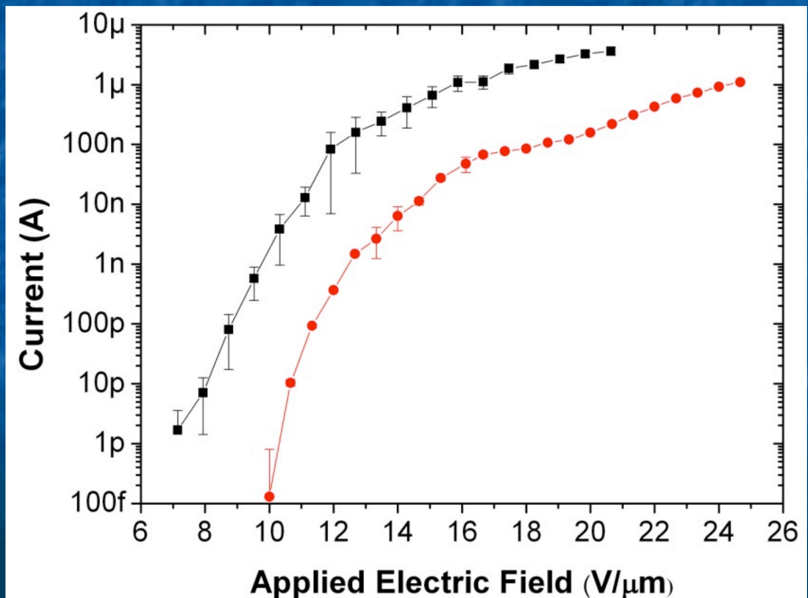


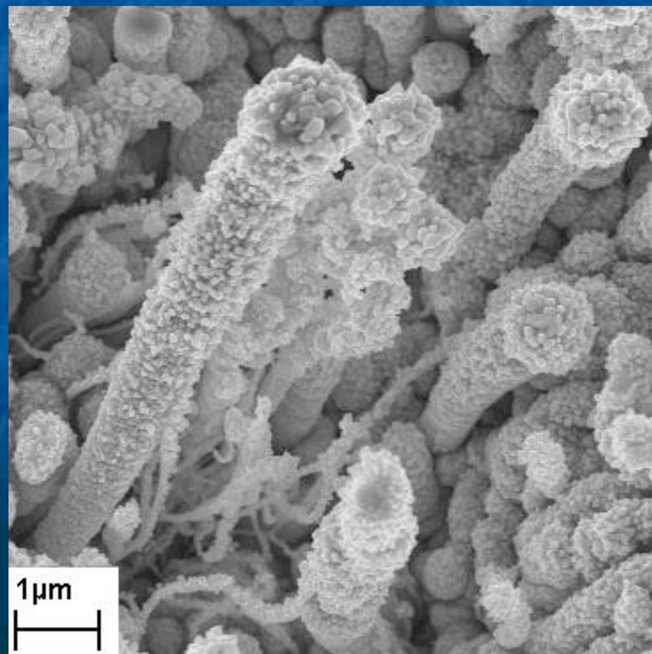
- Planar supports vs. SWCNT coated needles
- β increased by one order of magnitude: >10^3
- Threshold field (I = 1 nA) reduced by one order of magnitude

Hybrid CNT-nanodiamond structures



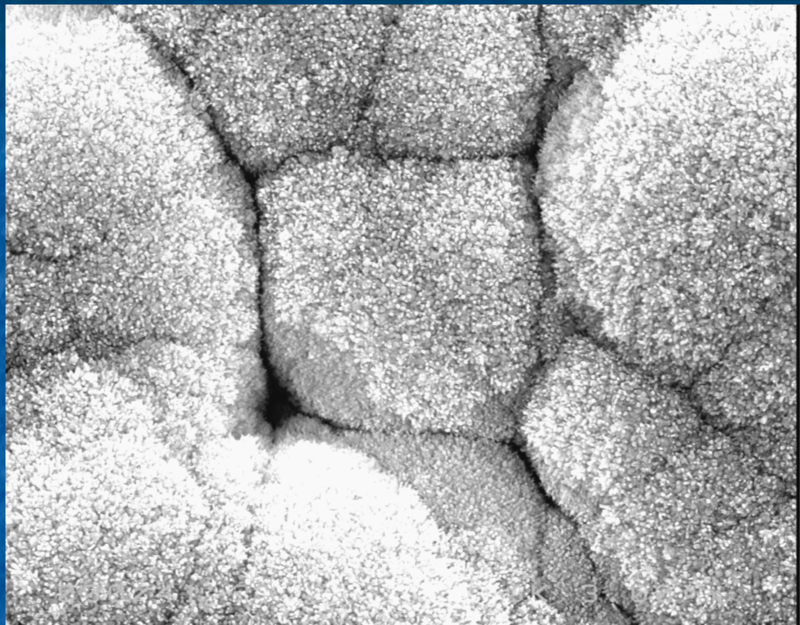


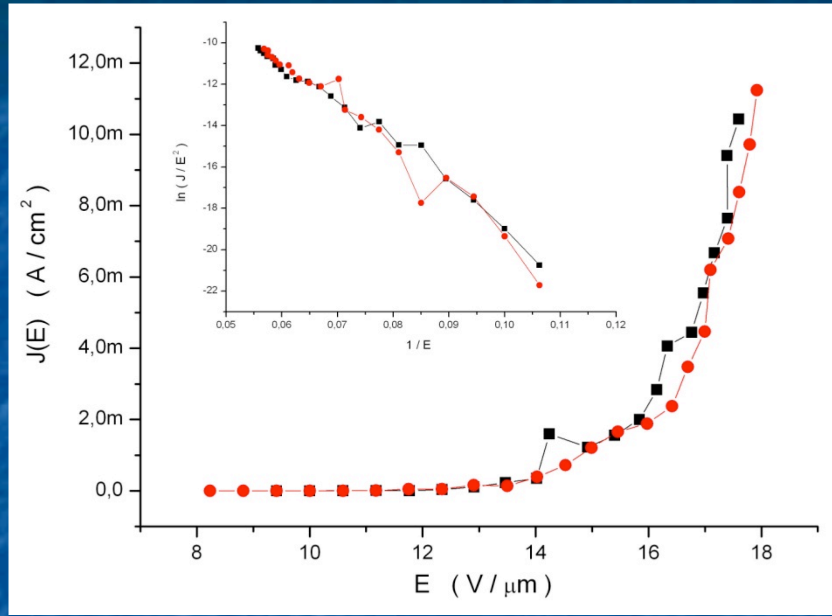


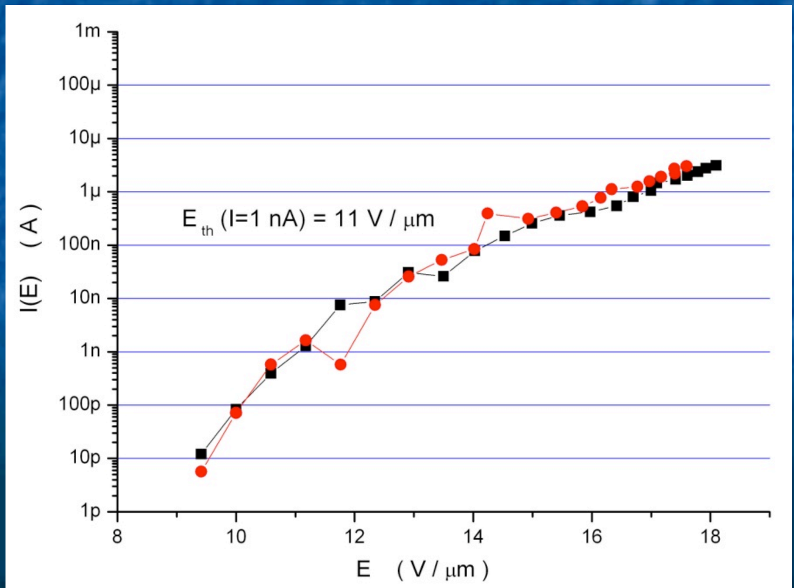


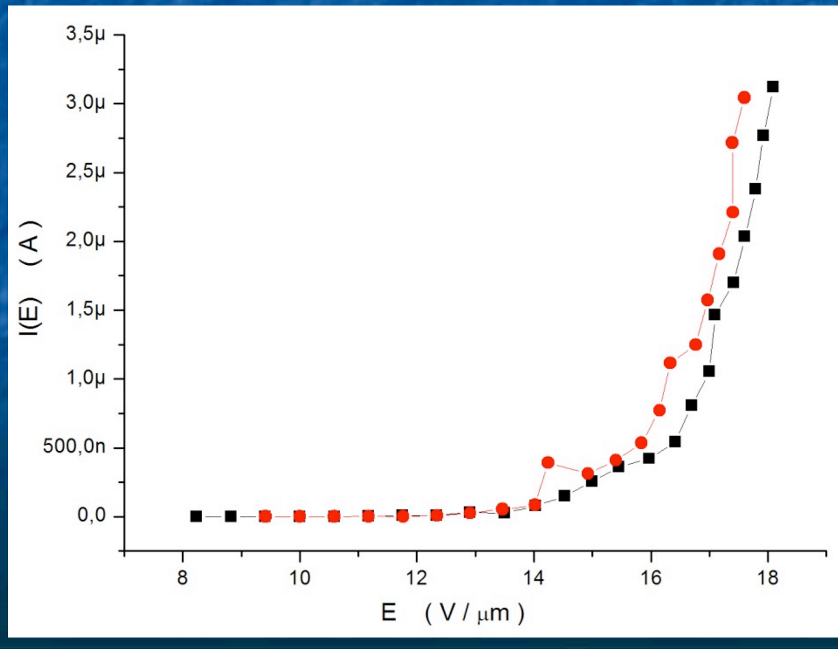
Emission from different regions: E(1nA)=9-13 V/µm

TiO_2 coated CNT

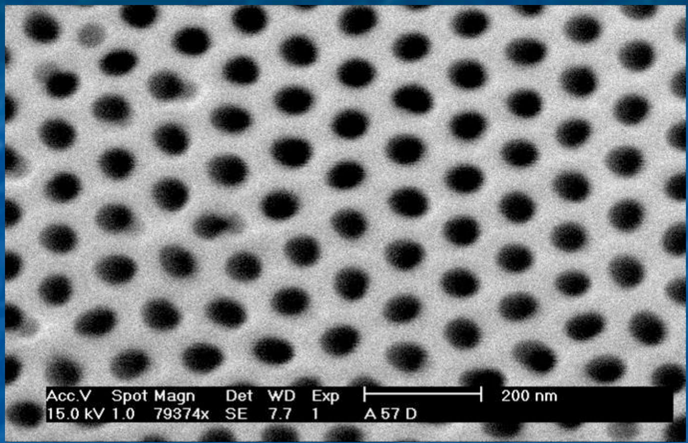


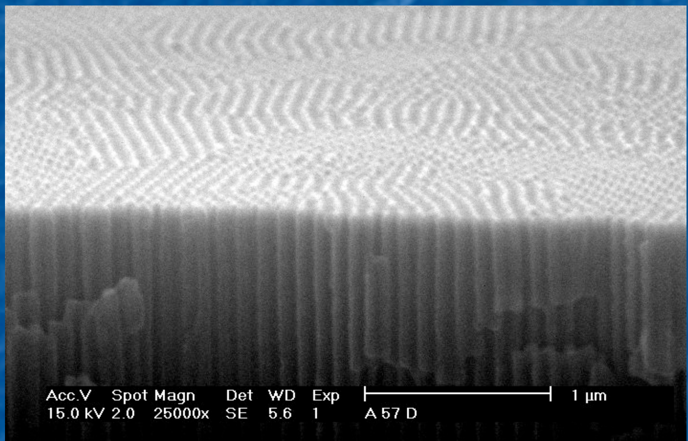




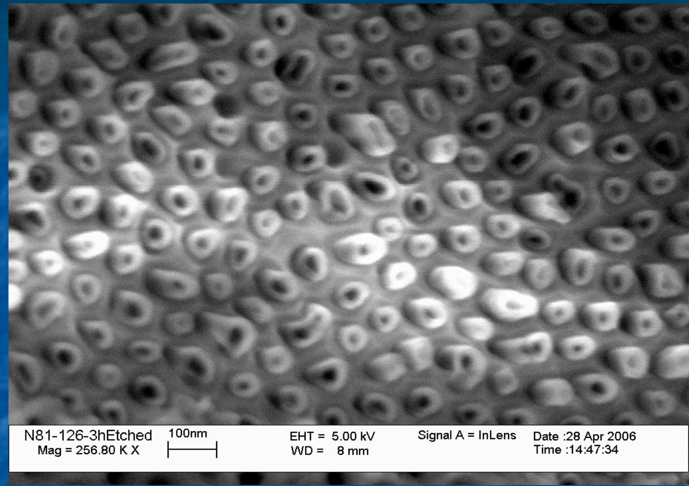


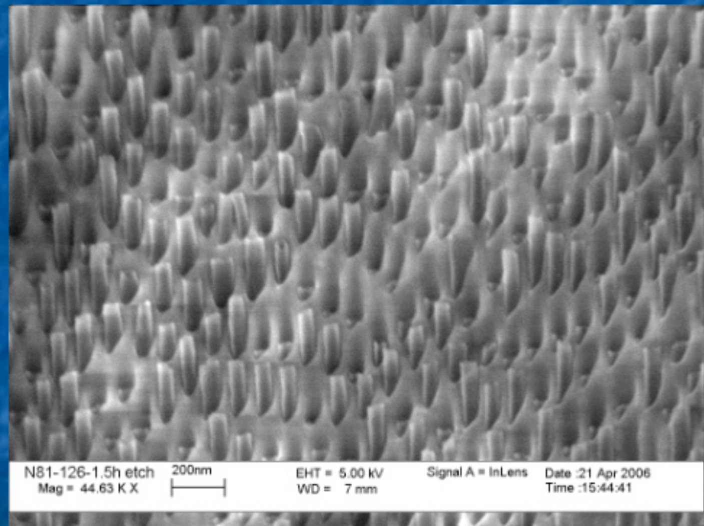
CNTs in nanoporous Al_2O_3 template (1/2)





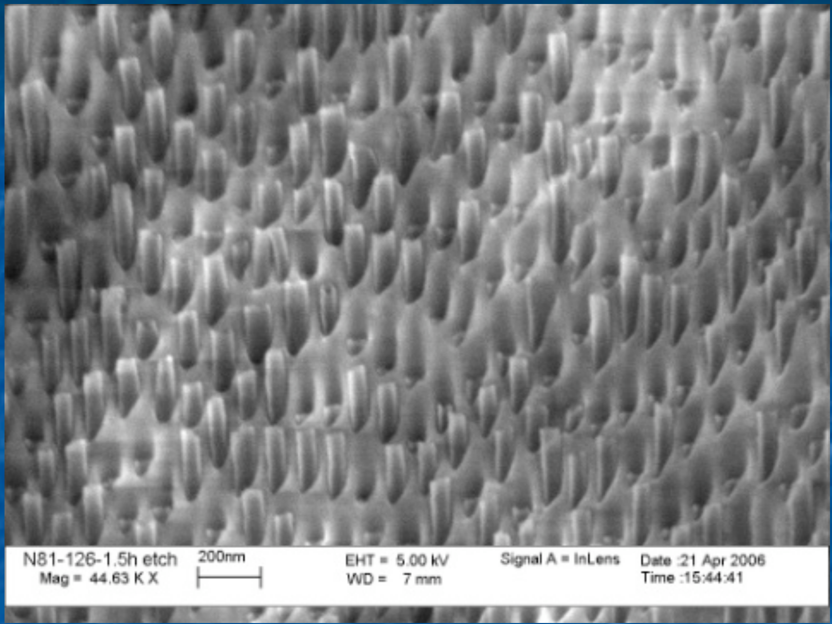
Nanoporous Al_2O_3 template

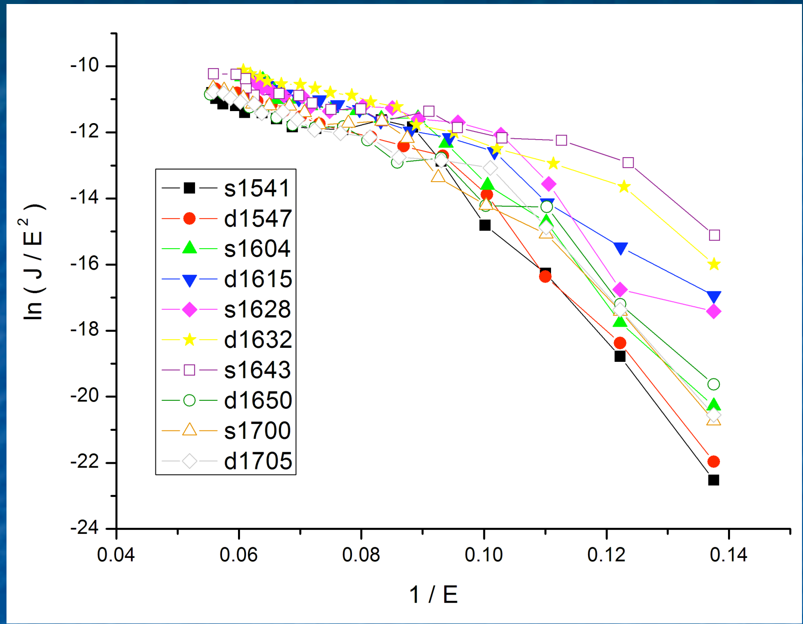


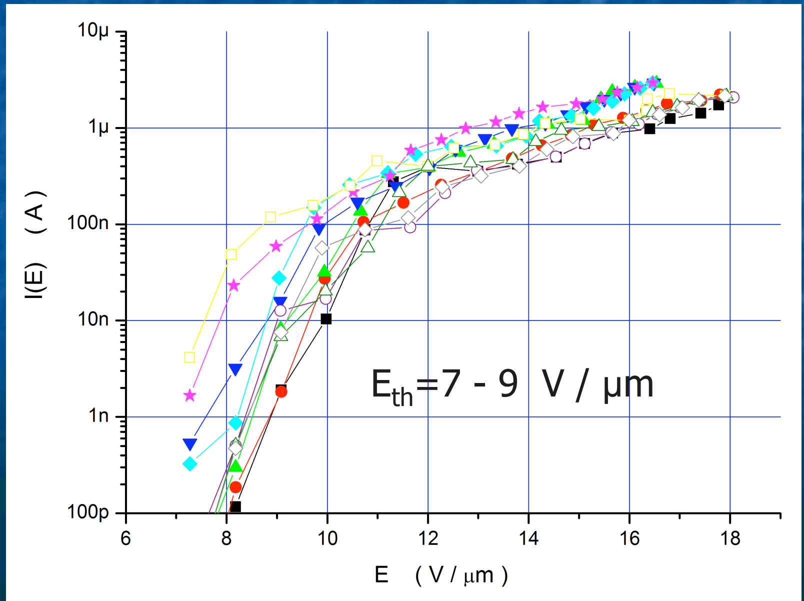


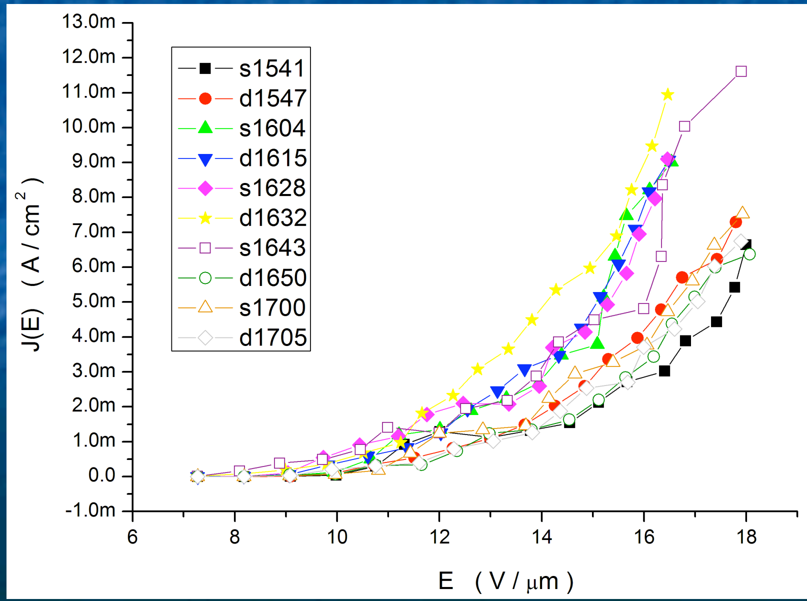
CNTs grown inside the nanopores and exposed by partial template etching

CNTs in nanoporous Al_2O_3 template









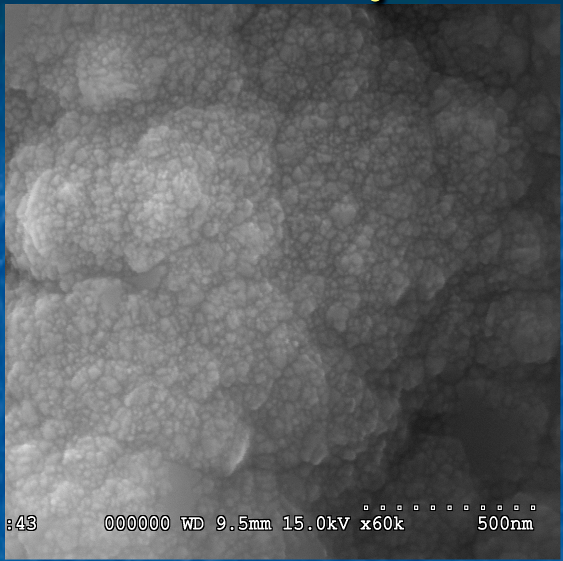
Work in Progress…

- Electron sources for plasma reactors and Electron-Cyclotron-Resonance Ion Sources (INFN-CANTES project)

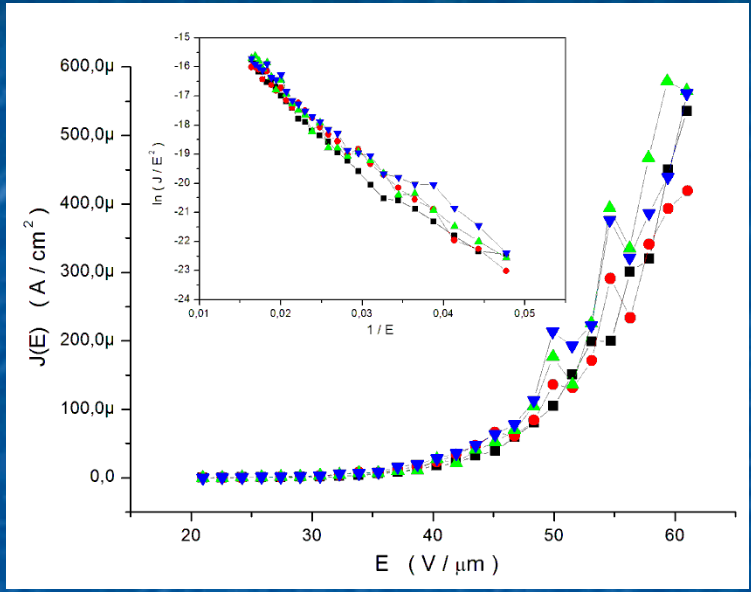
- Miniaturized X-ray high resolution sources (NANORAY project, FP7-SME-2007)

Thanks for your attention !!!

N2-doped nanodiamond Film



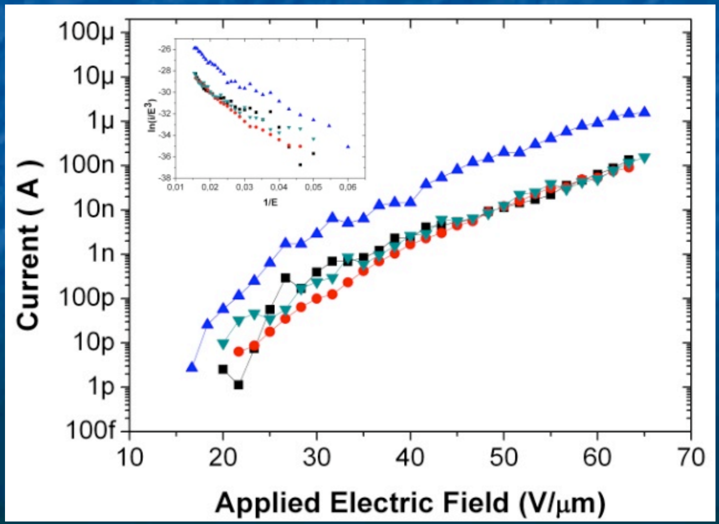
Emission from different regions

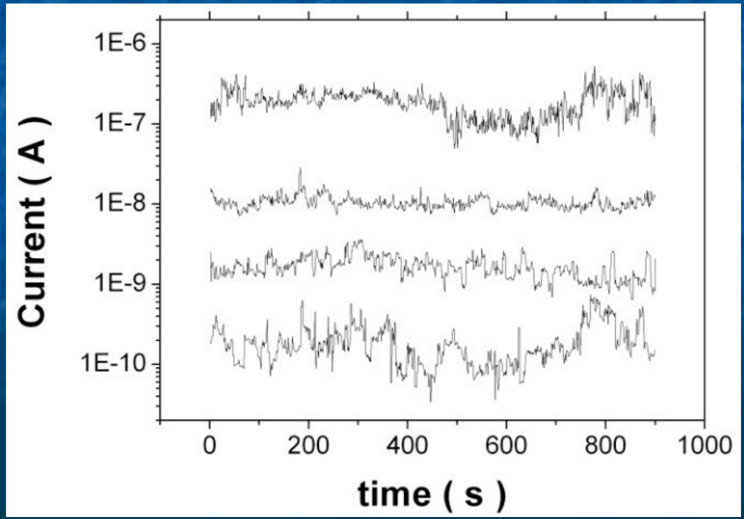


Diamand: 88%

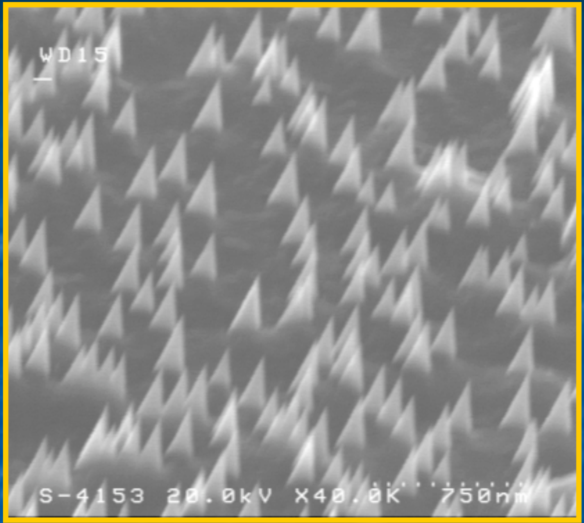
E(1 nA) = 25-30 V/μm

Current stability

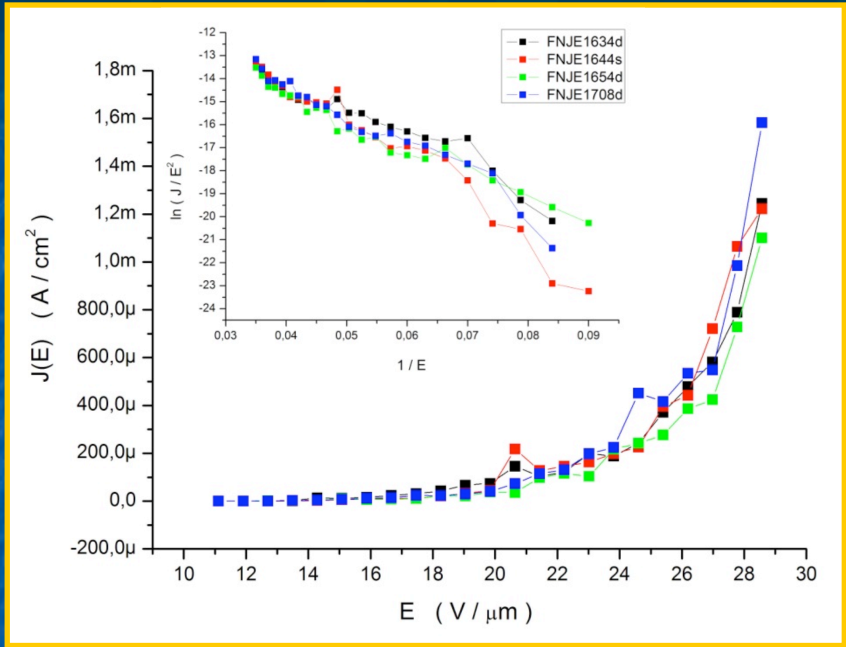


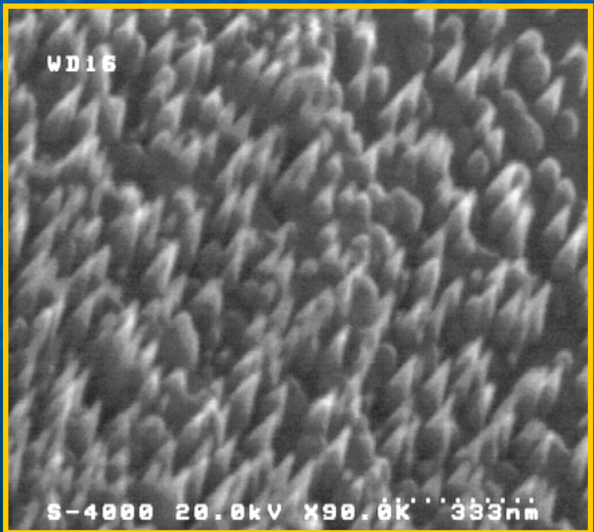


Diamond nanocones

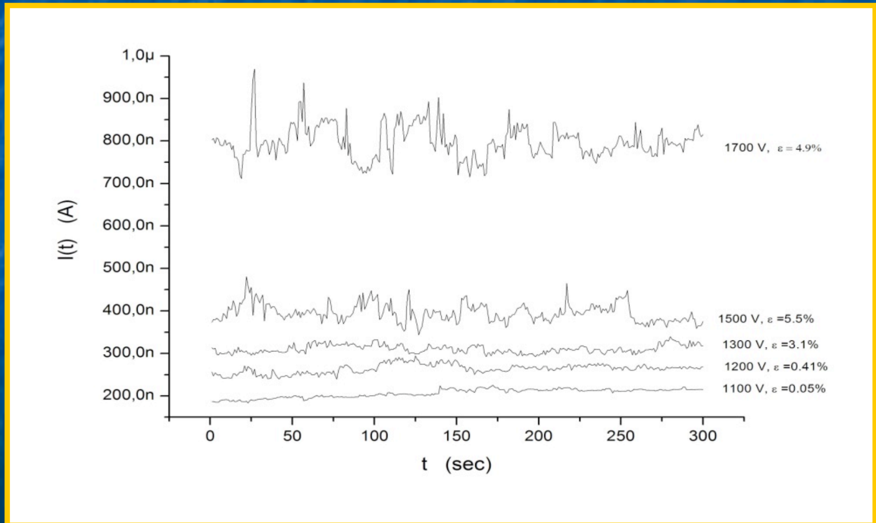


E(1nA) = 15 V/μm





E(1nA) = 20 V/μm



Current at different voltages