Carbon nanotubes based cold cathodes and channeling phenomena for a new generation of X-rays systems

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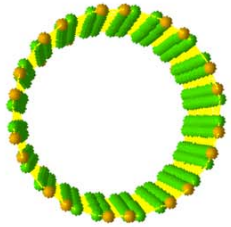
http://minima.stc.uniroma2.it

"Channeling 2010"

Ferrara, 3-8 October 2010

Carbon Nanotubes (CNTs) Properties

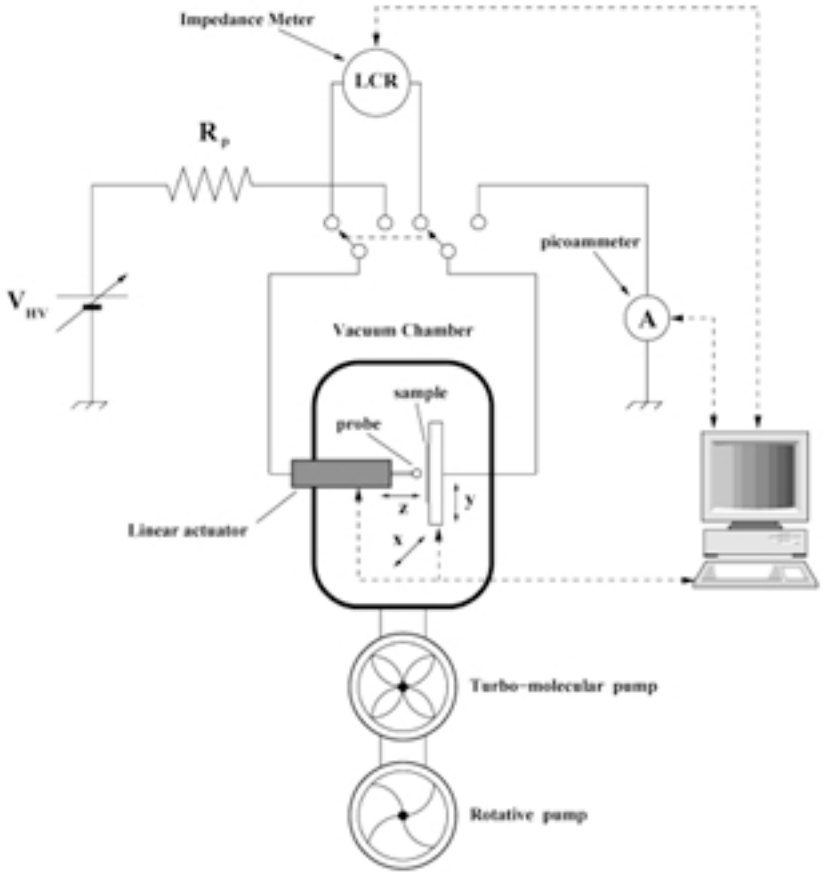
- *High chemical stability (inertness)*
- *Structural integrity after intercalation and de-intercalation*
- *High performances of gas storage*
- *Feasibility to attach chemical groups/species*
- *Thermal stability (up to 2000 °C under vacuum)*
- *Mechanical Resistance (Young modulus ~1.8 TPa)*
- *Breaking strength: 13-50 GPa (a strain of 6%)*
- *High thermal conductivity (2000-6000 W/m·K)*
- *Metallic or semiconducting behavior*
- *High electrical conductivity (1 GA/cm^2)*
- ***High efficiency of Field Emission (FE)***

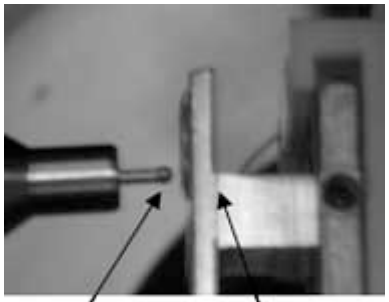


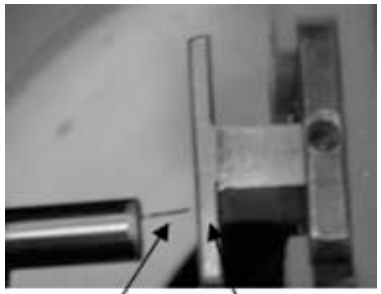
CNTs based Cold Cathodes

- *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 working conditions*

Field Emission apparatus @ Tor Vergata







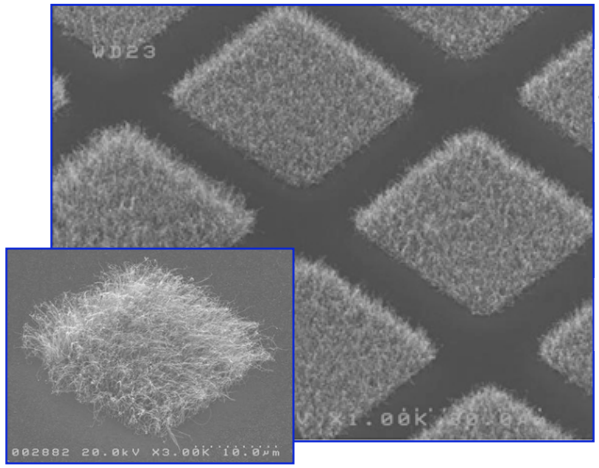
- Working pressure: 10^{-6} – 10^{-8} mbar
- Max applied voltage: ± 2kV
- Picoammeter resolution: 10fA
- Linear actuator accuracy: 0.1μm
- Anode/cathode distance evaluated by a capacimetric method

Fowler-Nordheim law

$$I = \frac{e^3}{8\pi h} \cdot \frac{\beta^2 E^2}{\phi} \exp\left[-\frac{4\sqrt{2m_e}}{3e\hbar} \cdot \frac{\phi^{3/2}}{\beta E} \right]$$

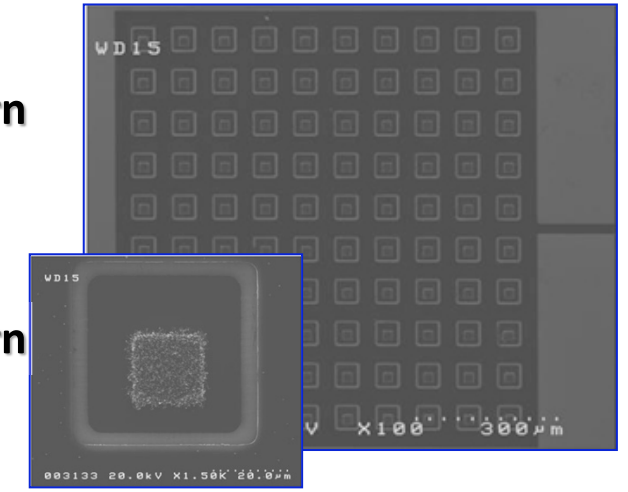
Carbon nanotubes on planar substrates

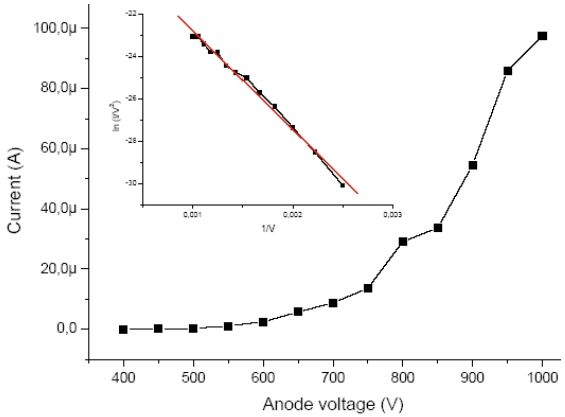
- Synthesis technique: Hot filament Chemical Vapor Deposition (CVD)
- Substrate: Si/SiO_2
- Catalyst: Ni/Ti



20X20 μm squared pattern

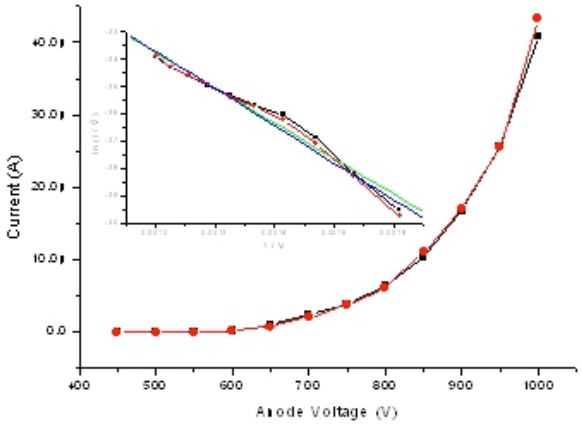
10X10 μm squared pattern



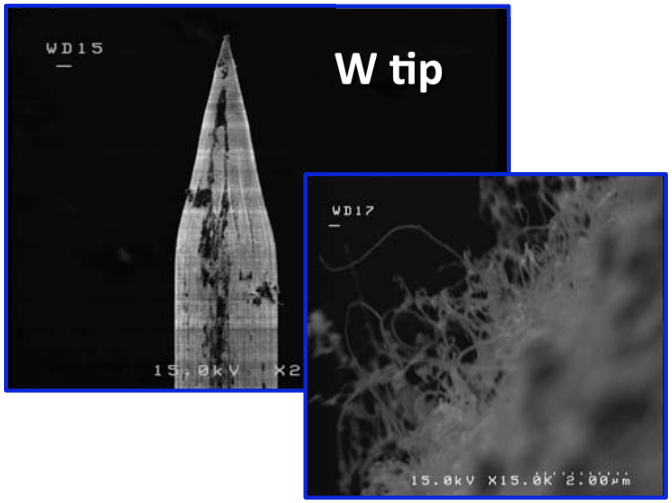


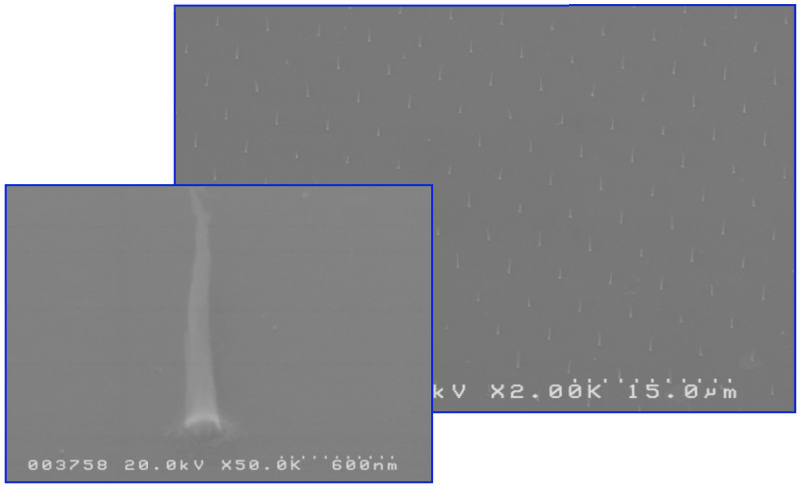
- Fowler-Nordheim behavior

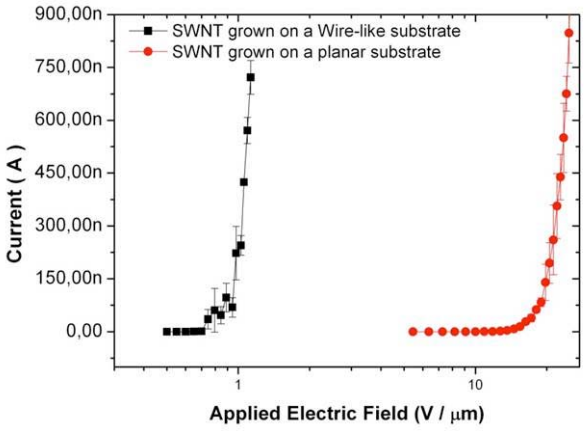
- High values of current

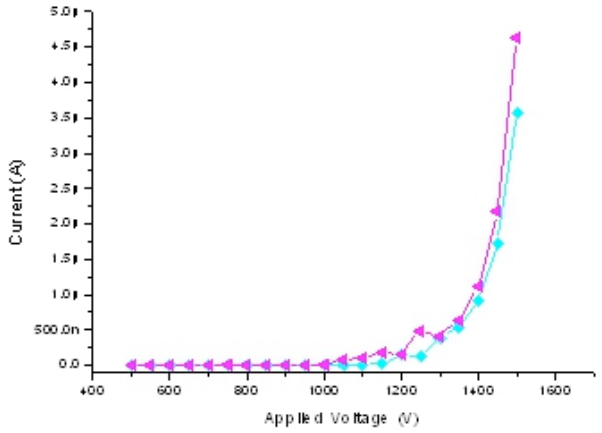


CNTs coated tips & CNTs based tips









- Increasing of enhancement factor (β)
- Reducing of threshold field by 1 order of magnitude
- Stable emission of current
- Lower values of current vs micrometric CNTs arrays

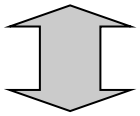
http://www.nanoray-project.eu/index.html

NANORAY: *"Development of a X-Rays tube based on the Field Emission properties of Carbon Nanotubes"*

NANORAY is an innovative device capable to generate X-rays by means of a novel concept of cold cathode, based on CNTs selectively grown upon ad-hoc synthesized nanostructures

The most relevant features:

- A reduced focal spot (down to 0.3 mm)
- A very low power consumption (due to the use of a field-emission based cathode)
- A pulsed X-rays radiation with programmable width and repetition rate
- A long life-time



Portable system (overall weight of less than 5 kg including power supply)

Higher image resolution thanks to the smaller focal spot

Effective solution for economic issue related to maintenance of thermionic cathodes

NANORAY Consortium

Ioffe Physical Technical Institute

nanocyl

SAPIENZA UNIVERSITÀ DI ROMA

LABOR
Laboratorio di ricerca industriale

NT-MDT
INTEGRATED SOLUTIONS FOR NANOTECHNOLOGY

SELEX Sistemi Integrati

METRIS

SINEUROP Nanotech GmbH

UNIVERSITA' degli STUDI di ROMA TOR VERGATA

TECNA

Project Objectives

First X-rays imaging systems developed more than 100 years ago but little developments in this technology

→ **Electron source is the most critical component!!**

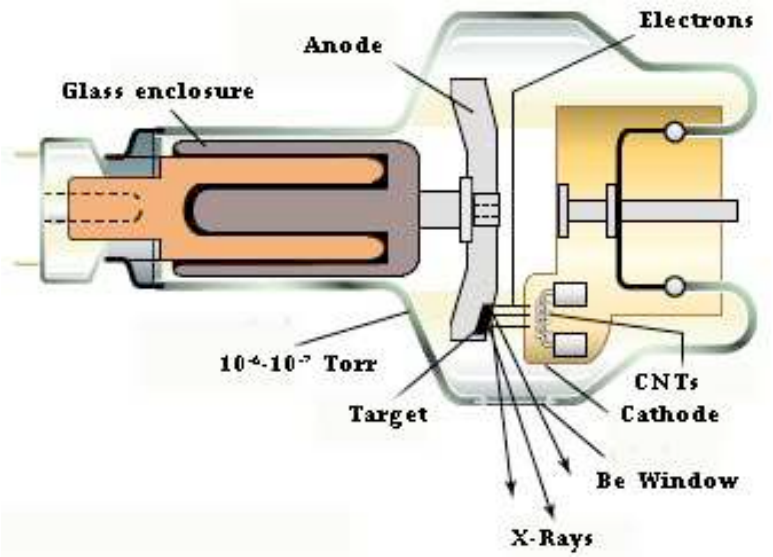
Nowadays breakthrough in X-rays devices is required in terms of reliability, cost effectiveness and performances

→
- **medical diagnostic devices**
- **archaeometric spectrometry**
- **fluorescence spectrometry**
- **security**
- **quality control in electronics, aerospace, mechanics…**

Drawbacks

Heat generation
Power consumption
Out-gassing
Thermal inertia/drift
Slow response times
High maintenance costs vs relatively short life cicles of electron sources

NANORAY device's scheme



- ***Technical target***:

NANORAY system will be basically a CNTs based microfocus X-rays tube, using field emission cold cathode with one focusing electrode

- ***X-rays generation:***

field-emitted electrons will be accelerated by the anode voltage to bombard on the target (Cu will be in particular investigated as possible material)

The cold cathode will be closed in a glass device, with suitable feed trough pins, under medium-high vacuum conditions (10^{-5} – 10^{-6} Torr).

Advantages

Fast response of time

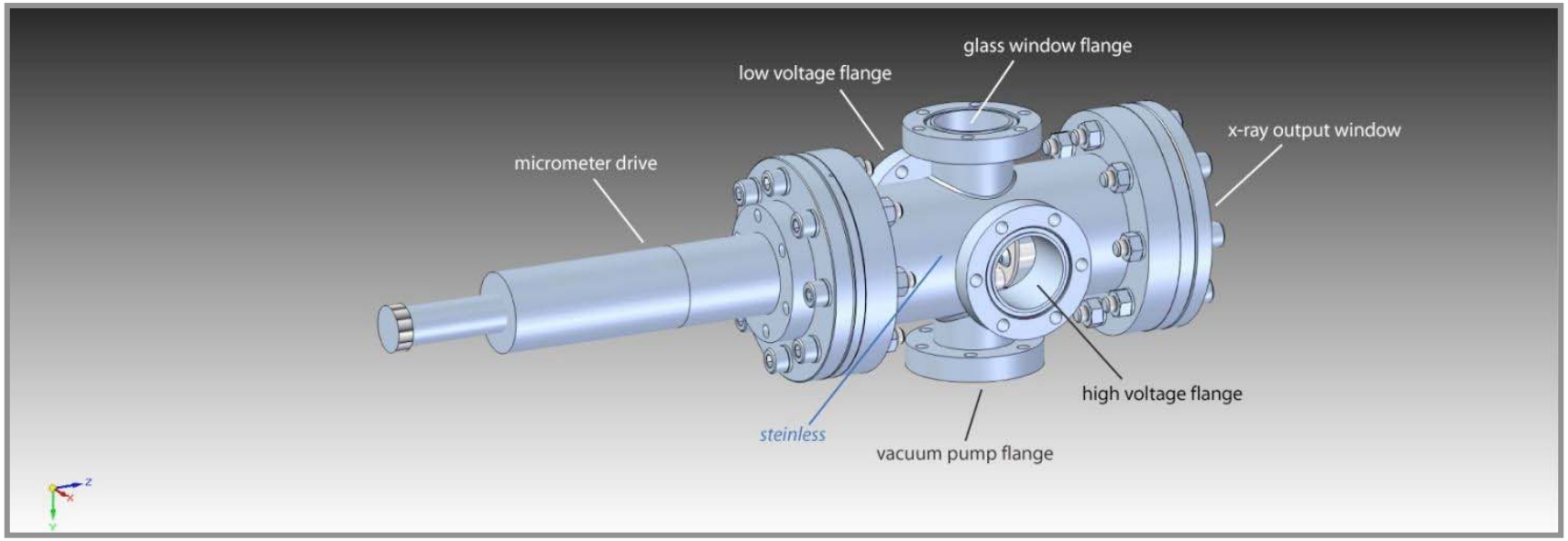
Drastic reduction in size and weight

Reduction of maintenance costs

Improvement of the focal spot

Focalization of both of electron beam and of X-rays

MECHANICAL AND ELECTRONIC DESIGN

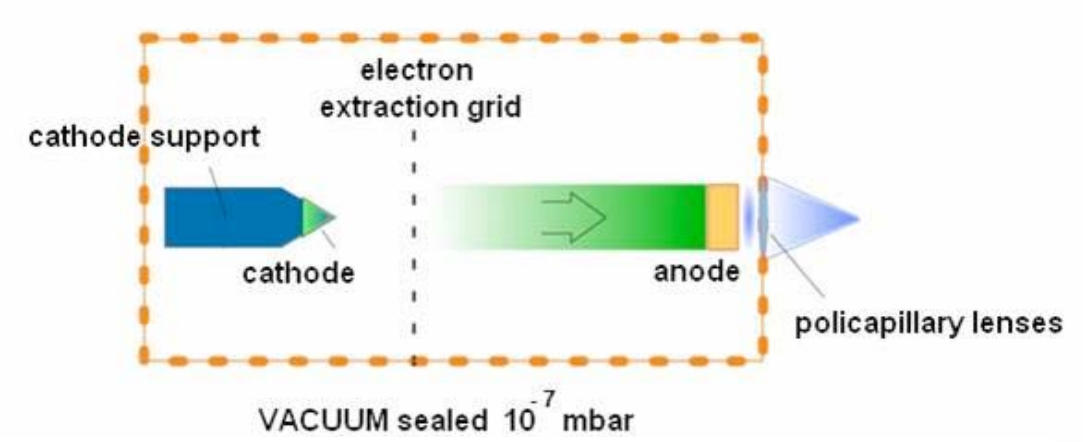


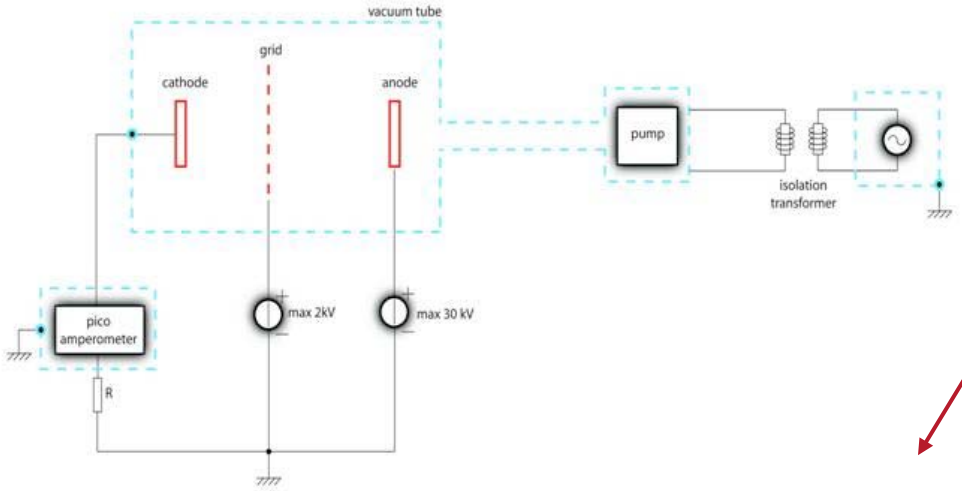
- A cathode holder flange with UHV micrometer drive (50 mm length)
- A flange for the connection to the vacuum pump (DN40 CF-KF adaptor)
- A flange for visual inspection
- A flange for High Voltage connection cable (anode)
- A flange with 3 connectors for cathode and grid voltage setting
- A flange for the output of X rays, with a beryllium disc window

NANORAY will be mainly based on the following systems/components with high and innovative technological content:

- **Cold cathode for electronic beam generation based on the Field Emission (FE) properties of CNTs**
- **Triode configuration with a focusing electrode able to reduce and control the X-rays spot**
- **Focusing X-rays system based on polycapillary lens**
- **The electronic control system**
- **Portable high voltage generator**

Test with NANORAY Alpha prototype – Preliminary results





Beryllium window

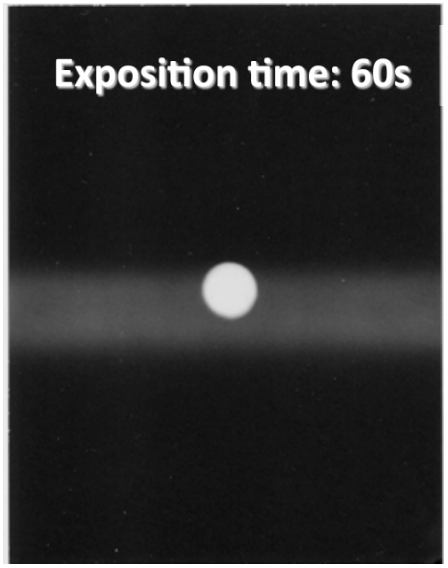
Micrometric actuator

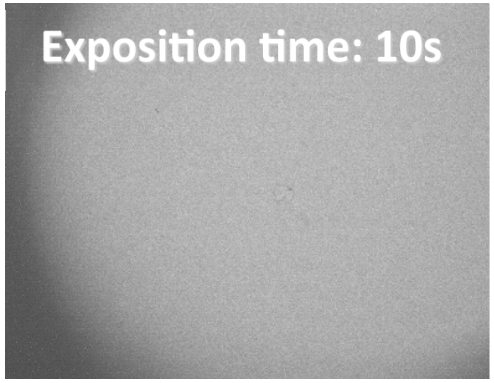
Test with NANORAY Alpha prototype – Preliminary results

Working conditions

1. Vacuum pump is switched on to reach 10^{-7} mbar
2. Tuning of grid voltage to activate field emission
3. Connect amperometer to X-rays tube -> cathode current measurement
4. Switch on the anode voltage generator to accelerate electrons towards anode (Cu)
5. Collect the X-rays by means of Polaroid, scintillator and CCD device (Photonic Science)

Cathode Current= 10 µA
Grid Voltage = 1600 V
Anode Voltage = 10 kV





Full bright spot!!!

X-rays focalization with polycapillary lens…

Using electron focalization systems

Gain factor for X-rays collected ~ 100

Conclusions

- NANORAY proposes the implementation of field emission based cold cathode, using as electron source suitable architectures/array of carbon nanotubes (CNTs)
- The use of CNTs field-emitters in X-rays source design could not only prolong the lifetime of such sources, but also — by reducing the size of the source tube and the power supply required to drive it — lead to portable X-rays diagnostic systems for use in many fields
- This system will provide higher image resolution with respect to the state of the art of X-rays devices thanks to the smaller focal spot (<0.3mm)
- NANORAY will represent a cost effective solution for everyone is facing the economic issues related to the maintenance of thermionic cathodes

- ***From the preliminary results:***

- Full bright spot on the Polaroid plate (the plate has been positioned perpendicularly to the flange) and CCD device
- The current flowing in the cathode-grid circuit remains substantially constant in time when the anodic current is progressively increased
- The CNTs cathode survive after prolonged tests
- Gain factor for X-rays collected about 100

Thanks for the attention