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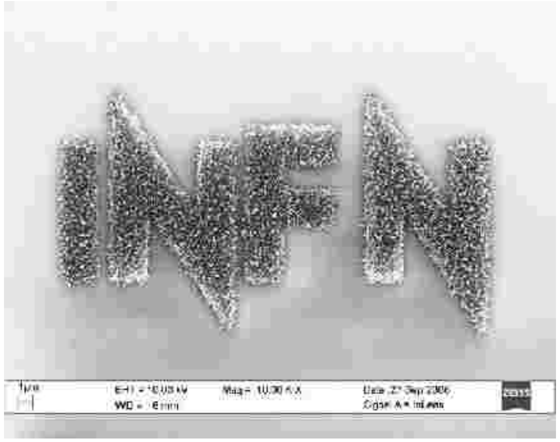
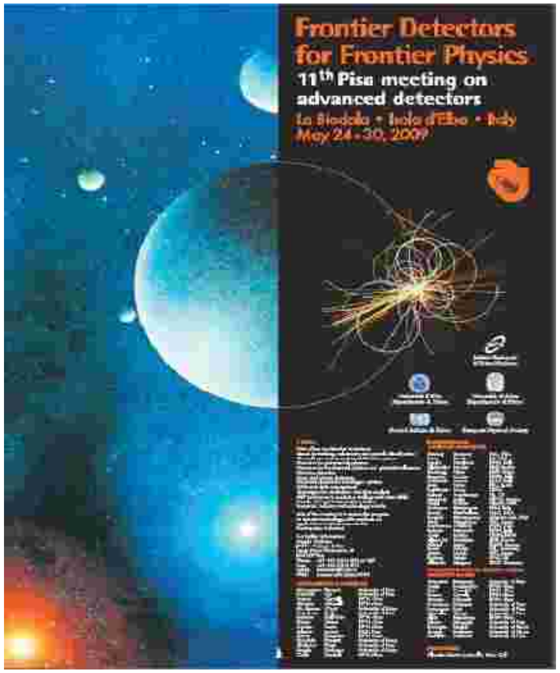


11th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2009

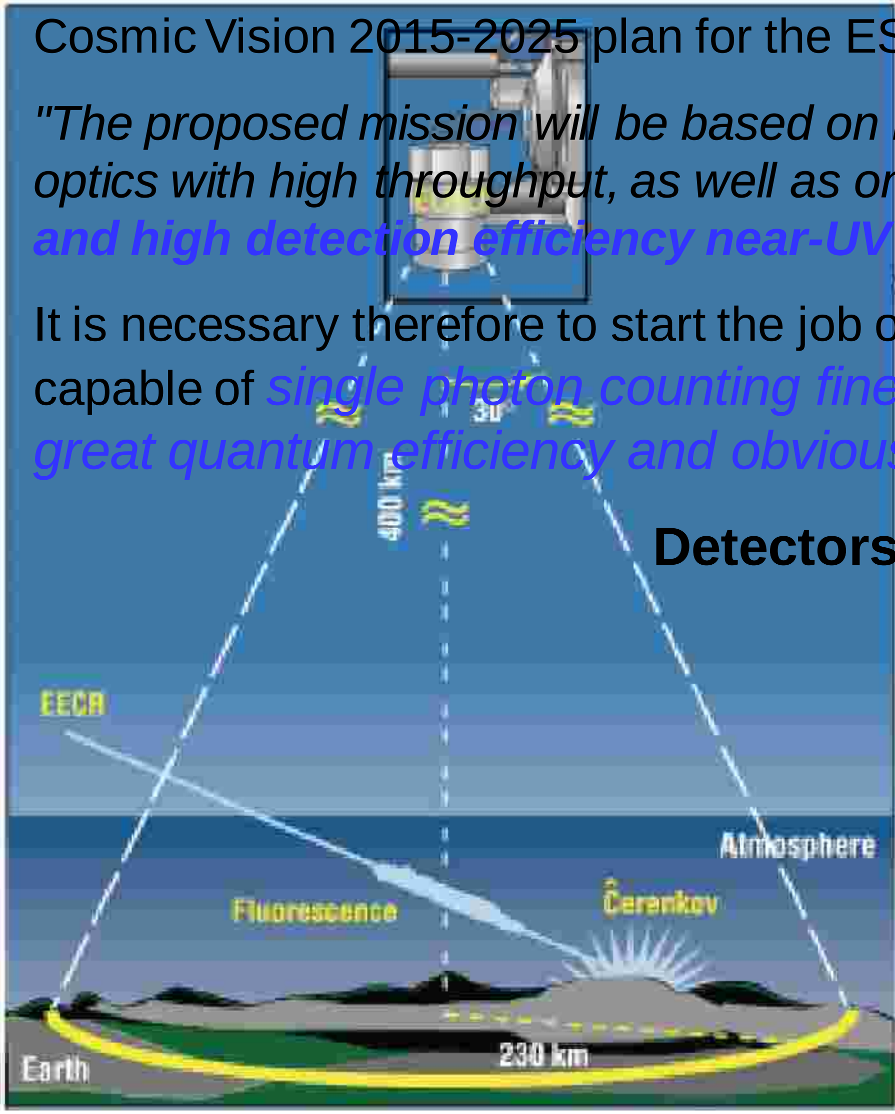


A Novel Photon Detector Made of Silicon and Carbon Nanotubes

Talk content

- Motivations: why a novel photodetector?
- The transition from macro to nanotechnology
- A new material: Carbon Nanotubes
- Properties of CNTs
- CNT photoresponsivity
- The CNT – Silicon junction
- Recent results

Motivations for space physics

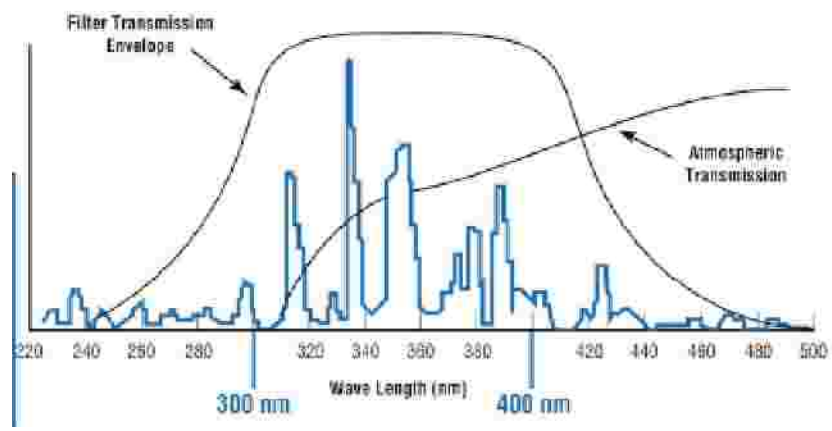


Cosmic Vision 2015-2025 plan for the ESA science programme cites:

"The proposed mission will be based on large openings and large field-of-view optics with high throughput, as well as on ***large area, highly pixelled, fast and high detection efficiency near-UV camera".***

It is necessary therefore to start the job of developing matrices of detectors, capable of *single photon counting finely pixelled on great surfaces*, with *great quantum efficiency and obviously low cost*.

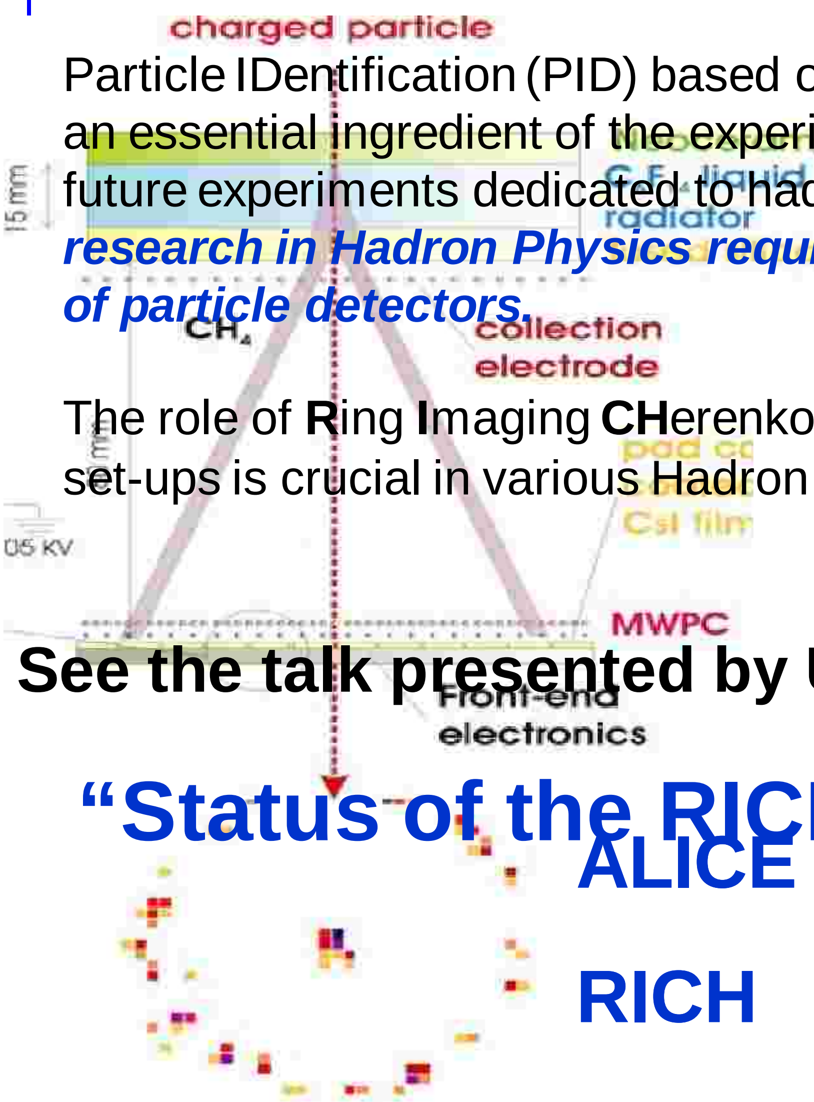
Detectors that at the moment do not exist.



Motivations for accelerator physics

Particle IDentification (PID) based on **Cherenkov imaging techniques** is an essential ingredient of the experimental apparata of several running and future experiments dedicated to hadron physics: ***the progress of fundamental research in Hadron Physics requires a continuous update of this family of particle detectors.***

The role of **R**ing **I**maging **CH**erenkov **(RICH)** counters in these experimental set-ups is crucial in various Hadron Physics domains.



ALICE

RICH

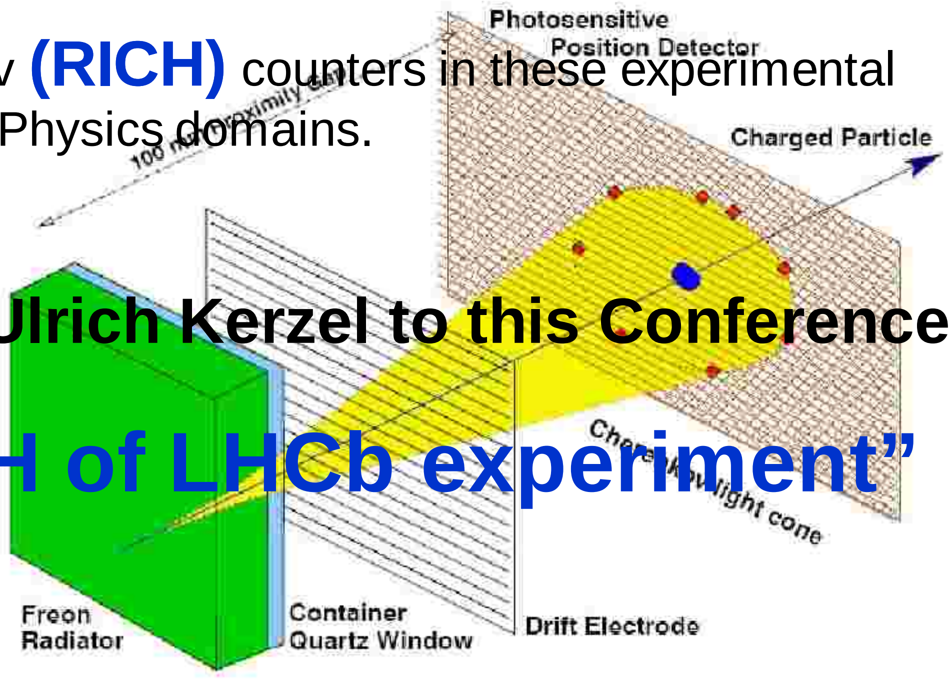


Figure 1. Schematic view of the proximity focusing RICH

See the talk presented by Ulrich Kerzel to this Conference:

"Status of the RICH of LHCb experiment"

Motivations for medical imaging

Medical imaging and acquisition of medical images requires more and more sophisticated radiation detectors in order to obtain higher space resolution:

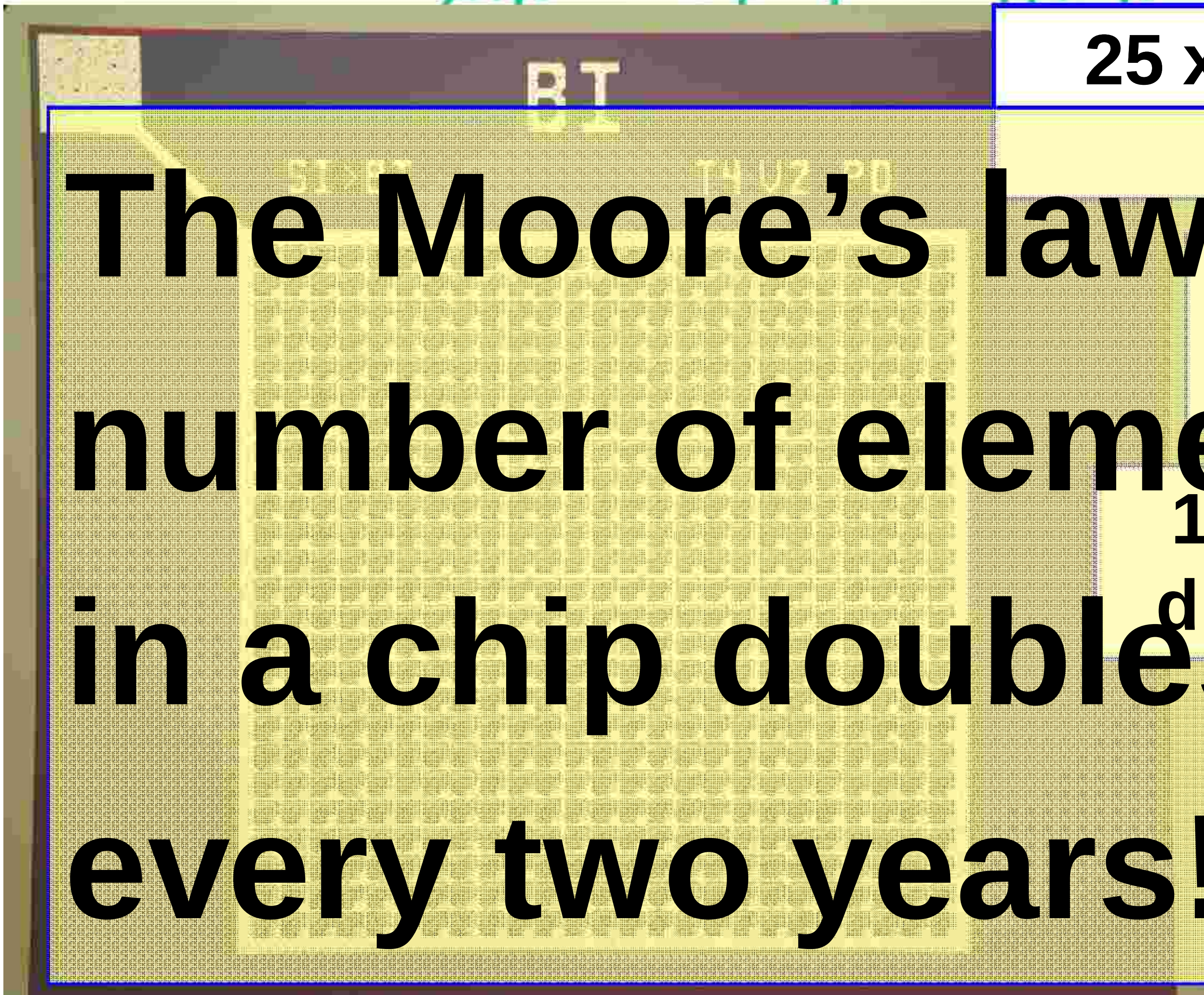
new photodetectors with high granularity can strongly improve the image resolution.

At the moment the role of **Silicon Photomultipliers (SiPM)** in this field is approached from various authors.

A finely pixelled *(micron or sub-micron)* and cheap photodetector can be very promising for the next future.

See the talk presented by Alberto Del Guerra to this Conference:

"Advantages and Pitfalls of the SiPM as Photodetector for the next generation of PET scanners"



25 x 25 pixel SiPM

40 m per cell

1 x 1 mm^2 dimension

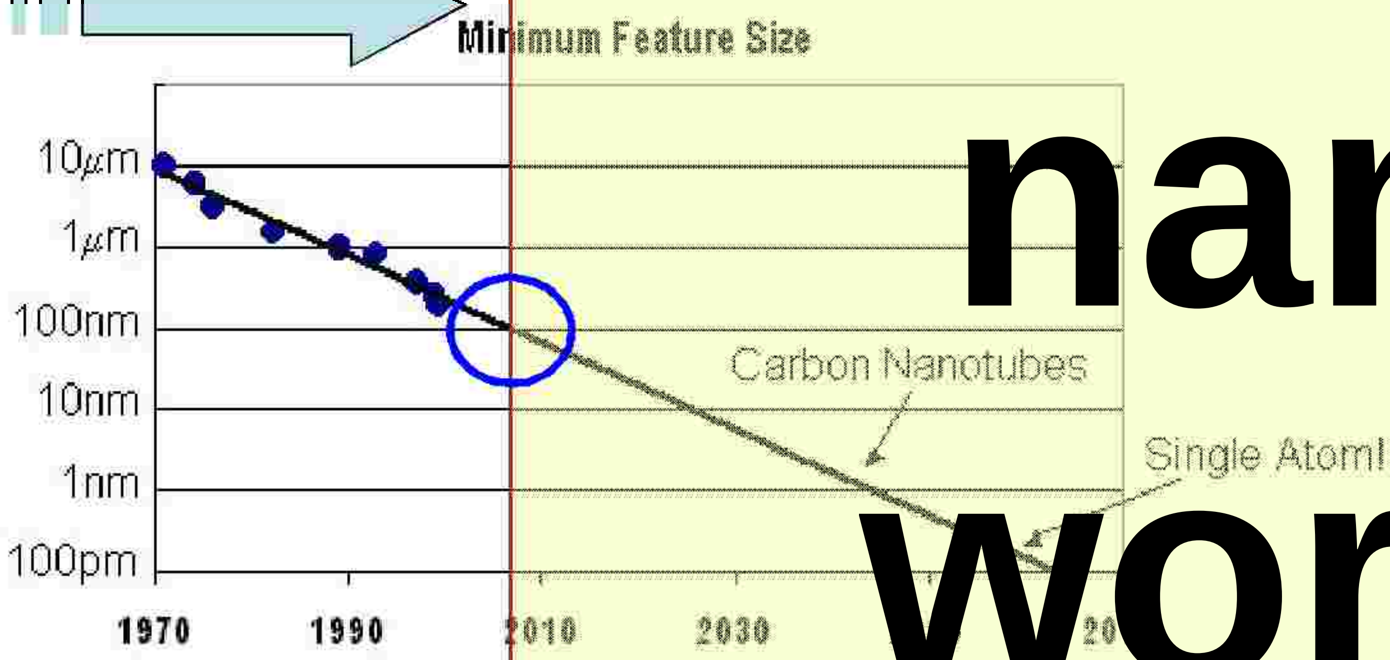
The Moore's law: the number of elements in a chip doubles every two years!

for details: NIMA 504(2003)48

Dolgoshein_Beaune 2002

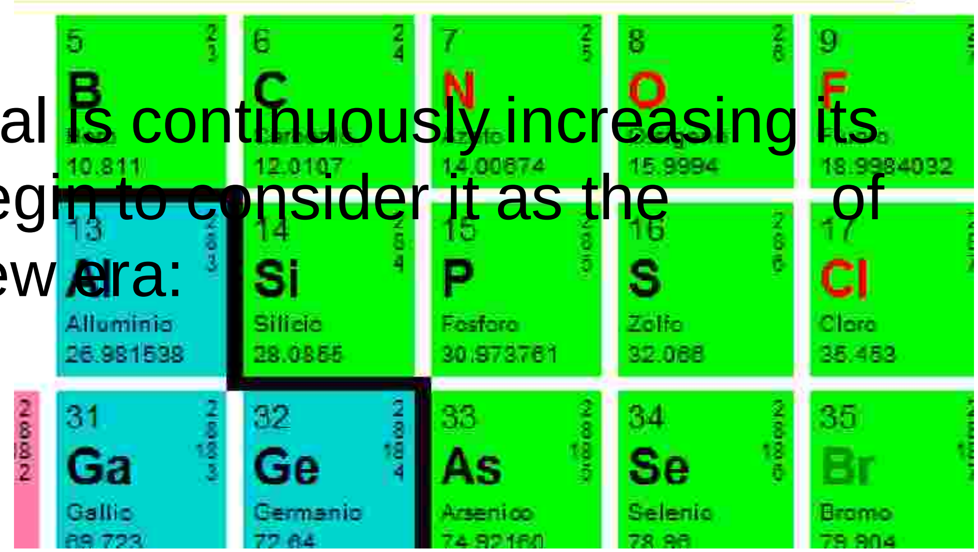
How long we can continue with the Moore's law?

The nano world



The ability of silicon semiconductor to efficiently conduct electric current is lost at a few nanometers

A new technology: carbon



Since 15 years a new material is continuously increasing its importance so that people begin to consider it as the of a new era:

The Post-Silicon ERA

This material is **CARBON** in the form of **NANOTUBES**.

…from Fullerene to Carbon Nanotubes (CNTs)

New Carbon Allotropes

Fullerene: C_{60}

C_{60} is a "tiny-droplet" of graphene sheet

- radius of 7.10 Å
- produced by arc-discharge

H. W. Kroto, R. F. Curl and R. E. Smalley 1985 Rice University

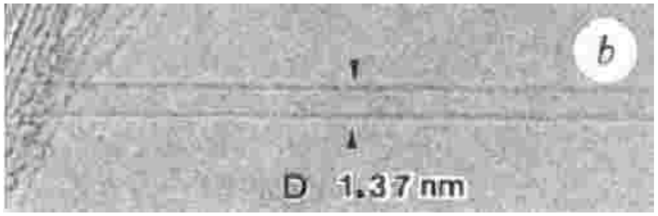
Carbon Nanotubes: CNTs

CNTs are rolled up graphene sheets

MWNTs

S. Iijima, Nature 354, 56 (1991) NEC Laboratories

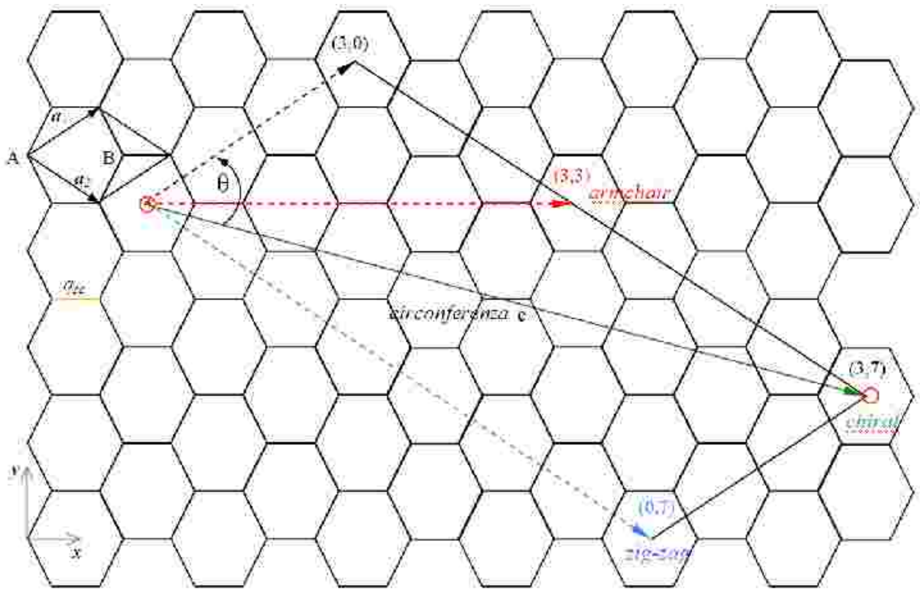
SWNTs



S. Iijima e T. Ichihashi Nature, 363, 603 (1993)

..the evolution of the experiments for the synthesis of C_{60} by Arc-Discharge has led to Carbon Nanotubes discovery

What is a SWCNT?



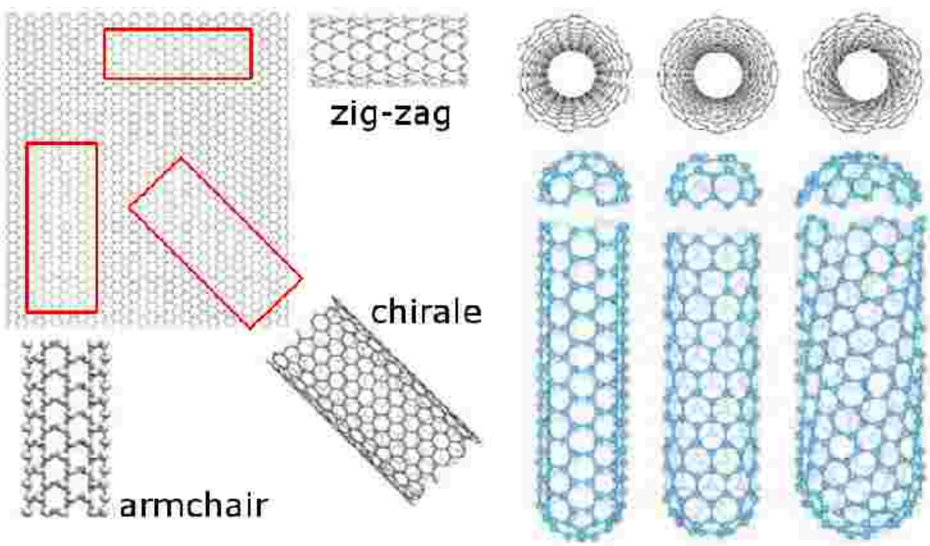
A graphene sheet can be rolled only one and more than one way, producing single walled and multiwalled carbon nanotubes.

$$d = \frac{a_0\sqrt{n^2 + nm + m^2}}{\pi}$$

$$a_0 = 249\,\mathrm{pm}$$

$E_{gap}=2\ y_0\ a_{cc}/d$

where y_0=0.1 eV, a_{cc}=0.142 nm and d is the diameter.



S. Reich, C. Thomsen and J. Maultzsch, *Carbon Nanotubes: basic concepts and physical properties*, Wiley-VCH (2003)

Possible vectors for general tubules specified by (n, m) Î N

Carbon Nanotubes (CNTs)

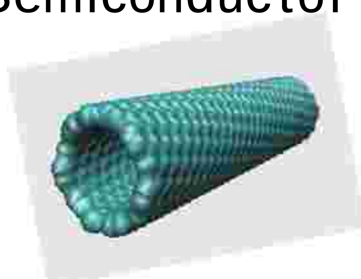
Molecular Nanowires (d ~ 1 nm, l ~ 1 mm)

SWNTs

Single Graphene Sheets (d ~ 0.7 ÷ 3 nm, l ~ -range)

ï N |n-m|/3 Î N

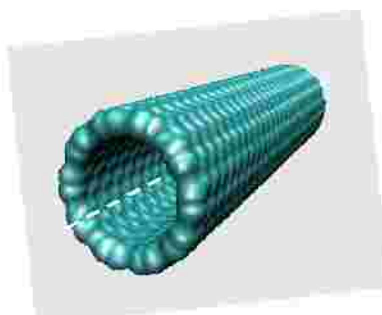
Semiconductor



Channel (FETs),

Luminescence

Metal



Ballistic Conduction,

e-wave guides, SETs

MWNTs

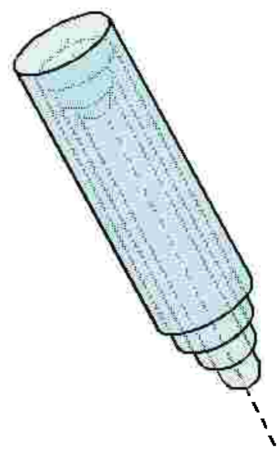
Coaxial graphene sheets

(d ~ 2 ÷ 100 nm, l ~ -range

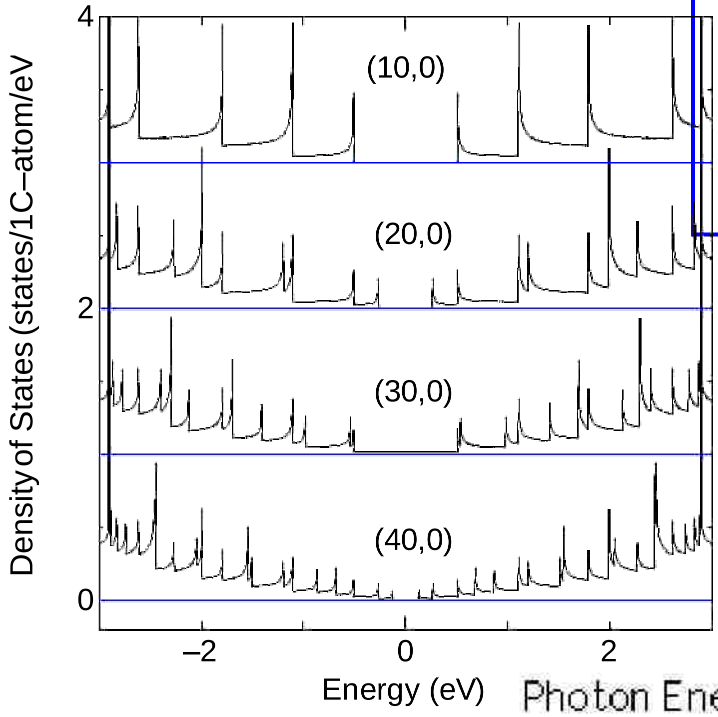
(d^{out} ~ 20_{AD}, 100_{CVD} nm)

Vias

Nanocomposites

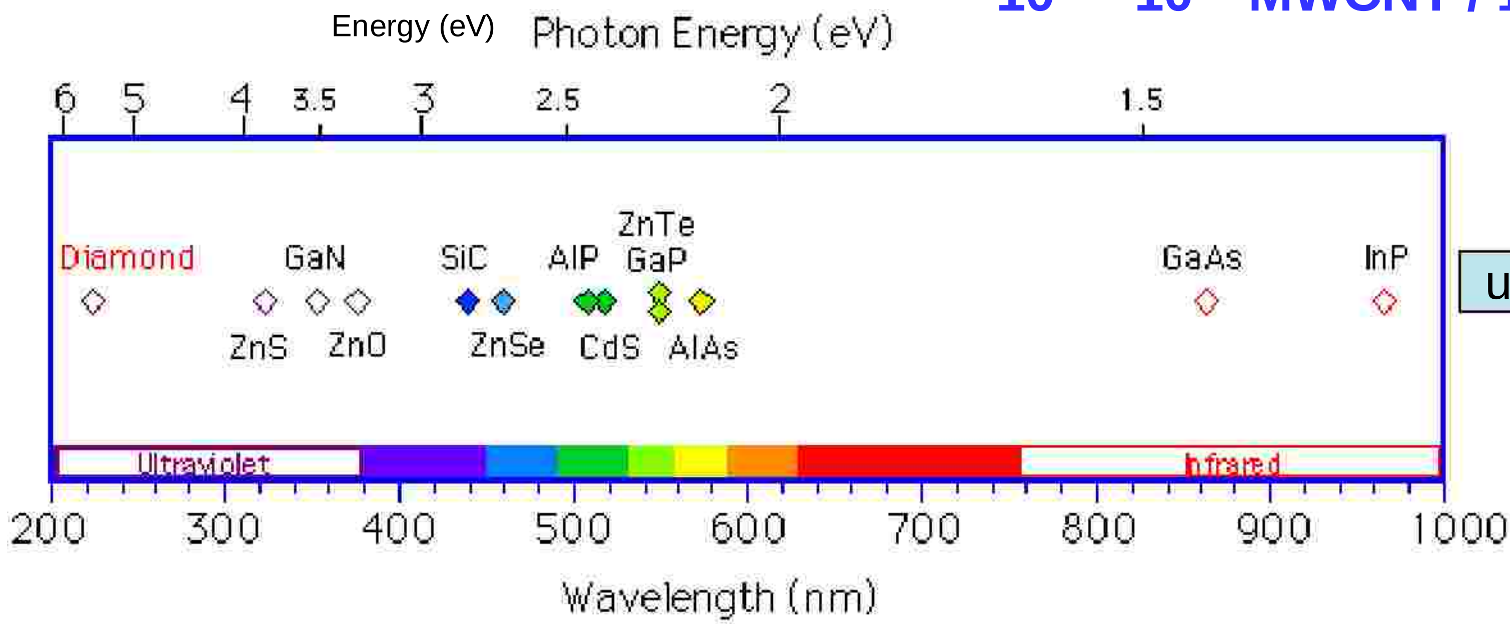


May MWCNT can be used as photodetectors?



A layer of Multiwall Carbon Nanotubes covers a wide range of diameters and chirality, offering a device sensitive to a wide range of radiation frequencies. In addition the CNT density is very high, allowing, every in a small area, a great number of tubes sensitive to the radiation.

~ 10^8 – 10^{10} MWCNT / 1 mm^2



up to 3 m (0.4 eV)

GINT

(Gruppo INFN per le NanoTecnologie)

INFN
&
University of

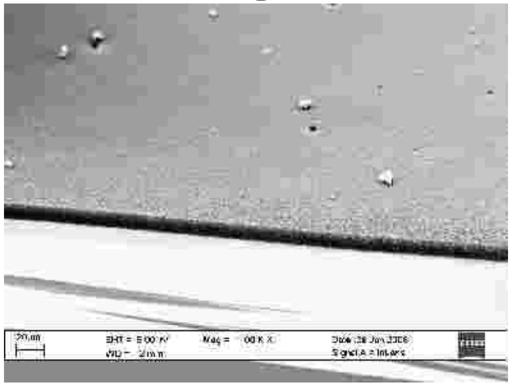
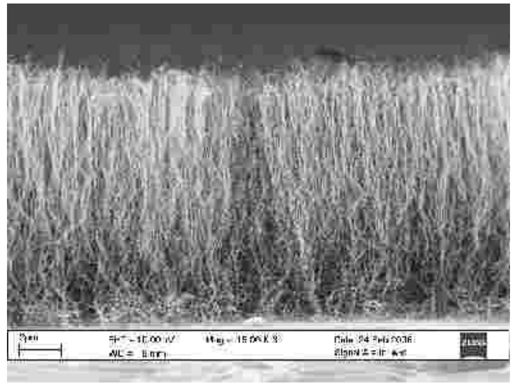
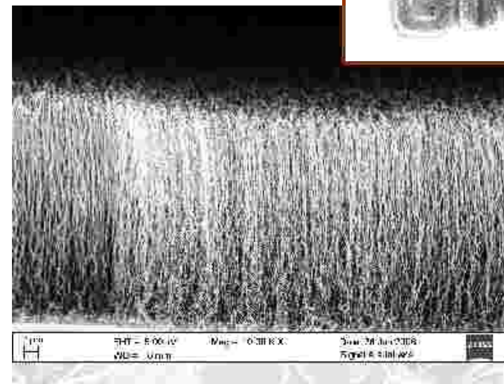
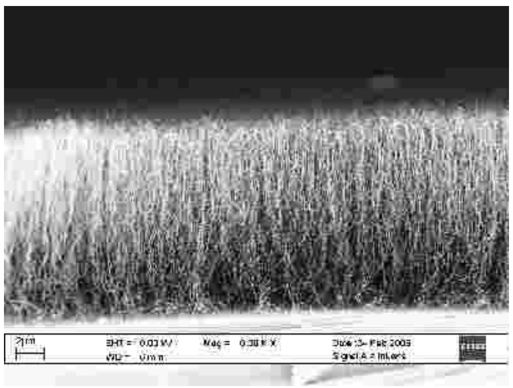
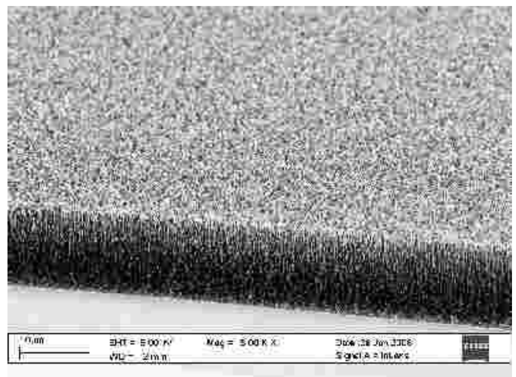
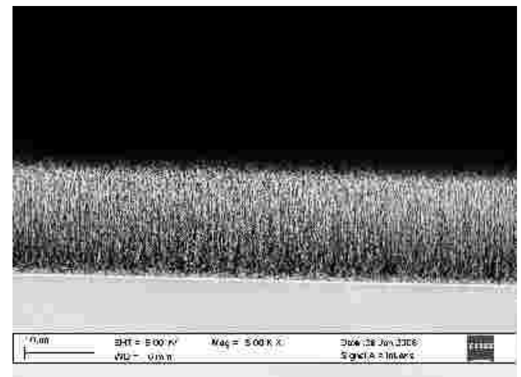
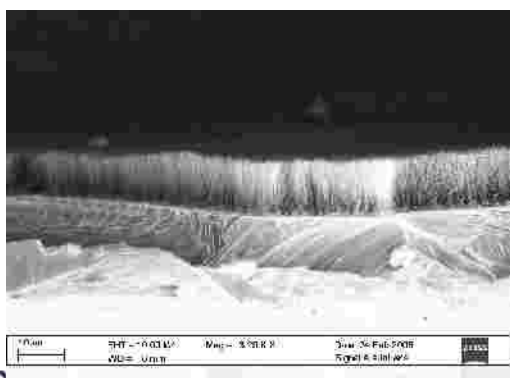
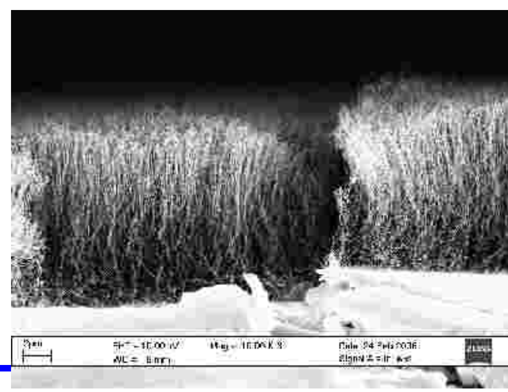
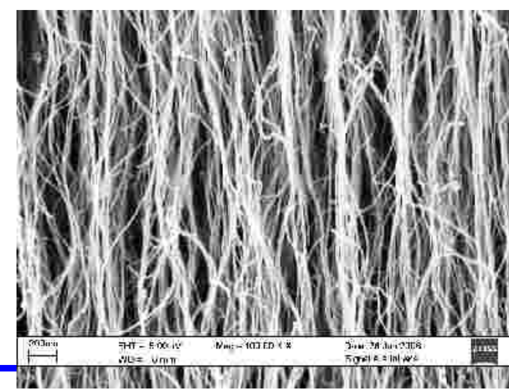
L'Aquila
Bari
Firenze
Napoli
Pisa
Salerno

http://gint.na.infn.it/

The activity started in early January 2006

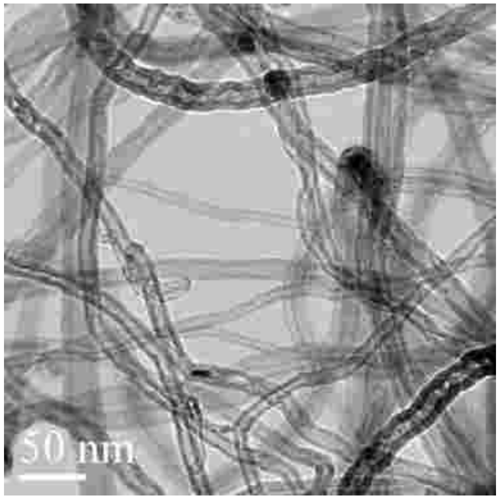
Realization of a finely pixelled photocathode based on the use of Multi Wall Carbon Nanotubes

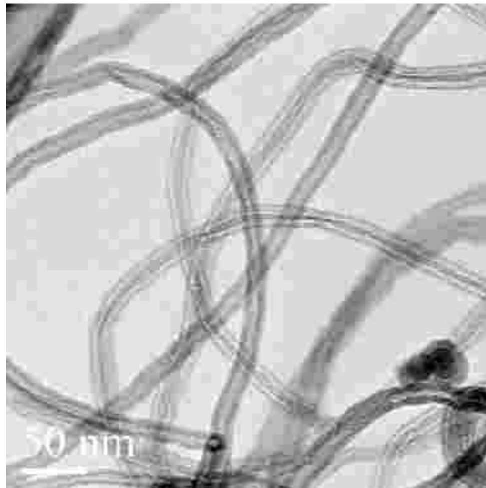
SEM Images

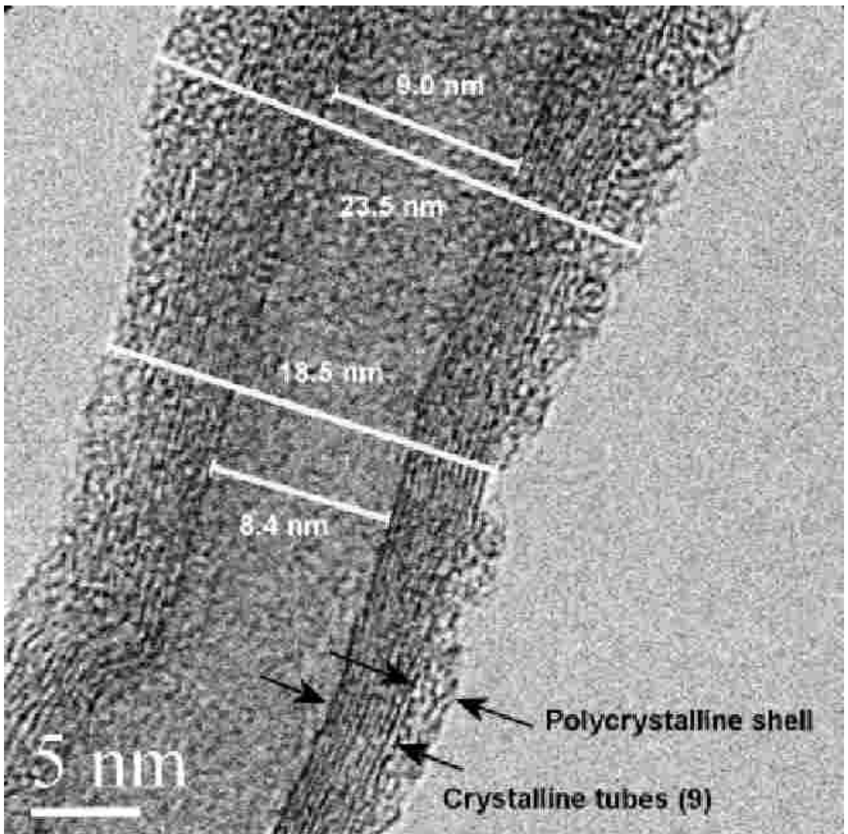










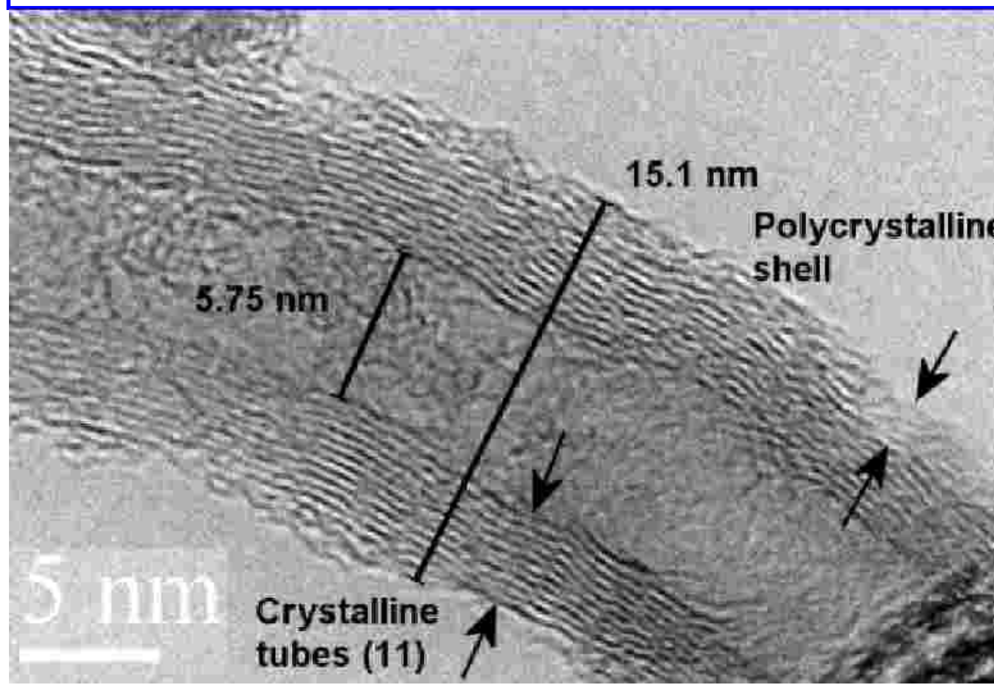
CNT Characteristics

- **External diameter: 15 – 25 nm**
- **Internal diameter: 5 – 10 nm**
- **Average number of nanotubes: 10 – 15**

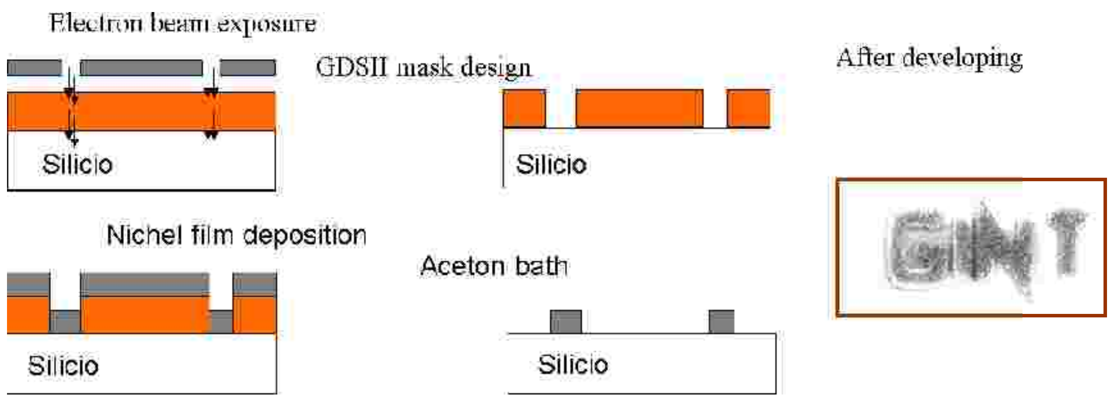


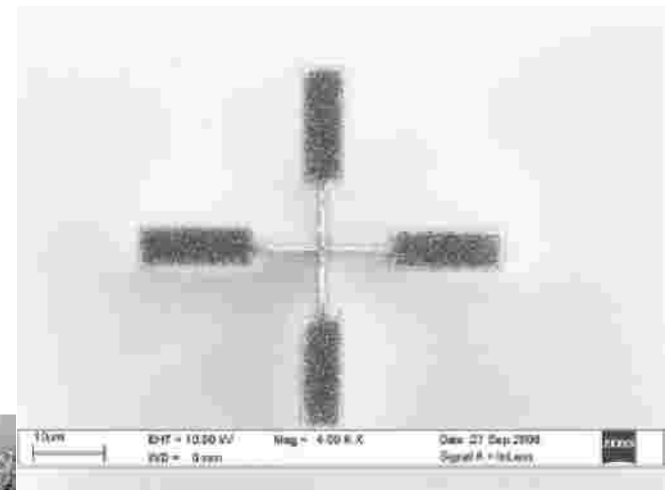


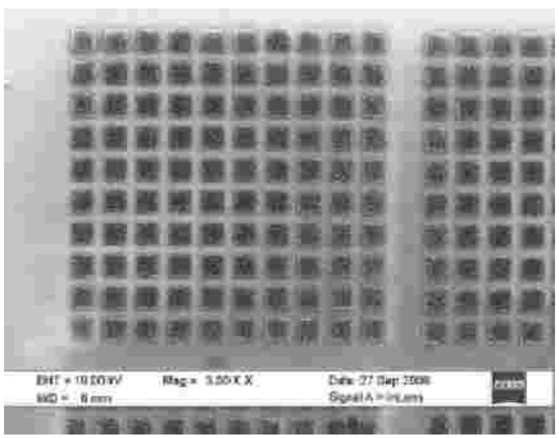


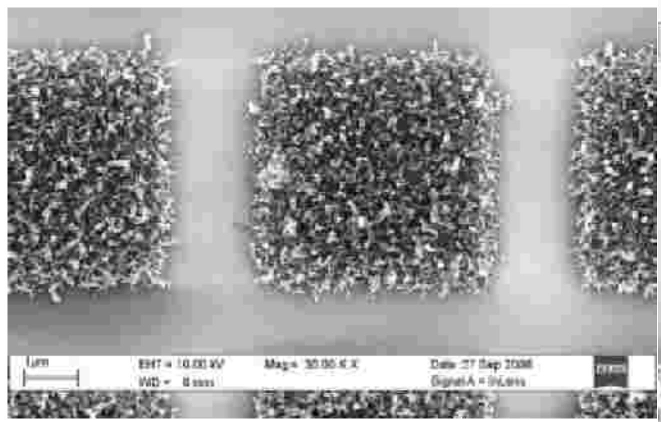


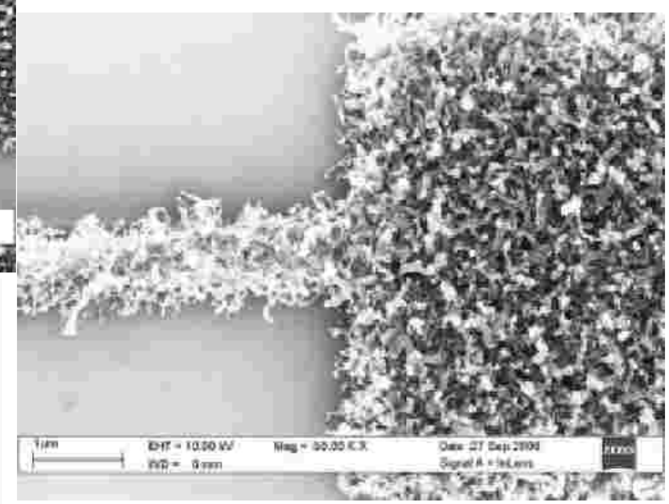
Nanolithography and patternization

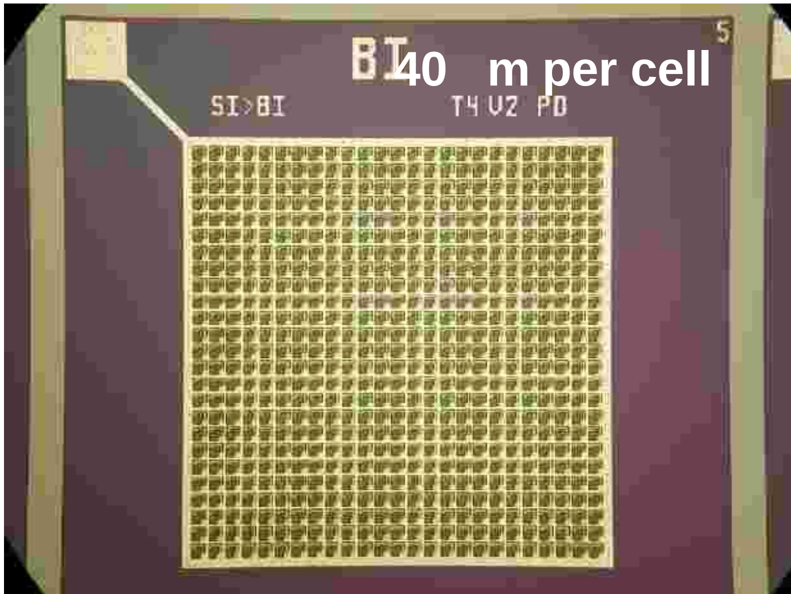


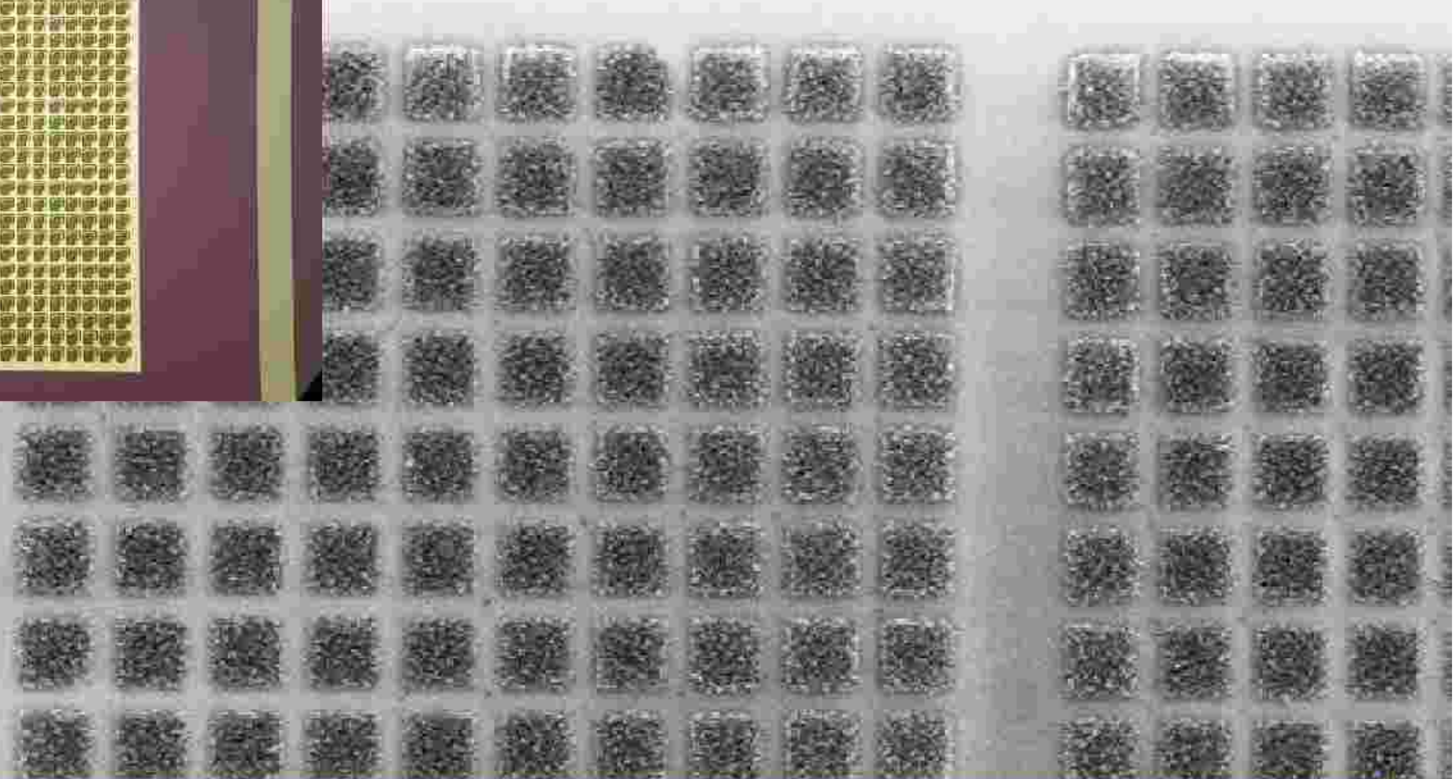






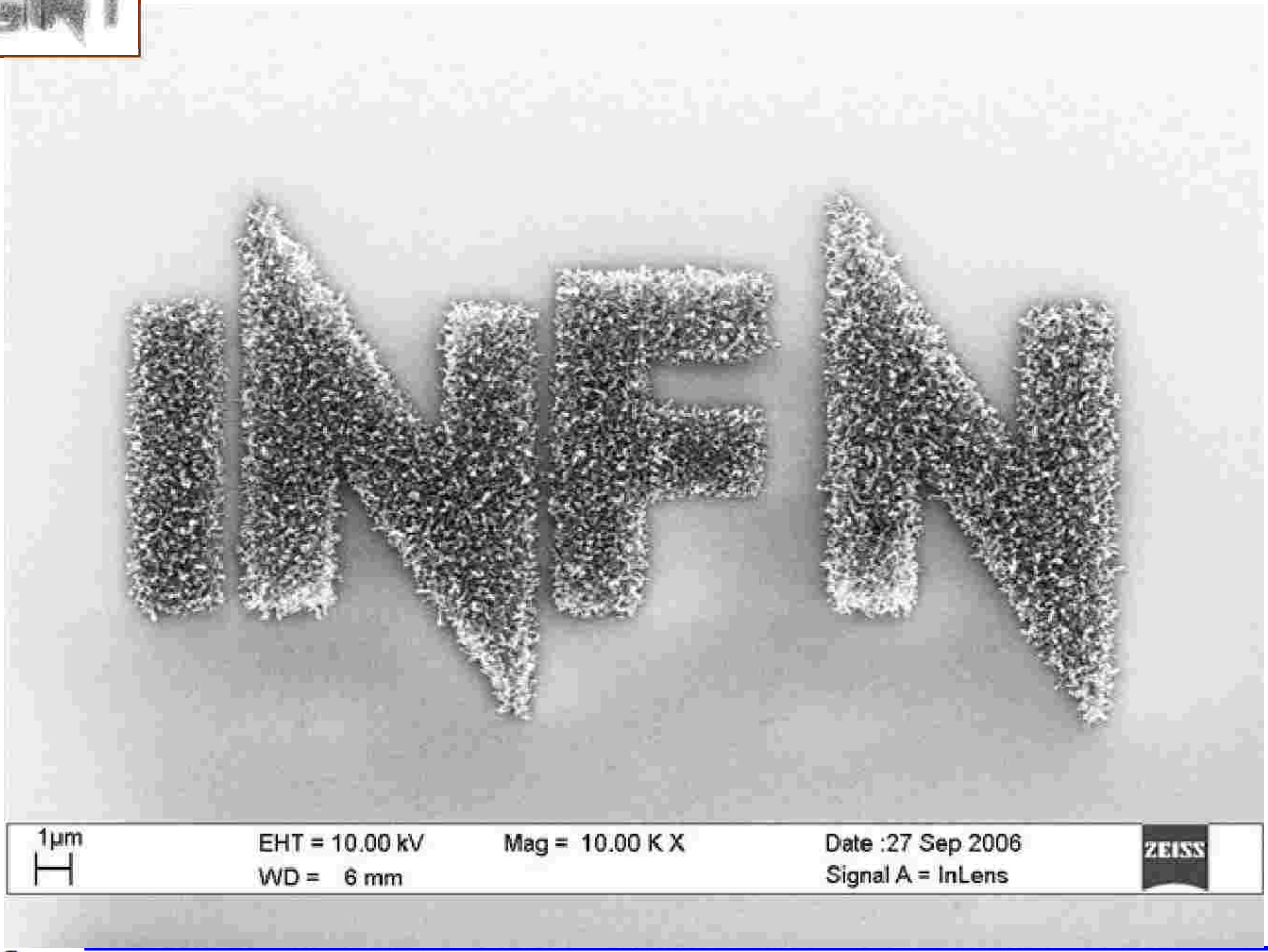






1. **We can easily obtain any desired geometry**

2. **The cost is low**


1µm
EHT = 10.00 kV
WD = 6 mm
Mag = 10.00 K X
Date :27 Sep 2006
Signal A = InLens
ZEISS

GINT

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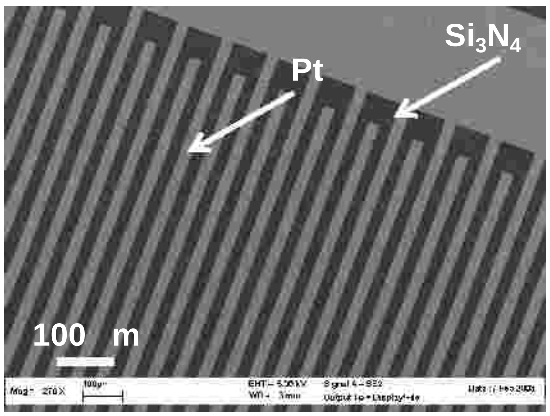
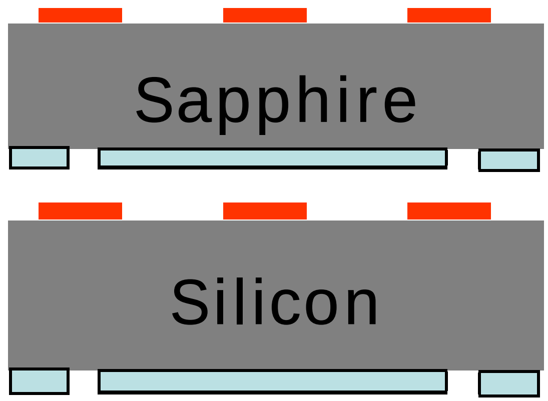
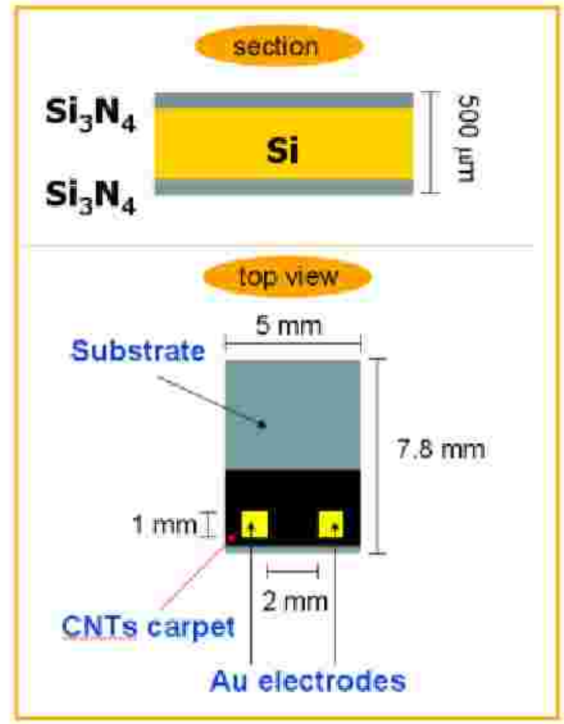
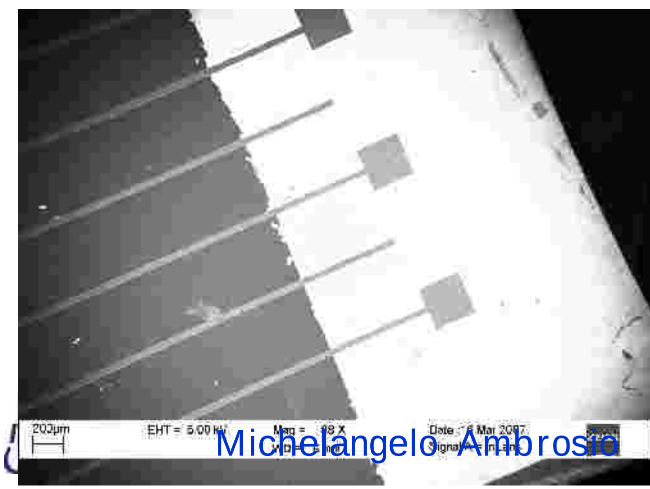
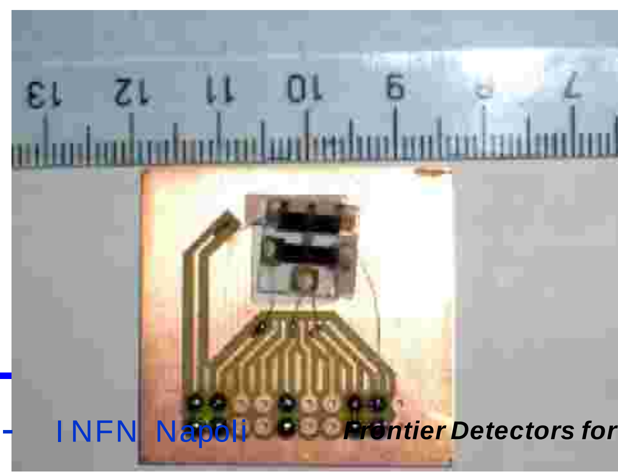






Various kind of substrates





The first nanotube radiation detector

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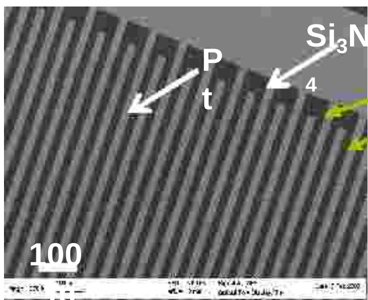
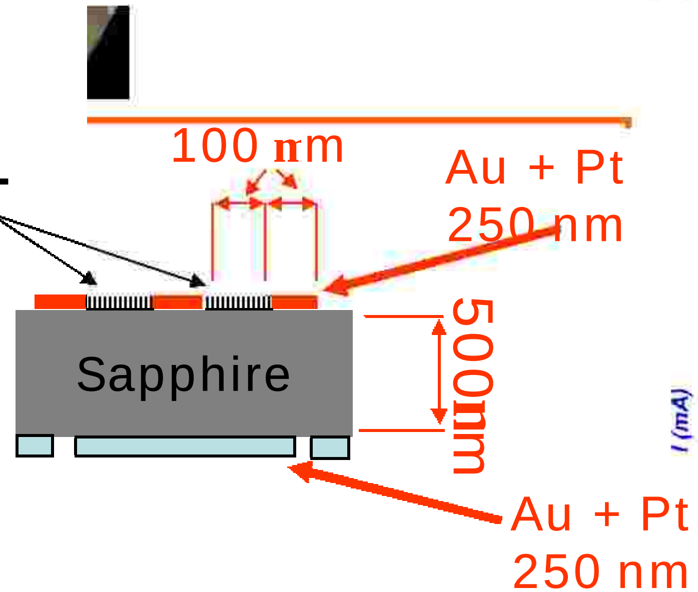
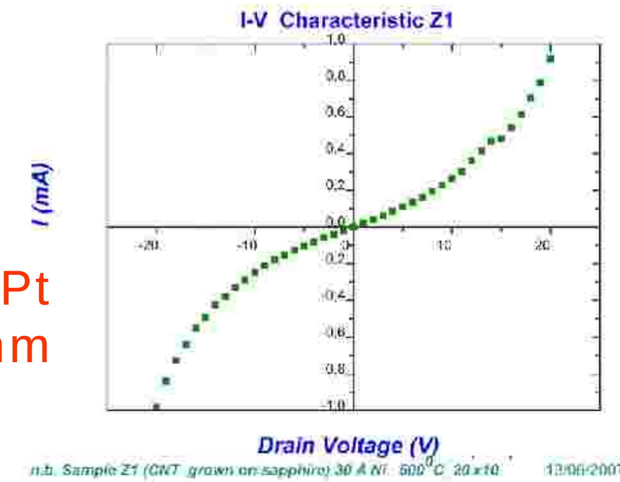
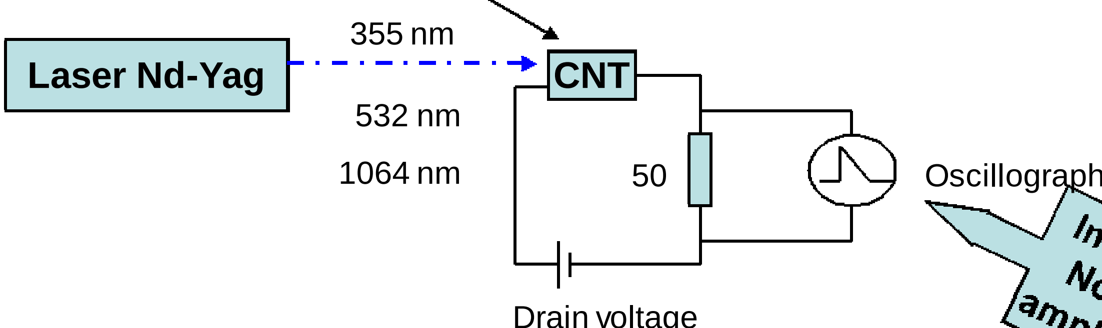
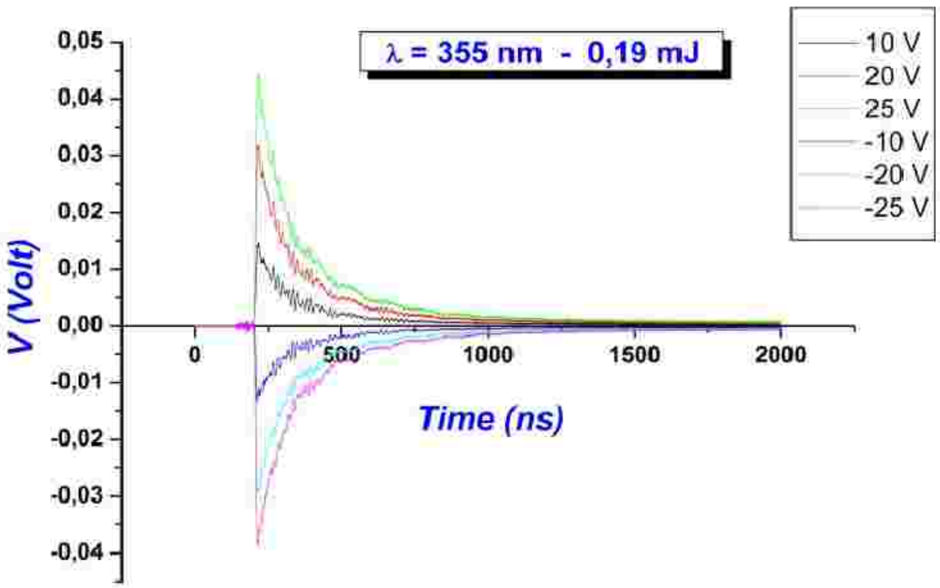




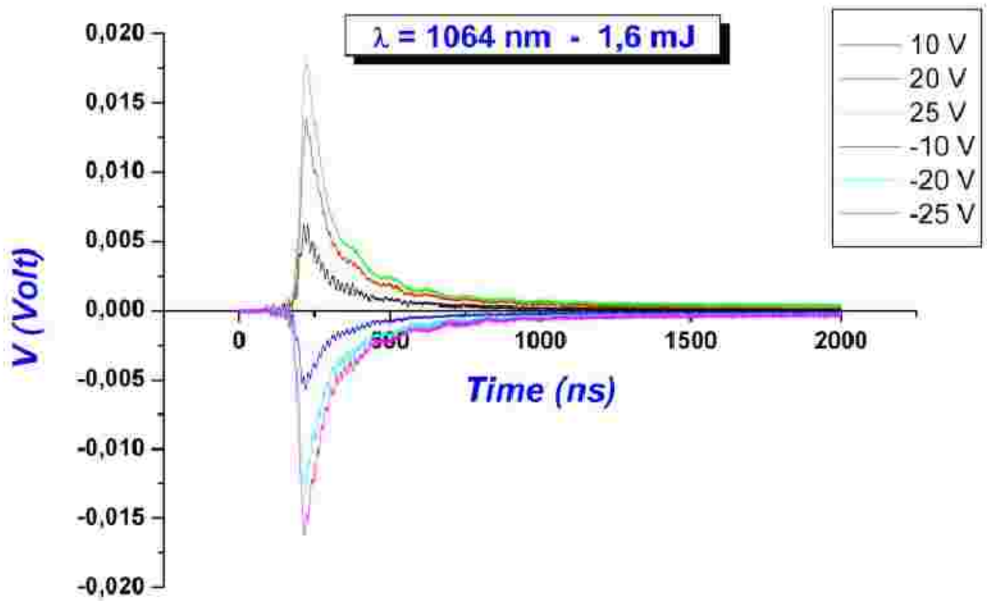


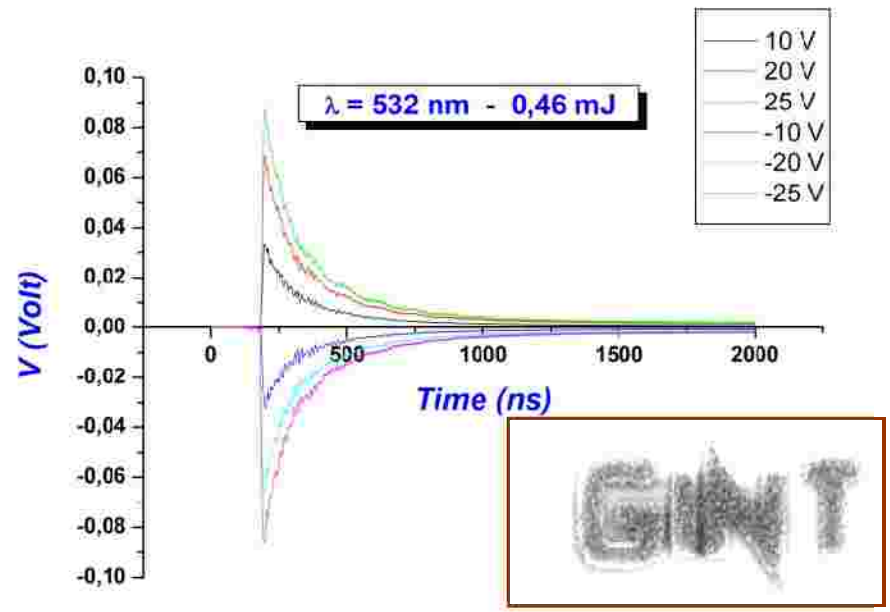


World first



Signals detected with the first carbon nanotube radiation detector

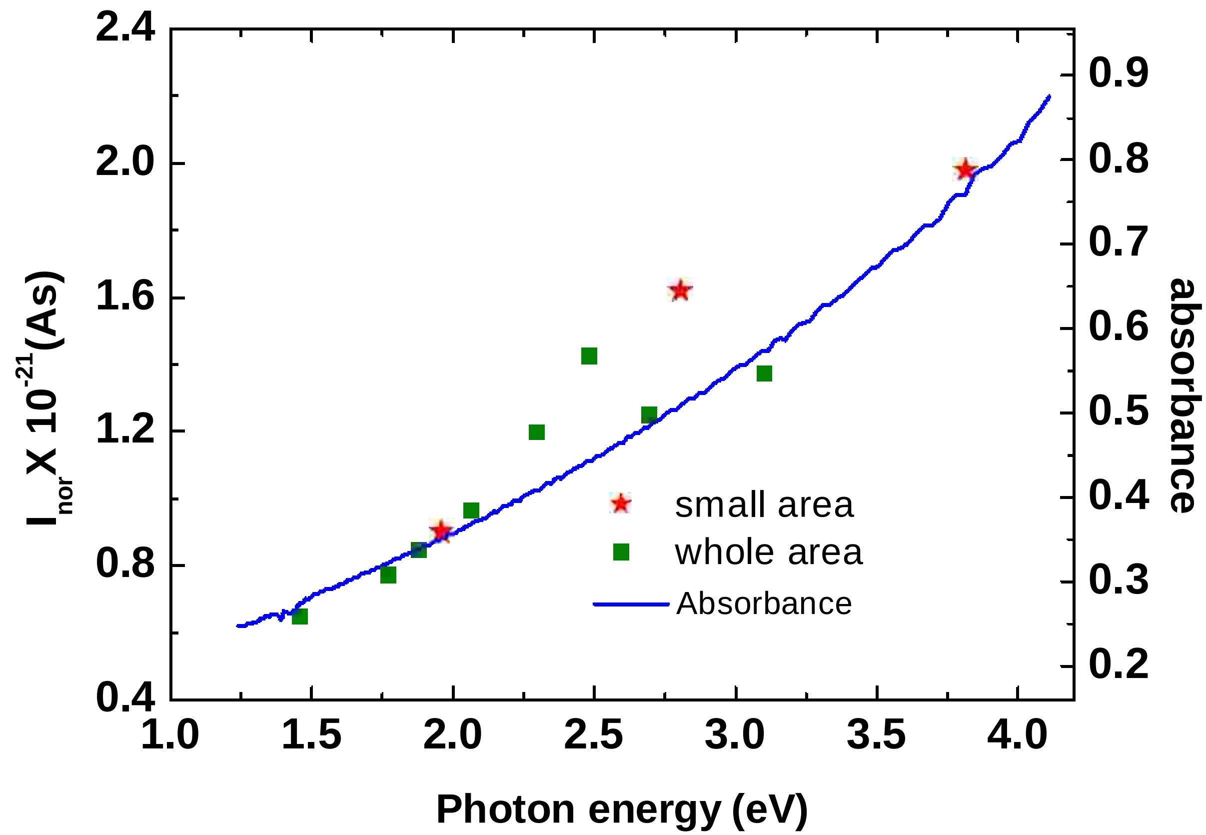




A. Ambrosio et al: ***"A prototype of a Carbon Nanotube microstrip radiation detector"***, **Nuclear Instruments and Methods in Physics Research A 589 (2008) 398–403**

Photocurrent vs

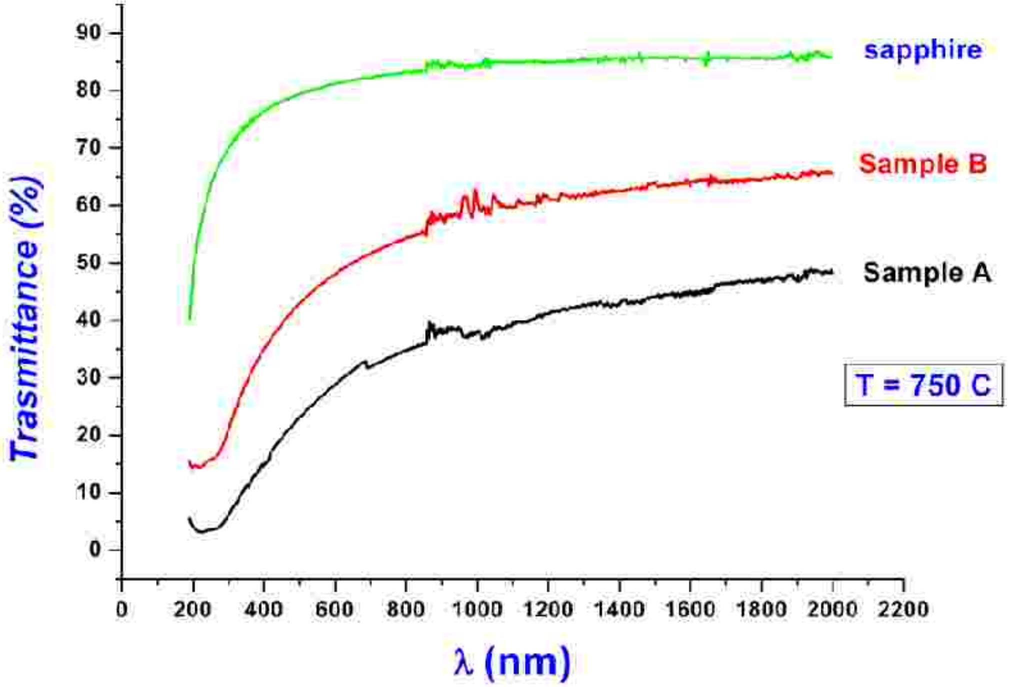
(Gruppo INFN per le NanoTecnologie)

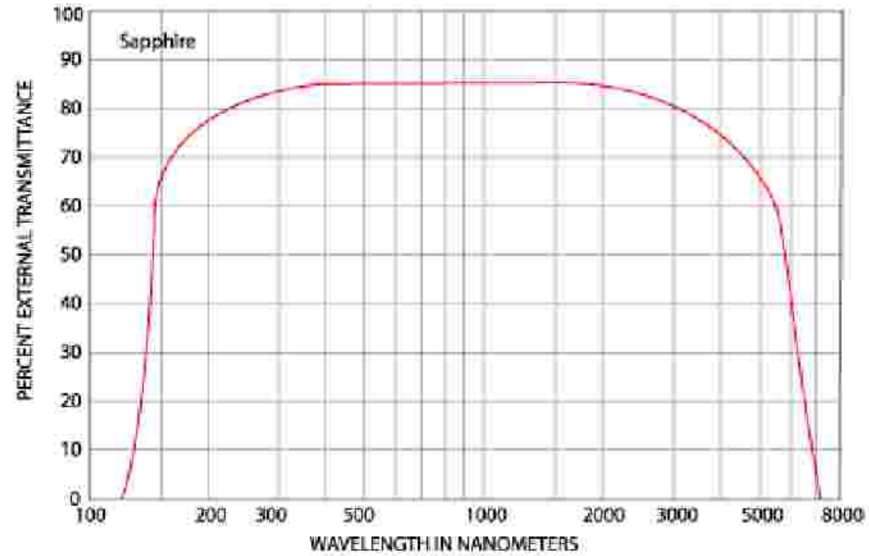


Photocurrent normalized to the number of photons I_{nor} vs photon energy, obtained illuminating the whole surface of a MWCNT sample with filtered light (¦) as well as small part of the surface

with laser spots (*). Continuous line indicates the absorbance spectrum of the same MWCNT sample

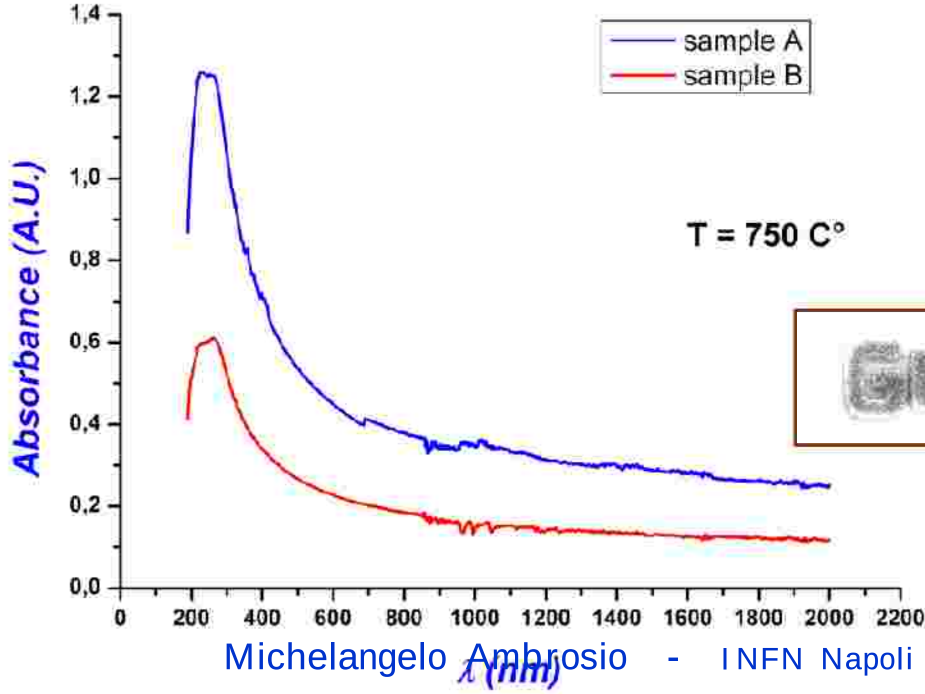
M. Passacantando et al: *"**Photoconductivity in defective carbon nanotube sheets under ultraviolet–visible–near infrared radiation**",* **APPLIED PHYSICS LETTERS 93, 051911 2008**

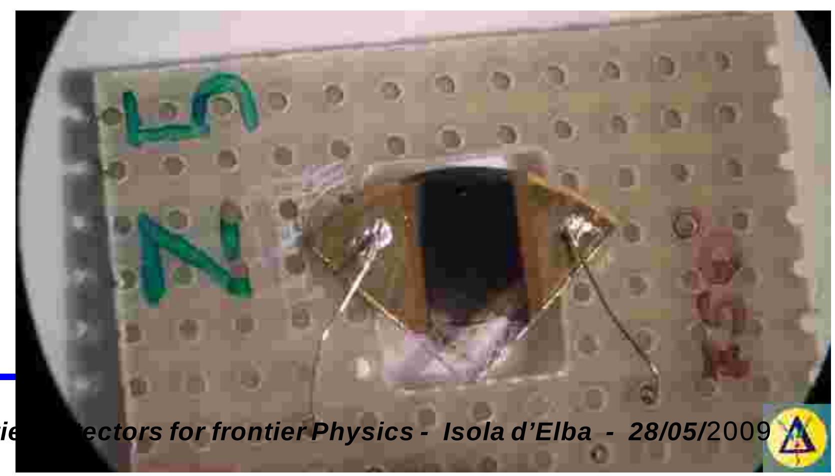




CNT absorbance

(log_{10} 1/T)





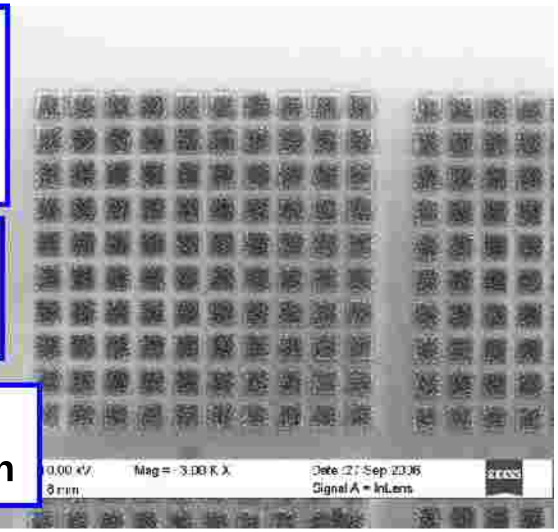
GINT: main results (1)

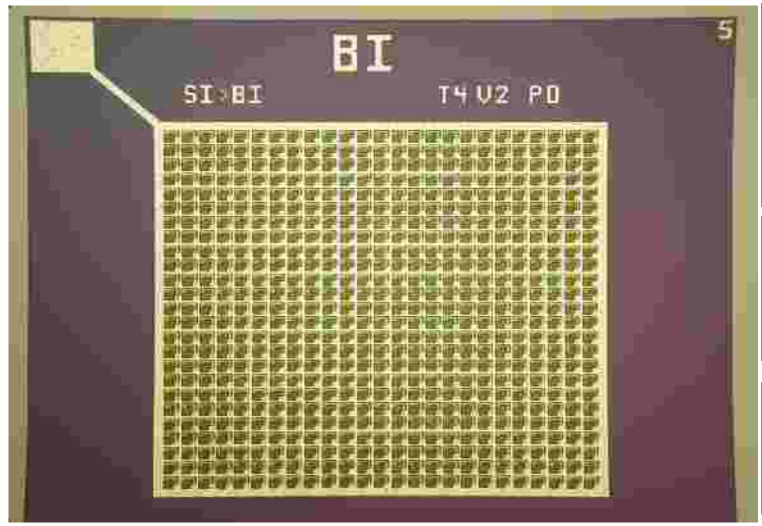
GINT demonstrated that MWCNTs can be grown on different kind of substrates according the desired geometry. Nanolithography process allows to obtain finely pixelled elements over large surfaces.

10 x 10 pixel CNT

4 m per cell

0.05 x 0.05 mm² dimension





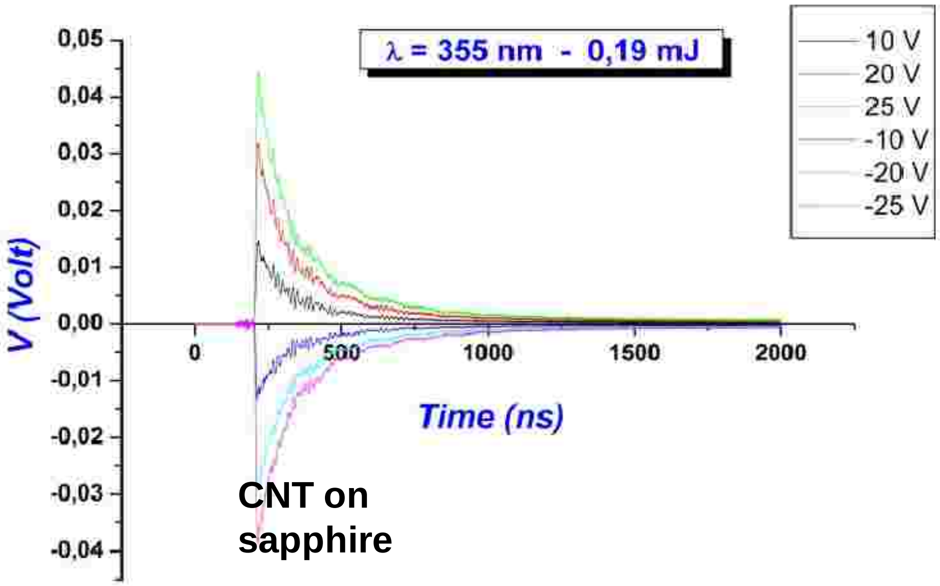
25 x 25 pixel SiPM

40 m per cell

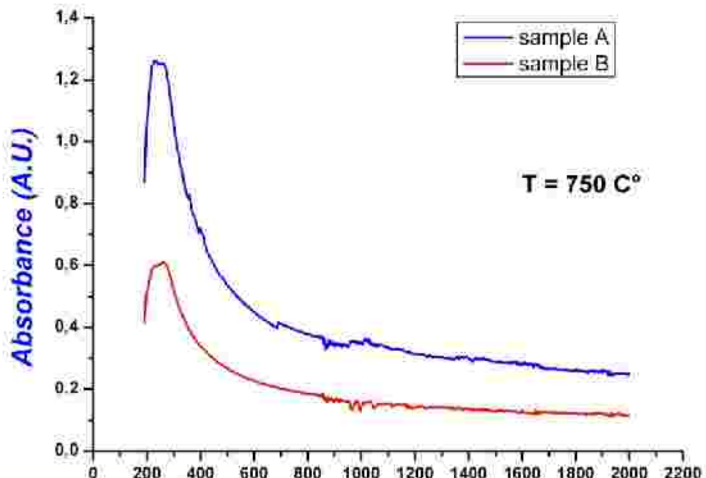
1 x 1 mm² dimension

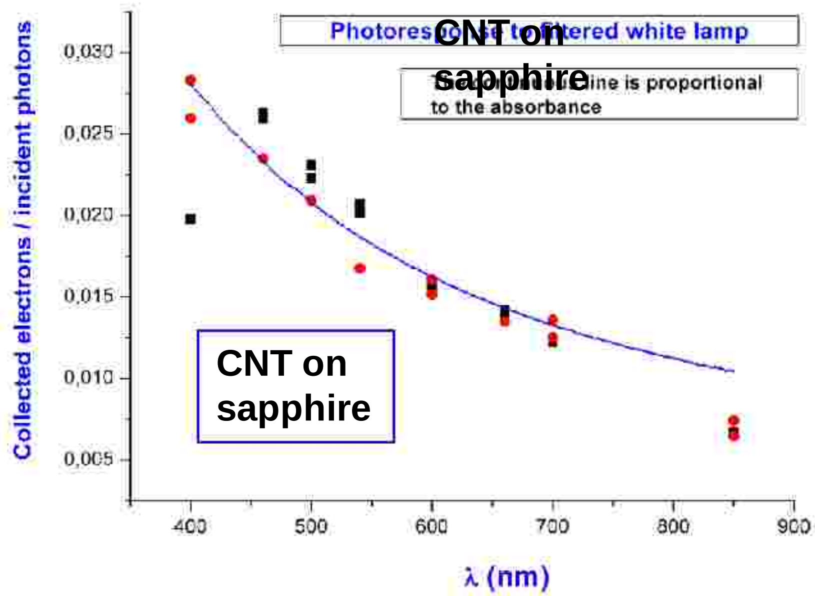
Nano-pixelled photocathodes sensitive to the UV radiation may be obtained by means of nanolithography in a very cheap and easy way!

GINT: main results (2)

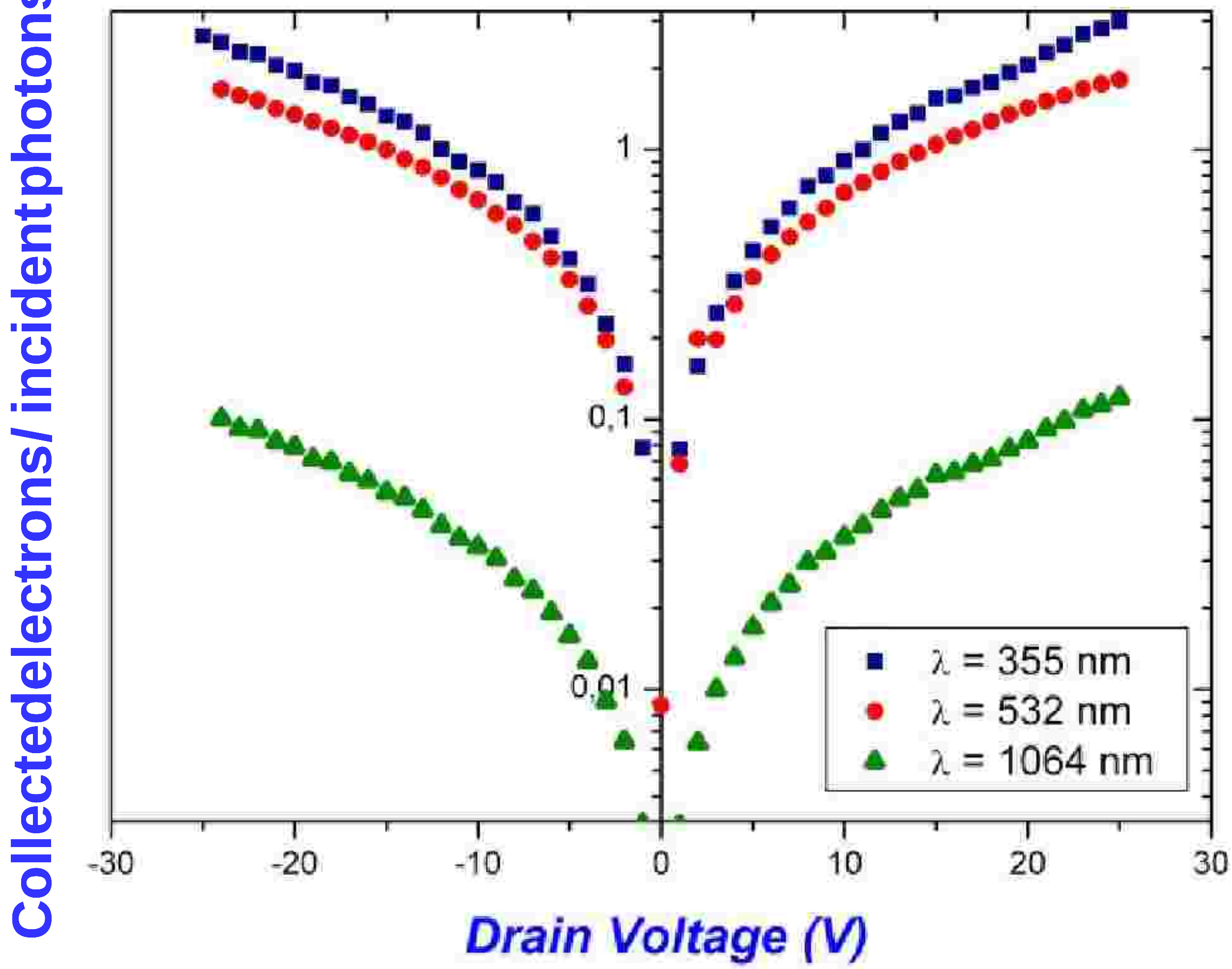


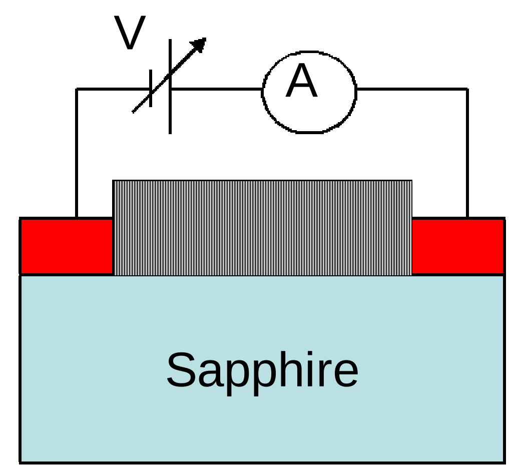
GINT demonstrated the good photoresponsivity properties of MWCNT, depending from temperature of the grown process and from radiation wavelength. The photocurrent encreases in the UV region.

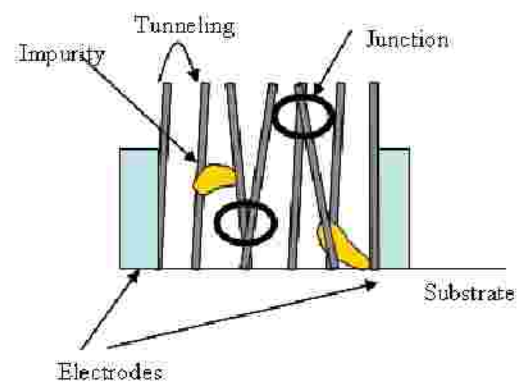




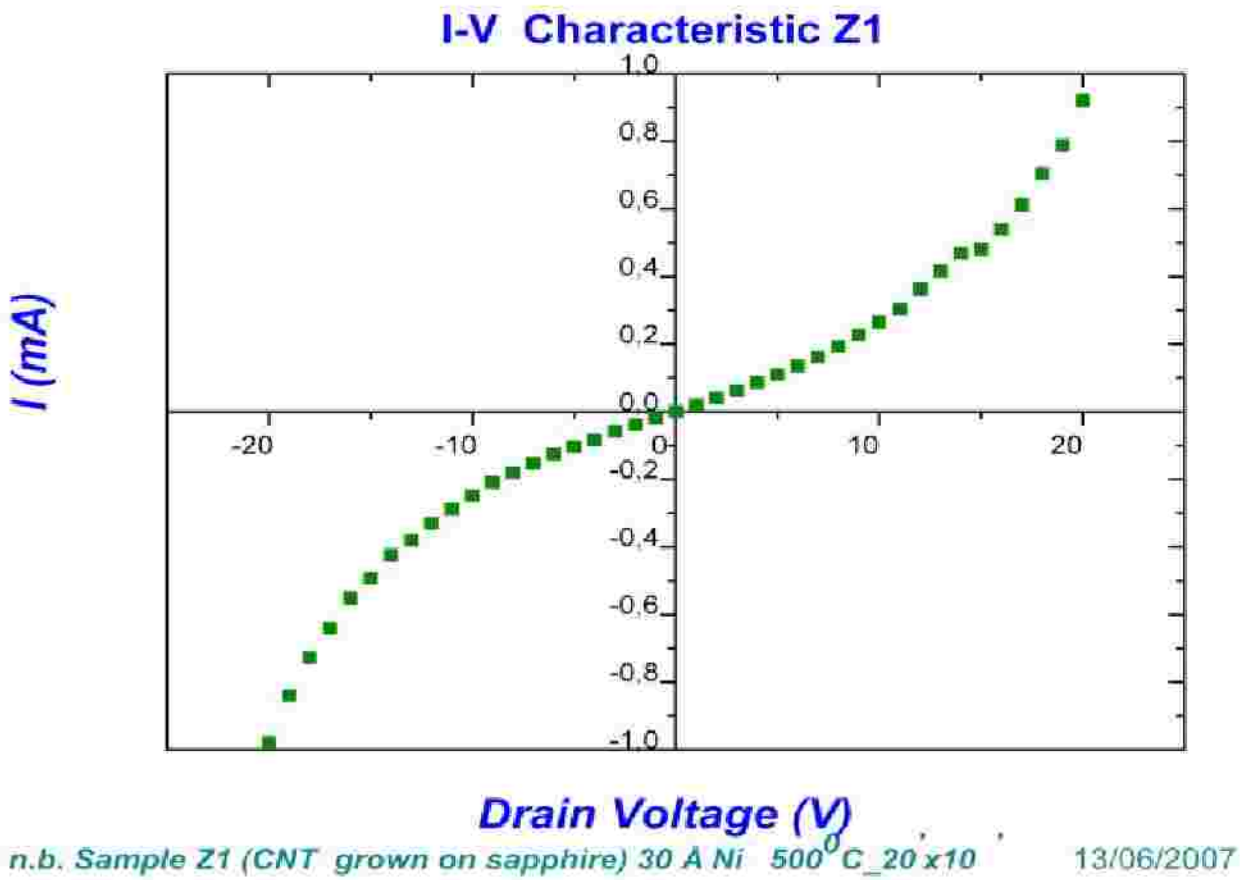
GINT: main results (3)

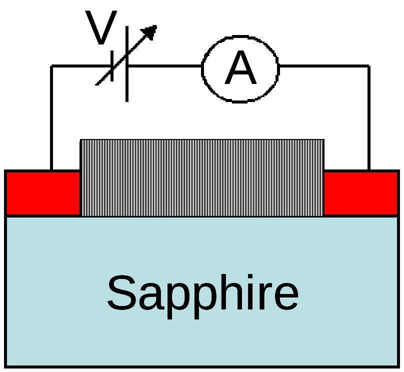






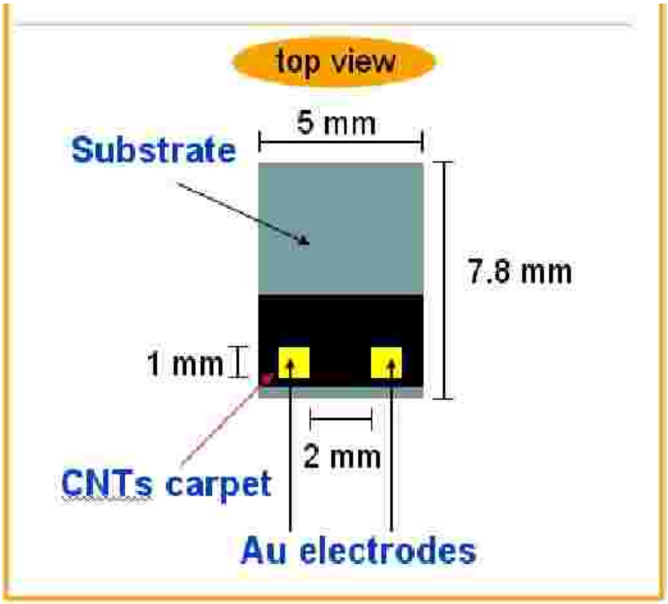
GINT: main results (4)

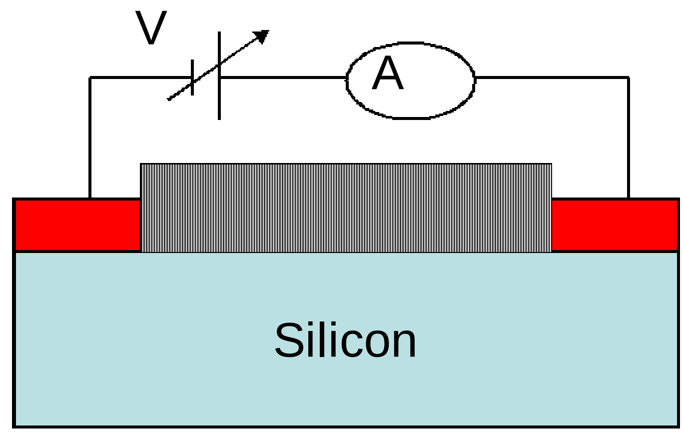




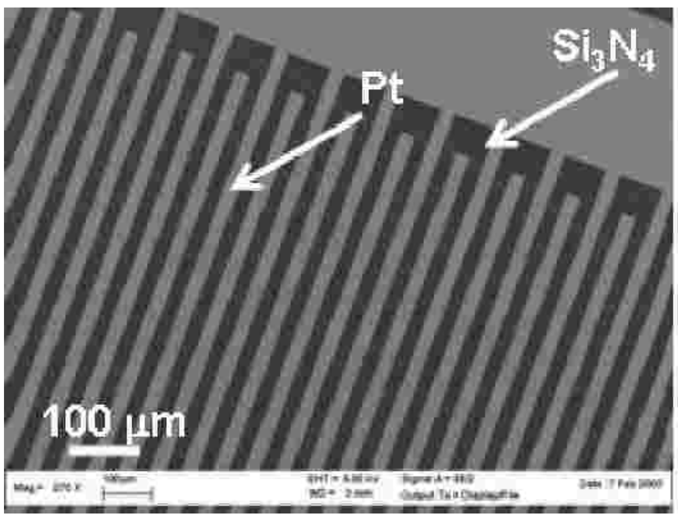
Dark current is the stronger limit!

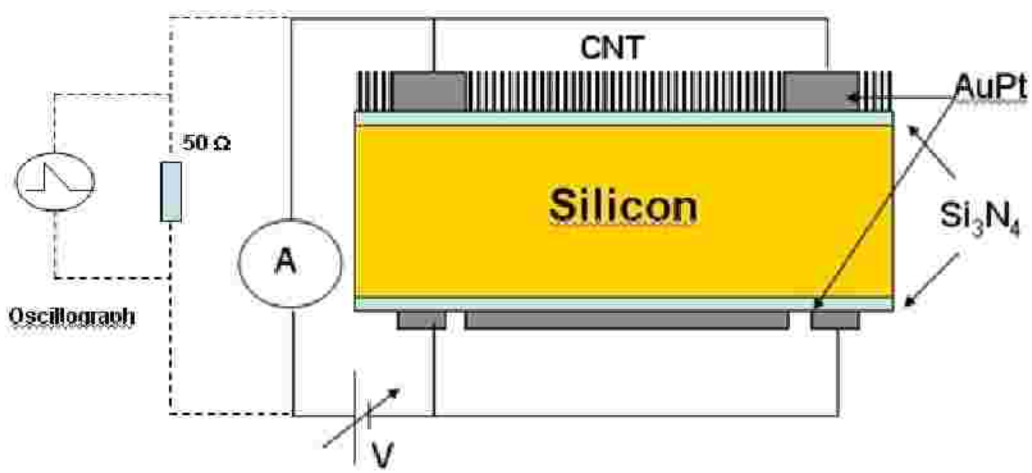
A different architecture under test



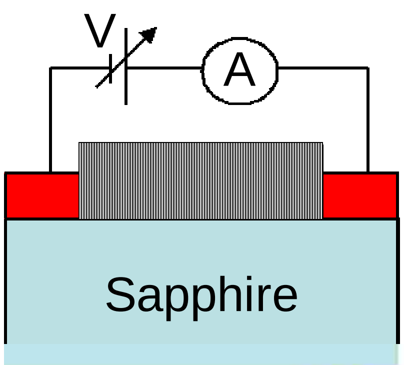


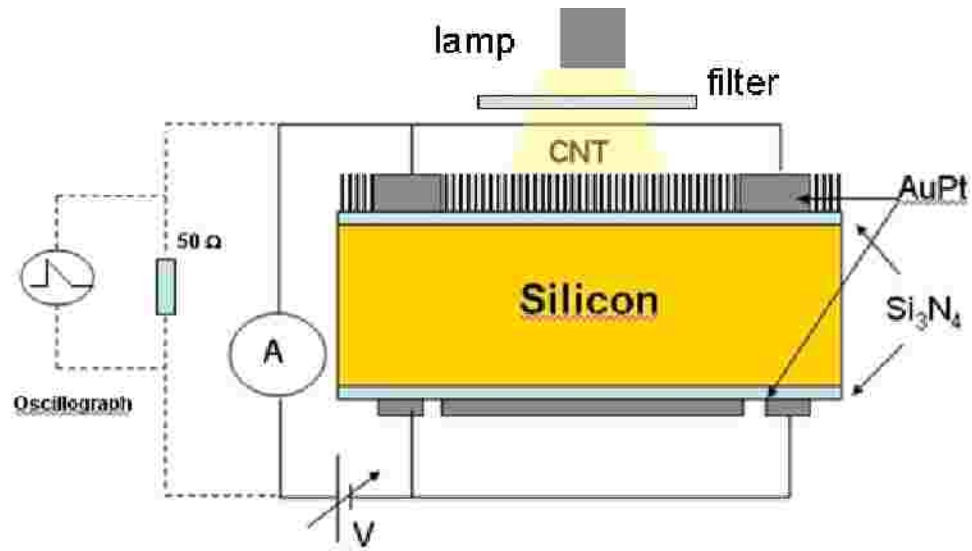
From planar to tridimensional

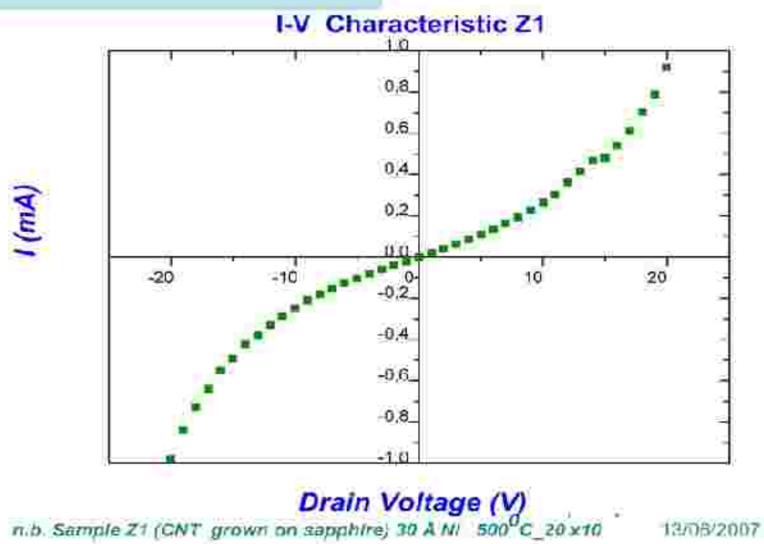


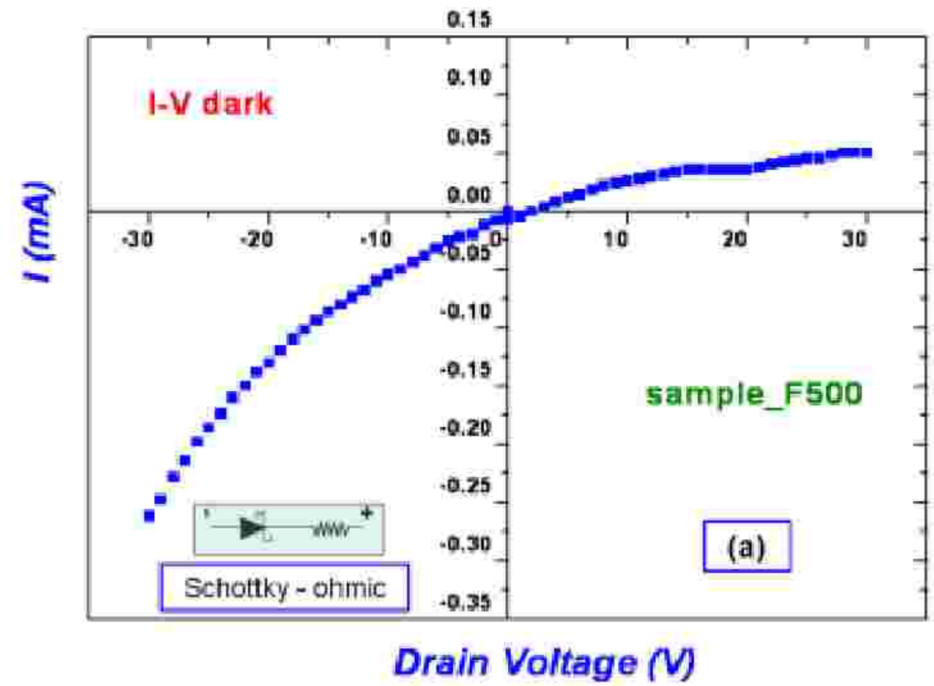


CNT-Silicon: a new **p-n** Junction

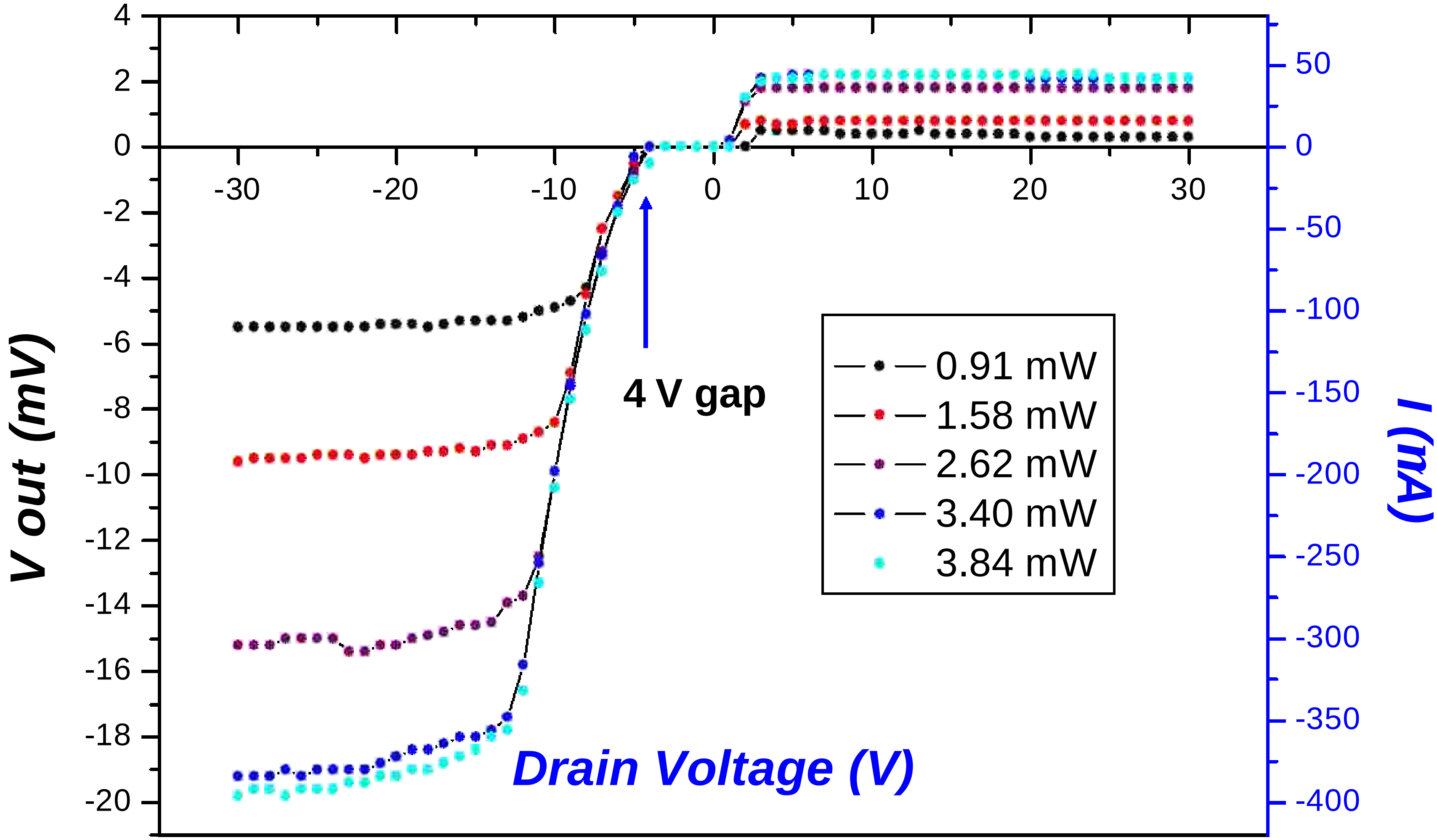




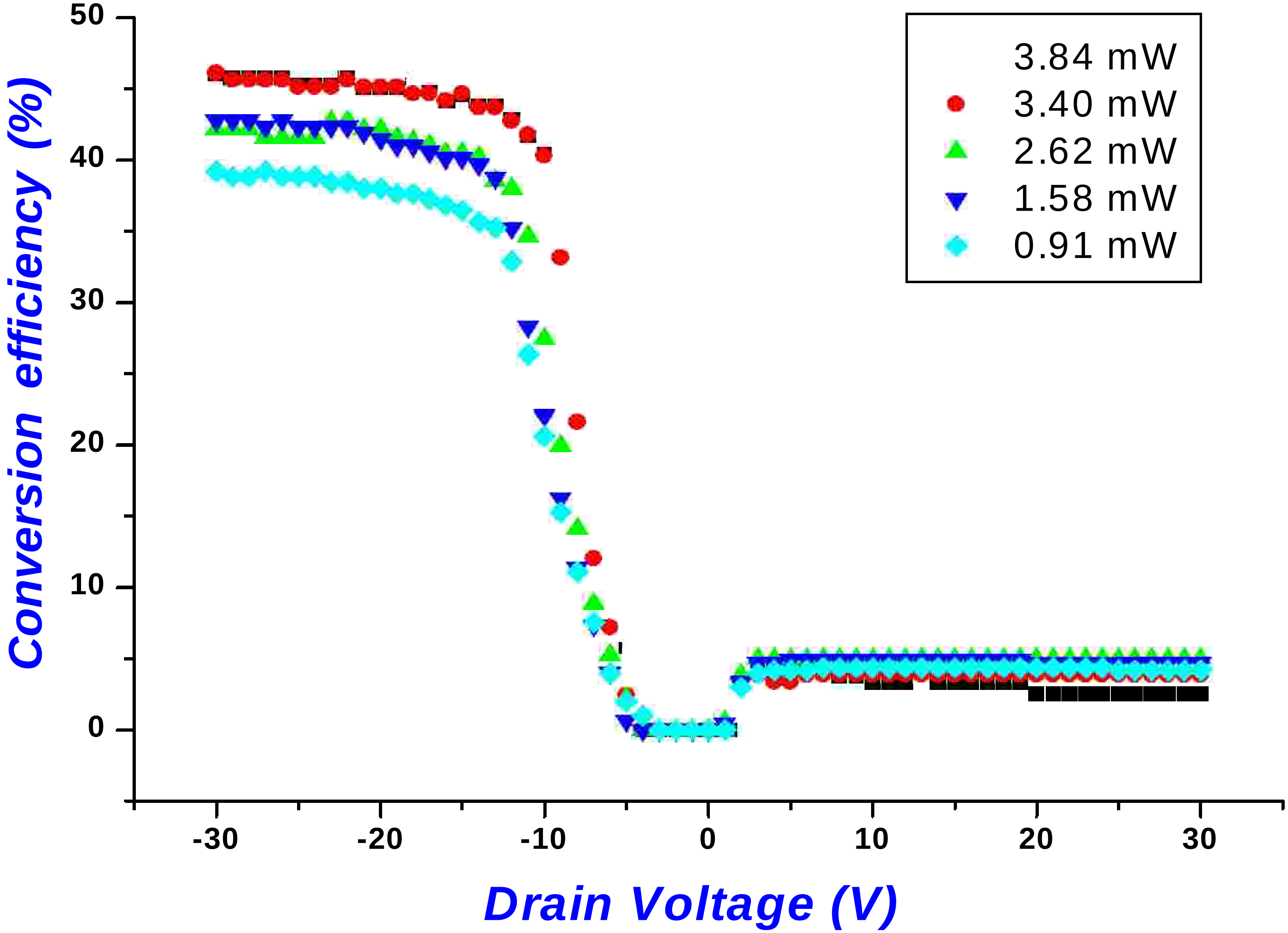




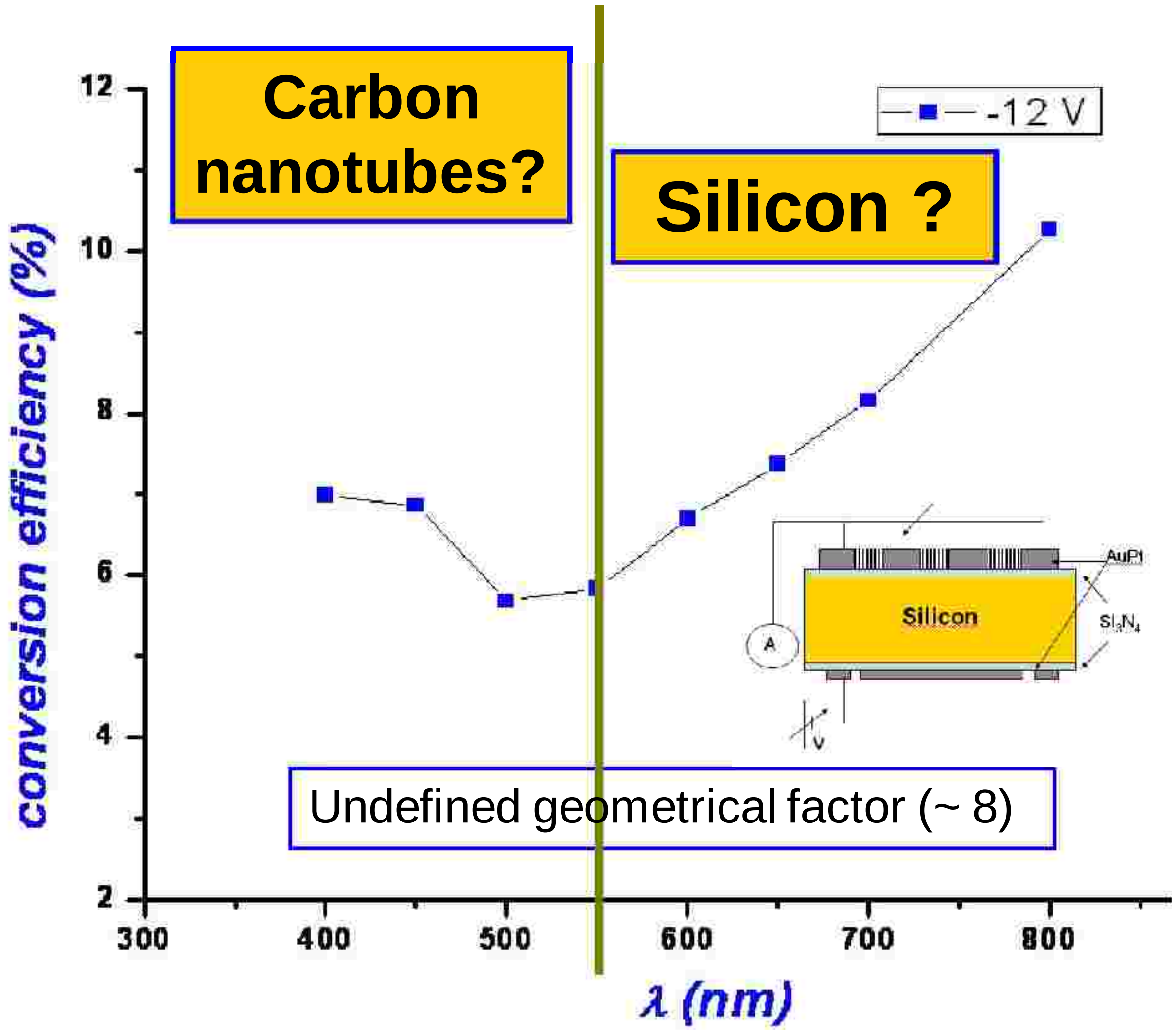
Photocurrent generated with a 650 nm radiation

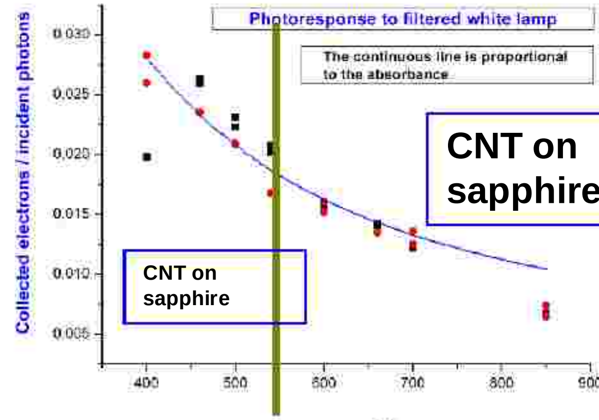


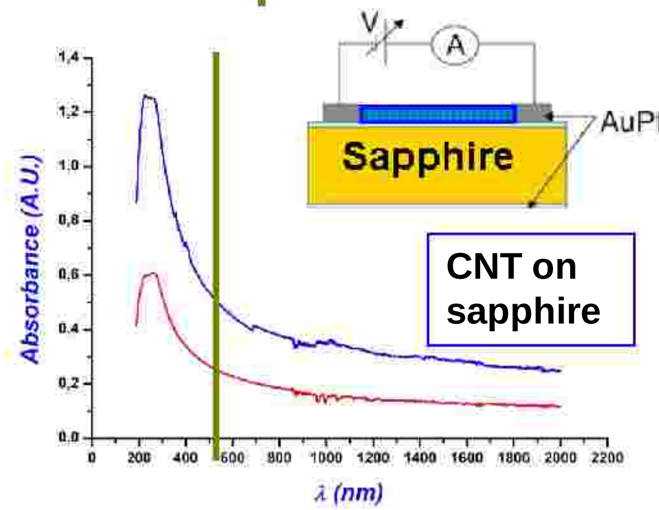
Conversion efficiency at 650 nm

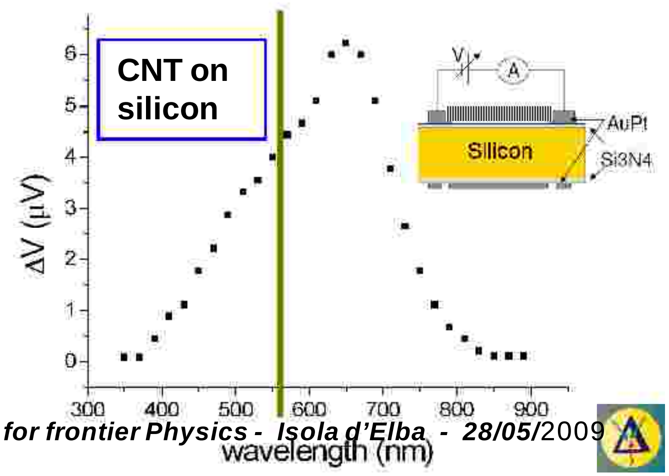


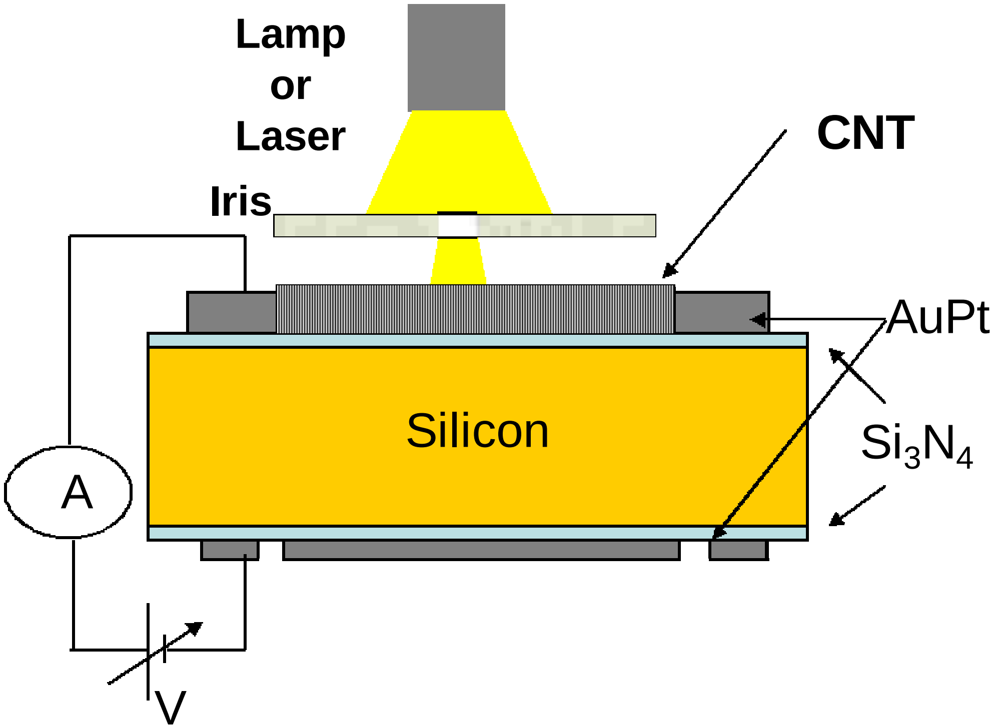
Behaviour at different wavelengths





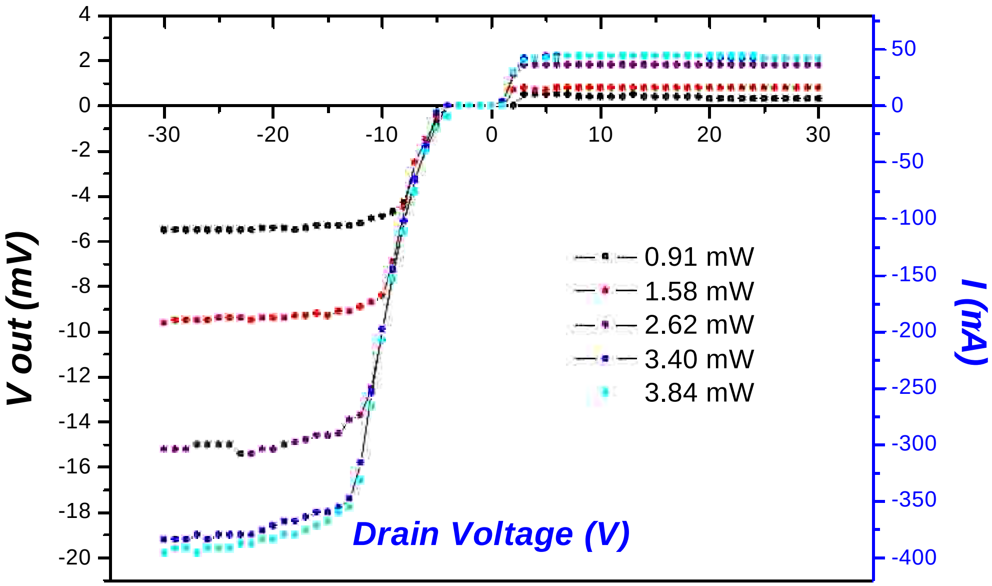


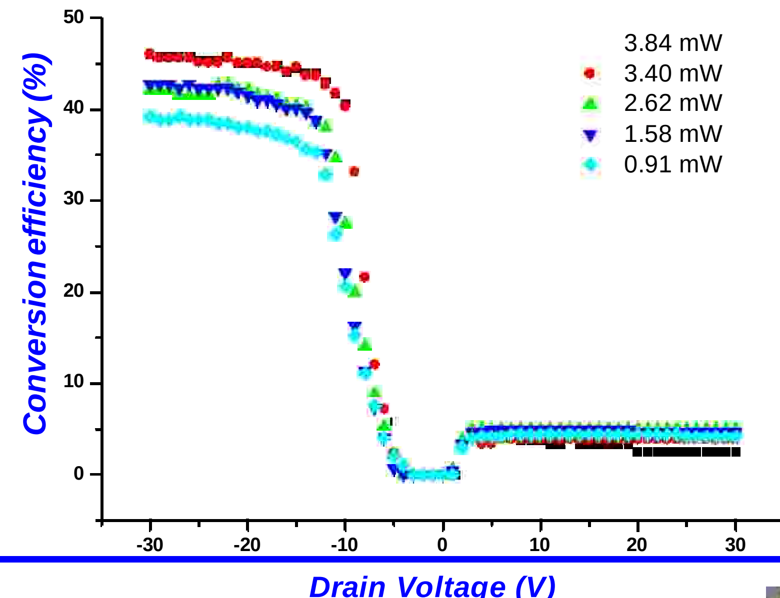


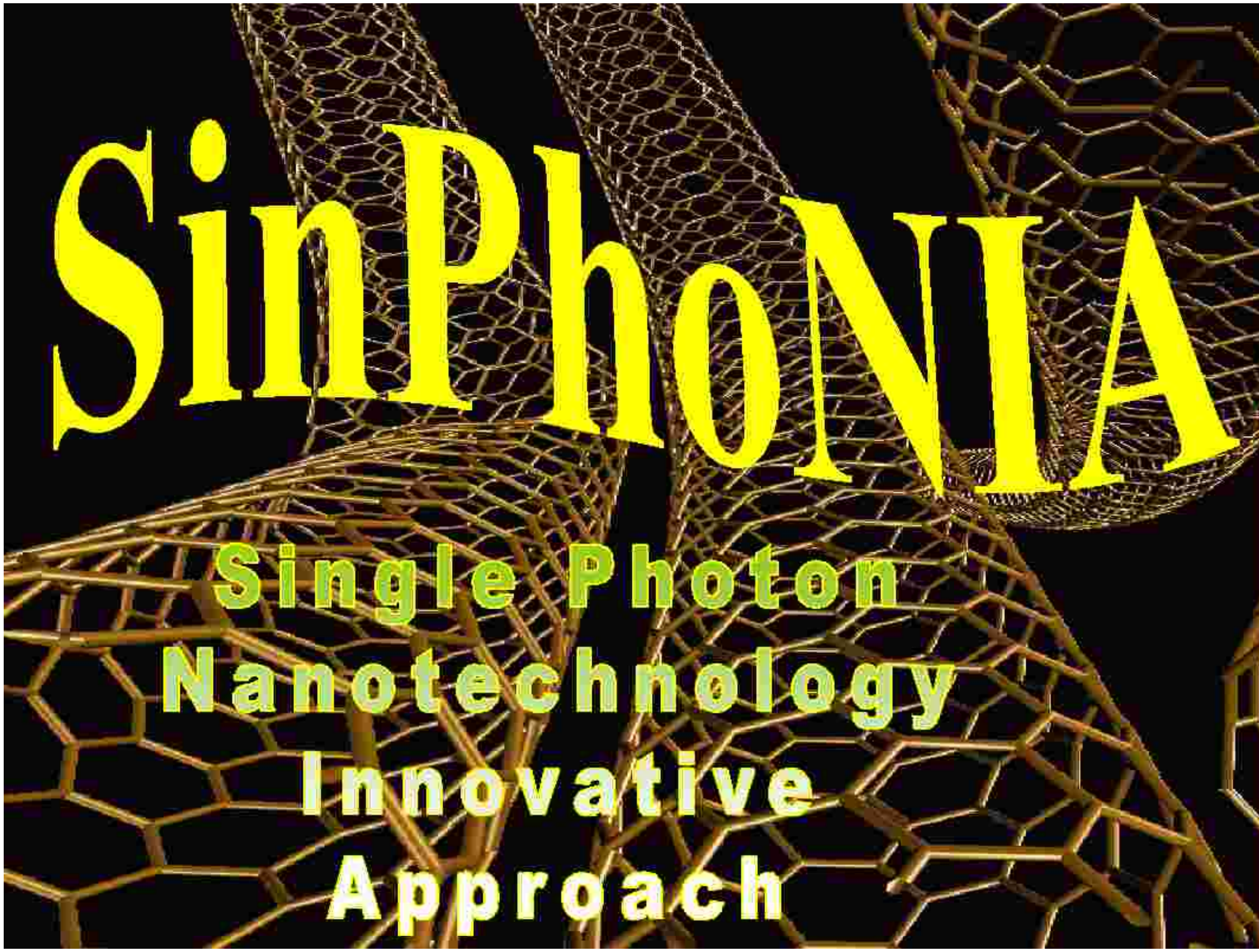


Is this the future:

the linked transition from silicon to carbon?







INFN
&
University of

L'Aquila
Bari
Napoli
Perugia
Roma 2

Development of Single Photon Detector based on MWCNT

The SinPhoNIA collaboration

L'Aquila — 6 **fisici, 3.2 f.e**. ***(produzione CNT, nanofibre, funzionalizzazione, caratterizzazione, proprietà chimiche, coating, …)***

Bari — 7 **fisici, 3.4 f.e.** ***(Misure proprietà elettriche dei film di nanotubi, caratterizzazione UV-VIS dei fotocatodi, …)***

Napoli — 10 **fisici, 4.2 f.e.** ***(rivelatore, nanolitografia, responsivity, indagini ottiche, fotocorrente, photoresponse, …)***

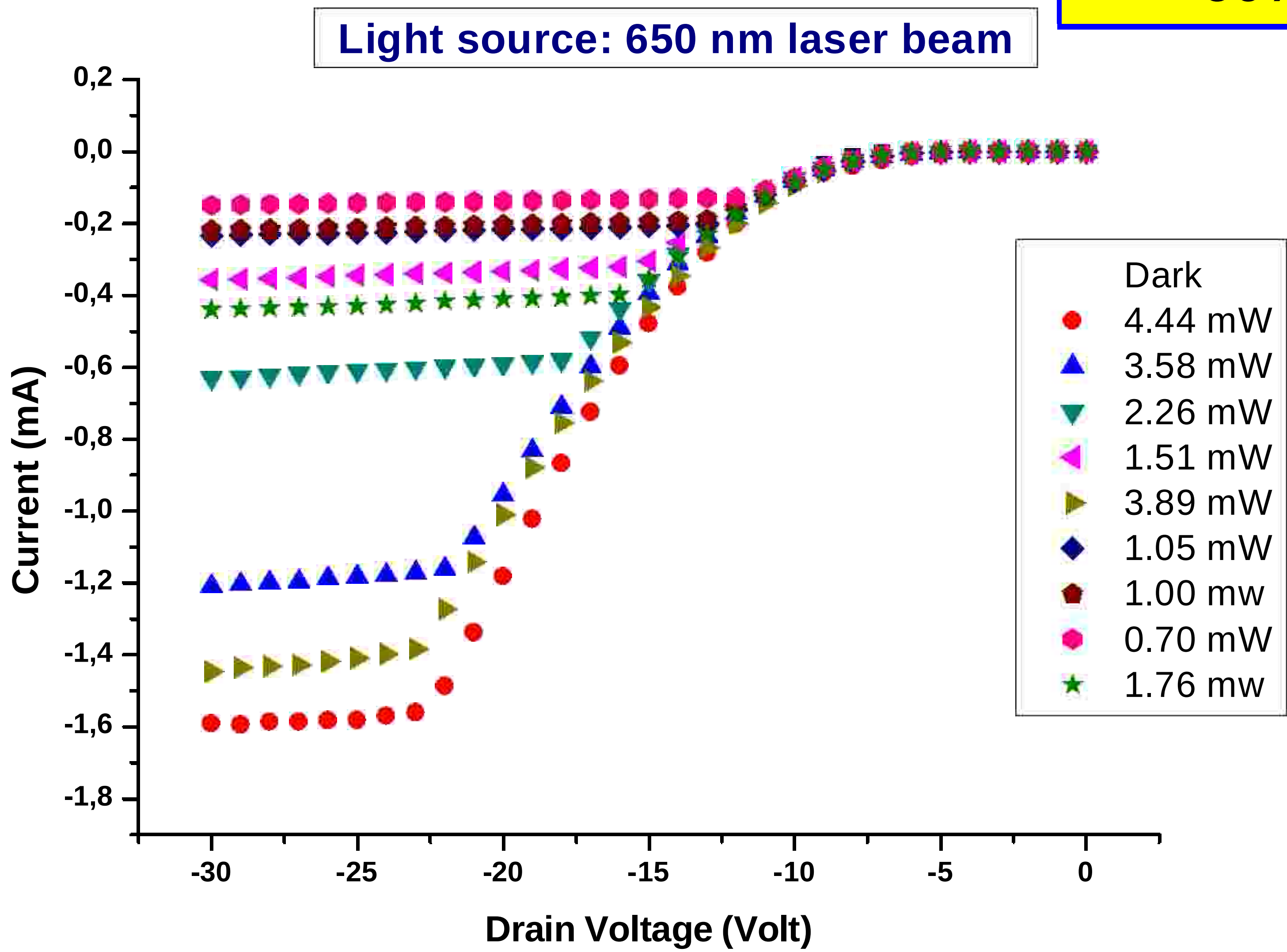
Perugia — 6 **fisici, 2.6 f.e.** ***(Caratterizzazione opto-elettriconica, studio interfaccia, produzione di substrati strutturati, …)***

Roma 2 — 5 **fisici, 1.7 f.e.** ***(Funzionalizzazione dei nanotubi con elementi metallici (Cu, Ag e Au), caratterizzazione con Raman, TEM in alta risoluzione, EXELFS, nanoscopie AFM/STM, …)***

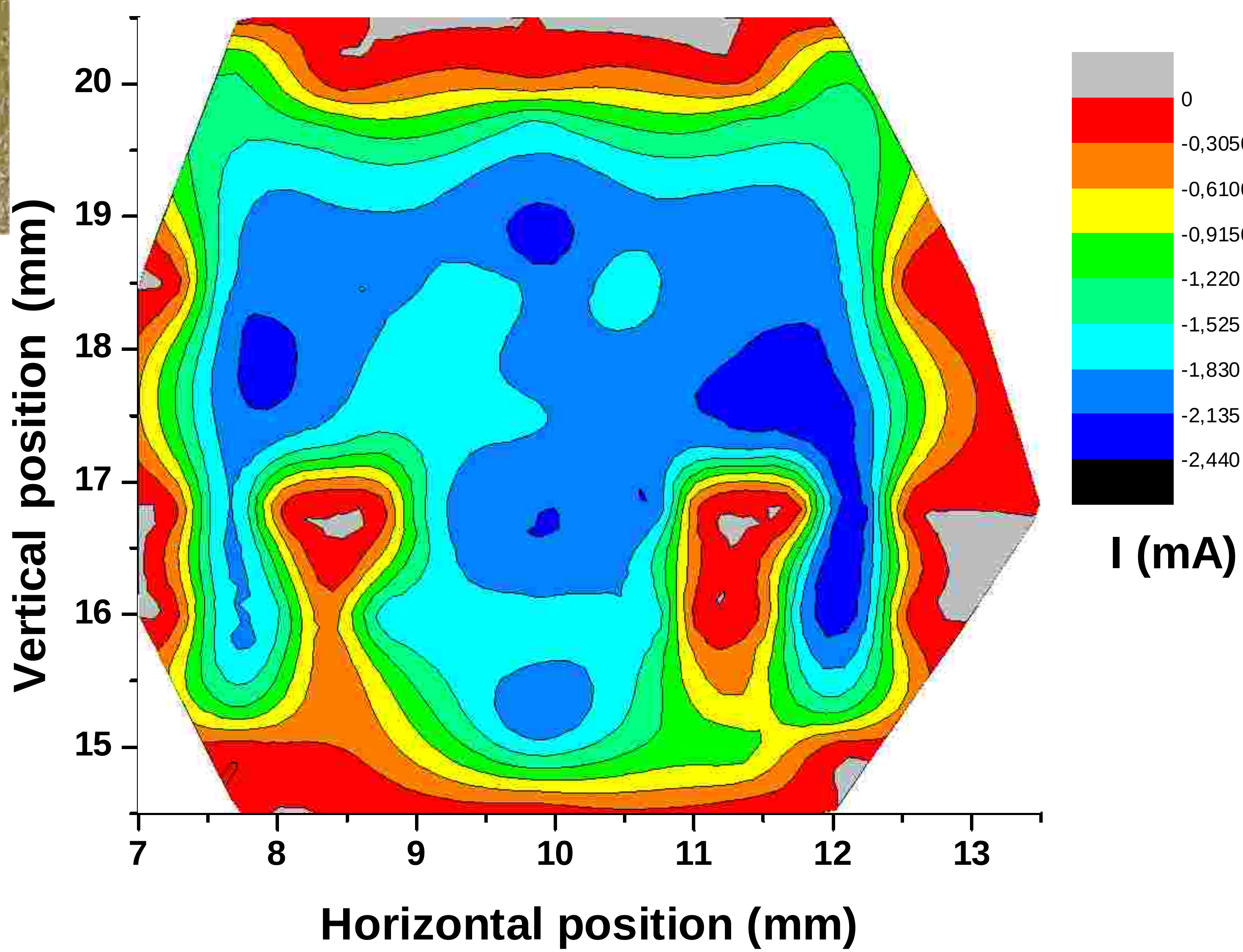
Totale 34 fisici - 15.1 FTE *(44.4%)*

Recent results

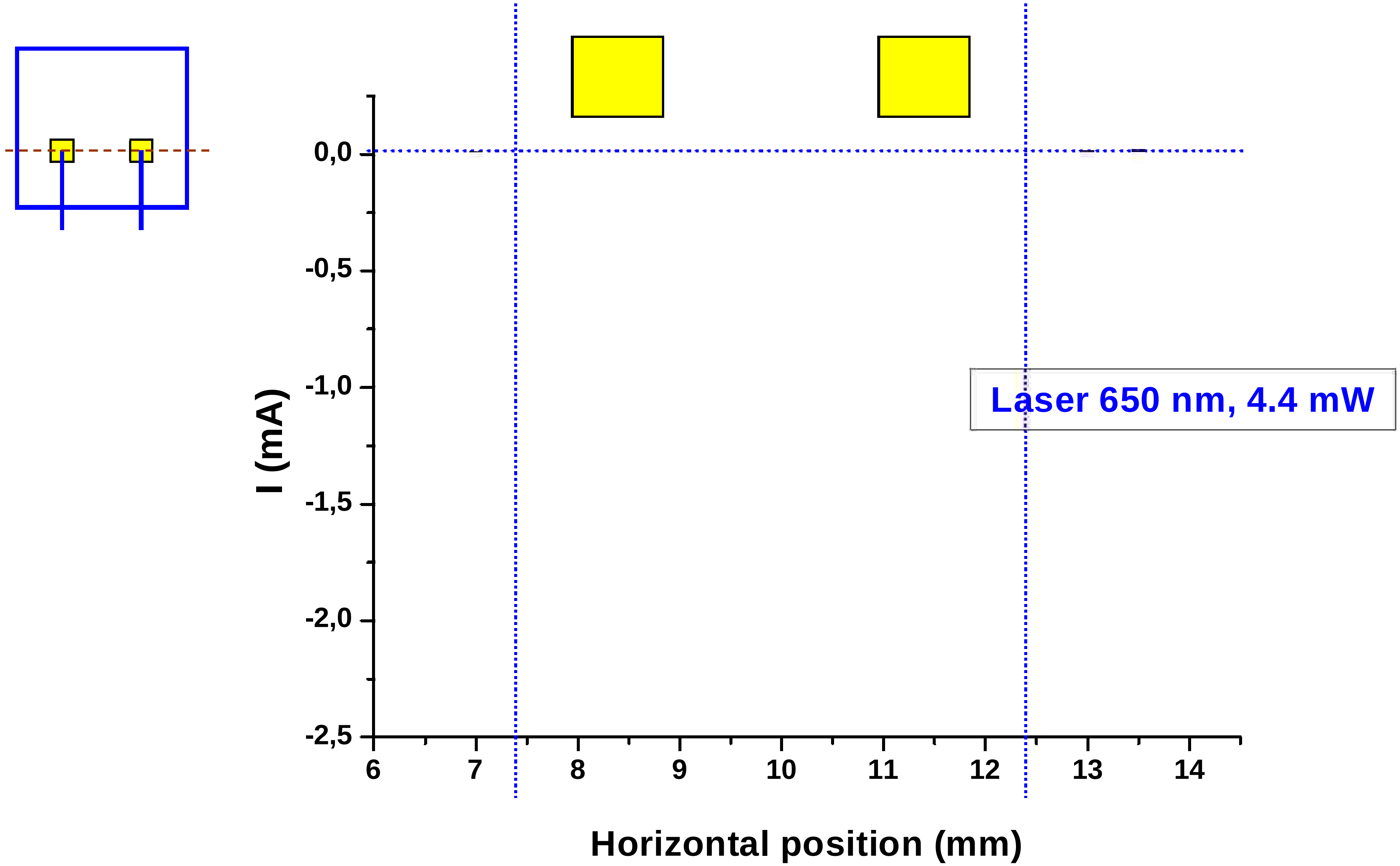
Conversion efficiency ~ 60%



Map of detector surface

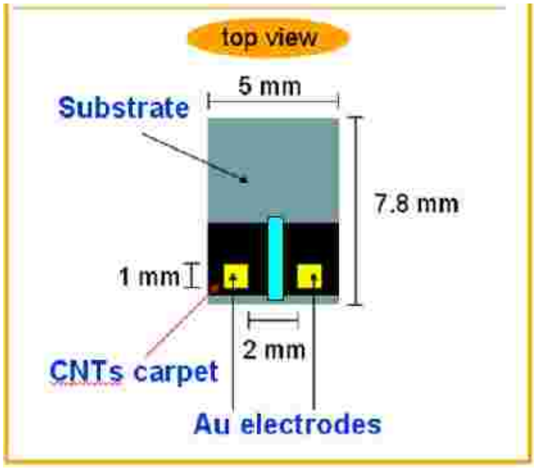


Linear scan

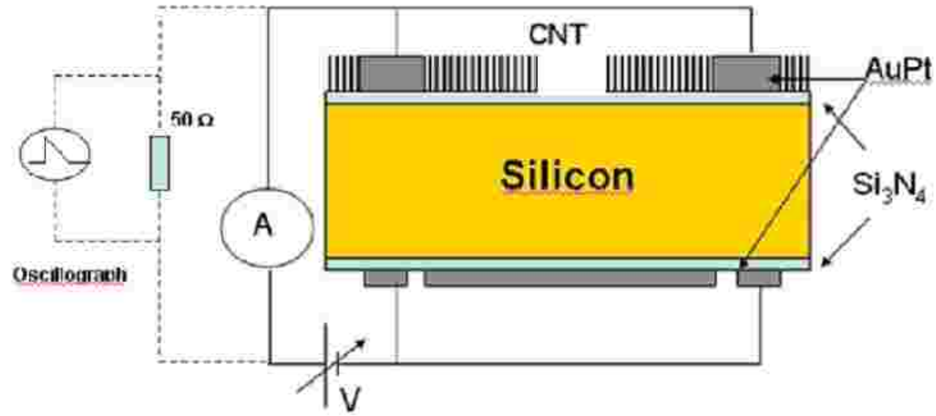


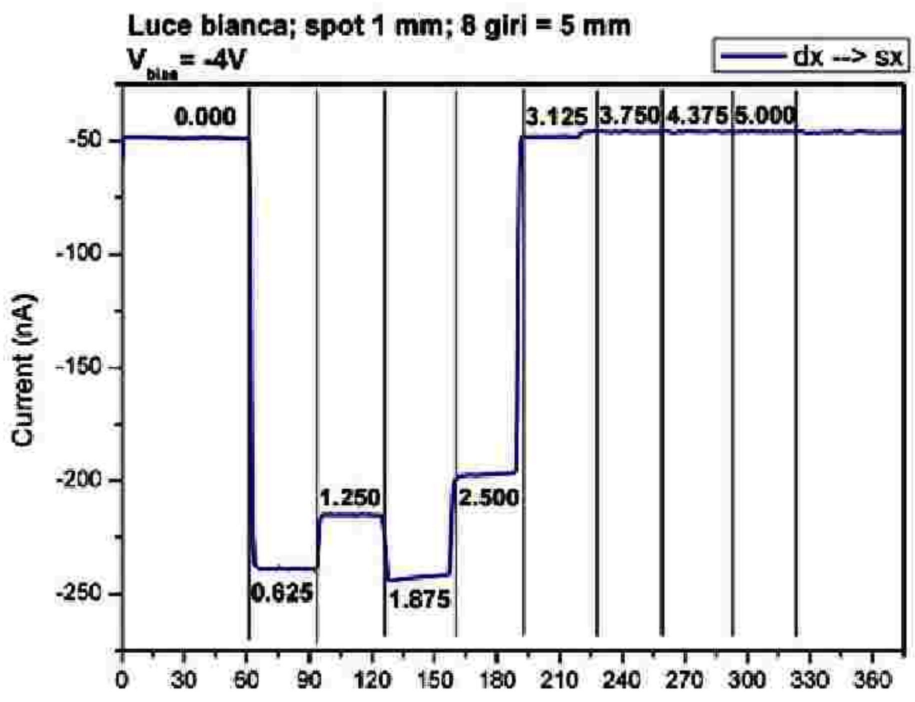
0,0
-0,5
-1,0
-1,5
-2,0
-2,5
I (mA)
6
7
8
9
10
11
12
13
14
Horizontal position (mm)
Laser 650 nm, 4.4 mW

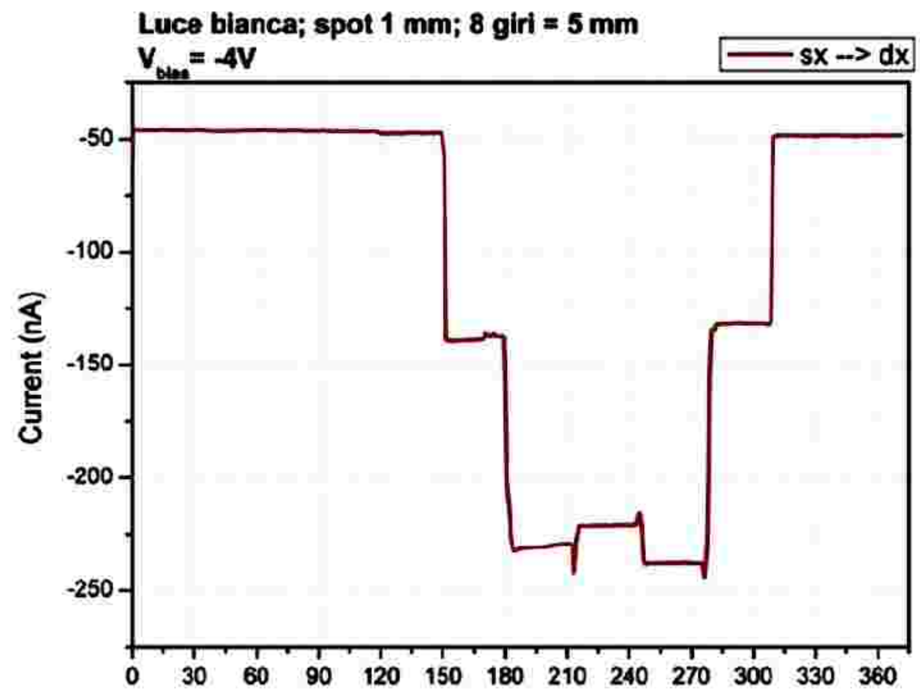
Two insulae sample



Scan with optical fiber

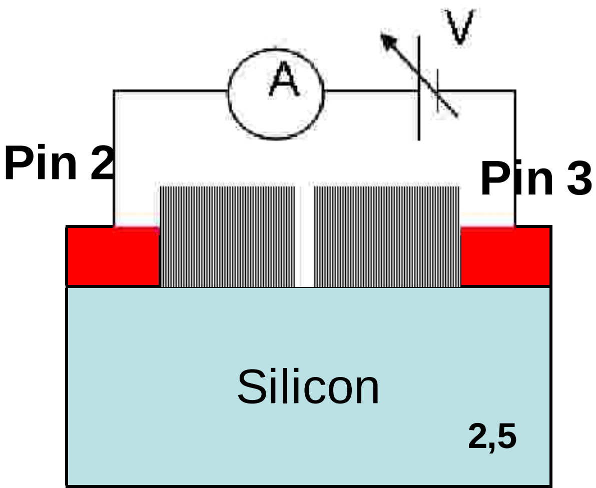


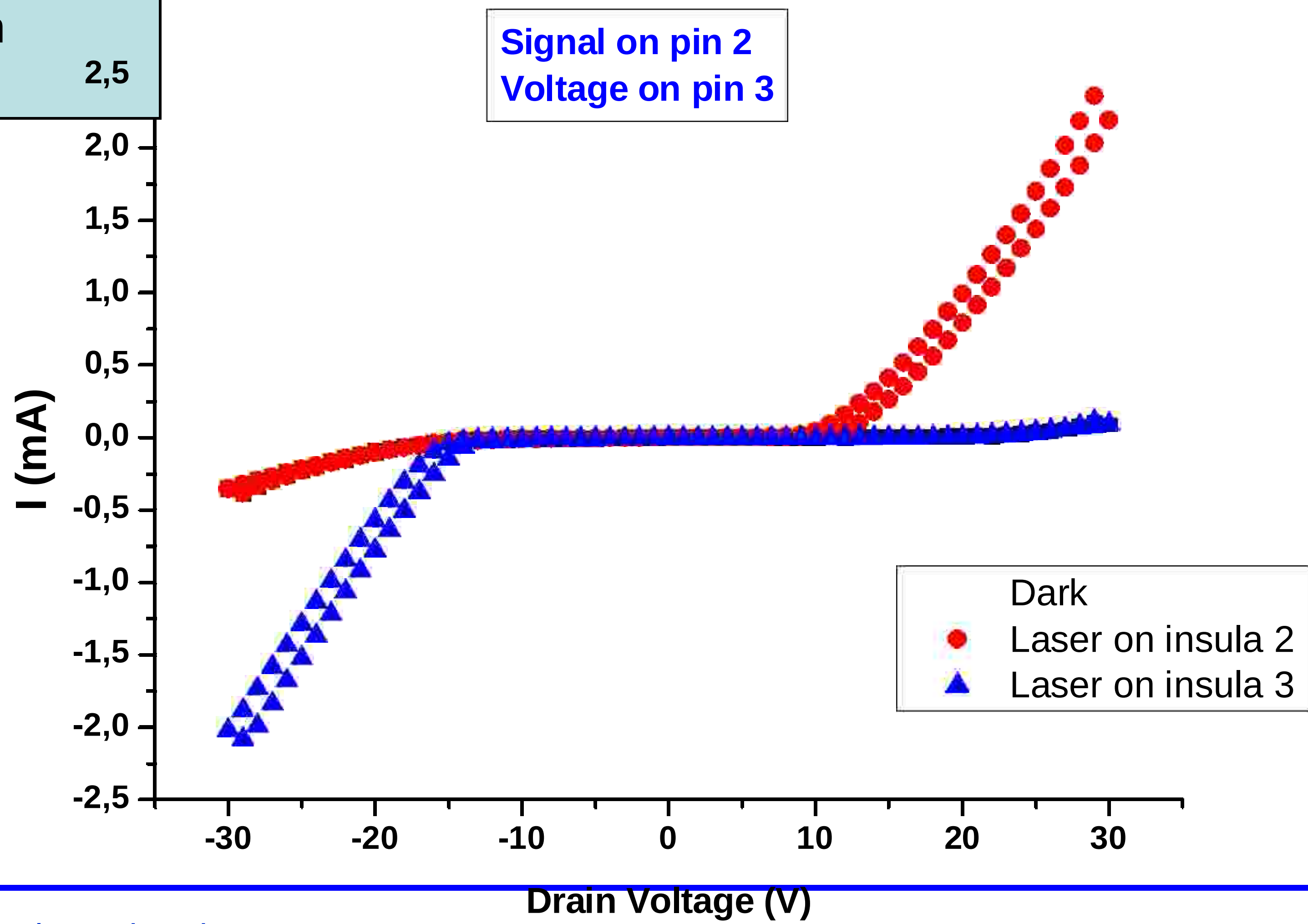




Two insulae sample

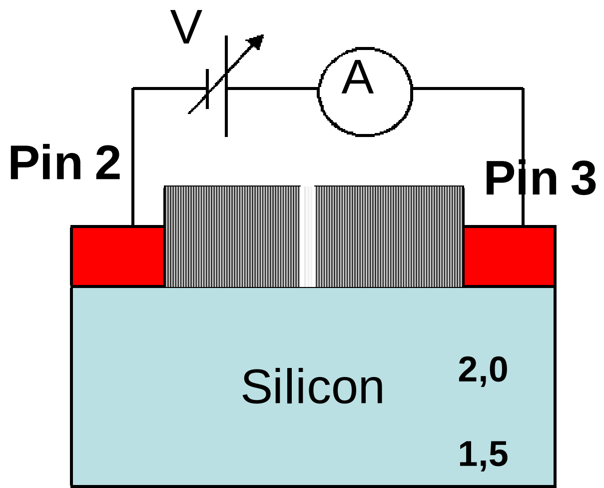
Scan with 650 nm laser

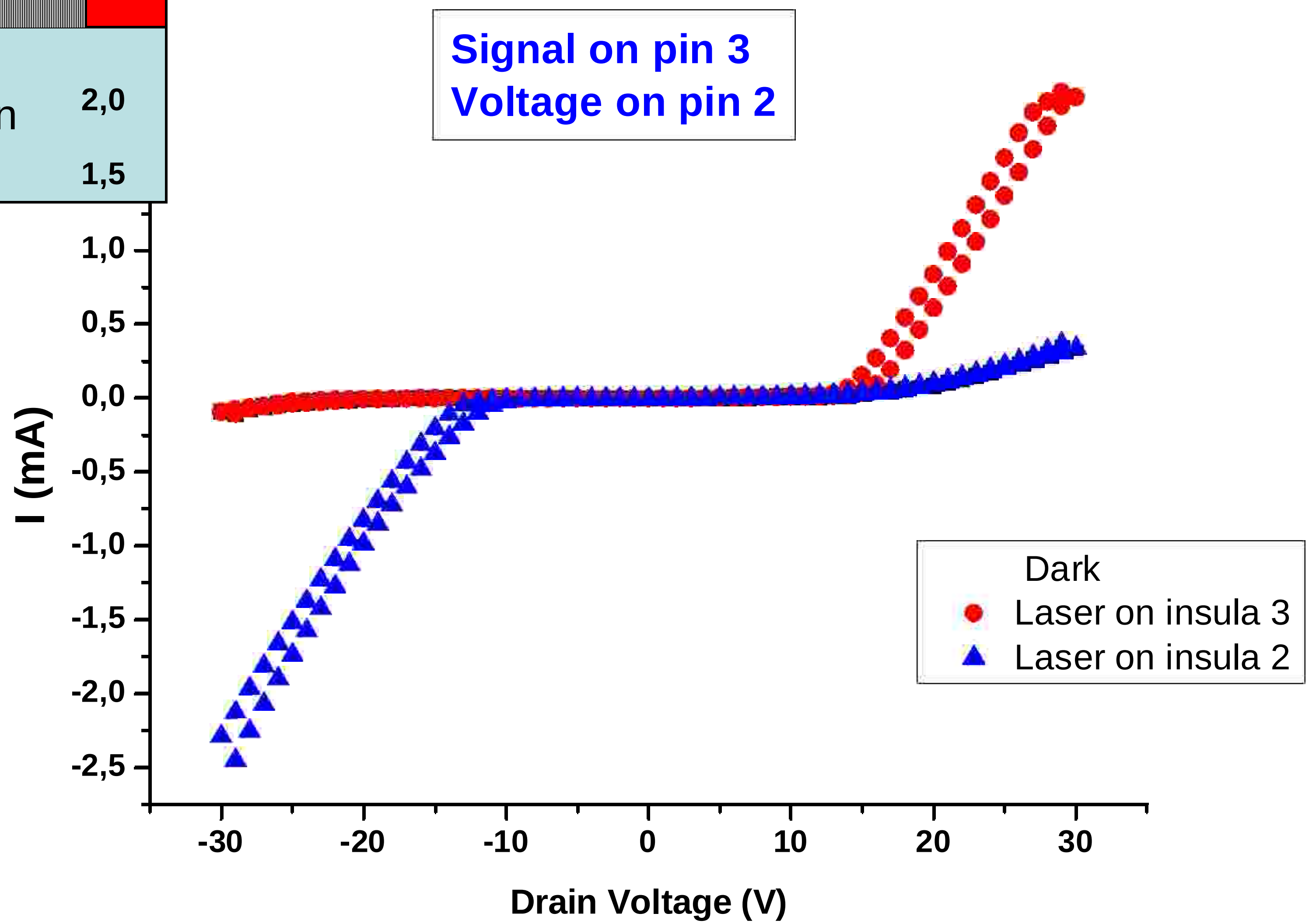




Two insulae sample

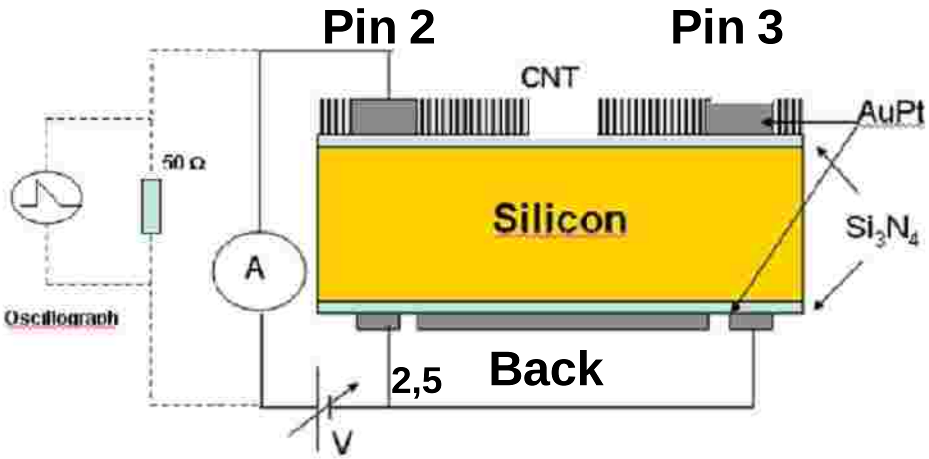
Scan with 650 nm laser

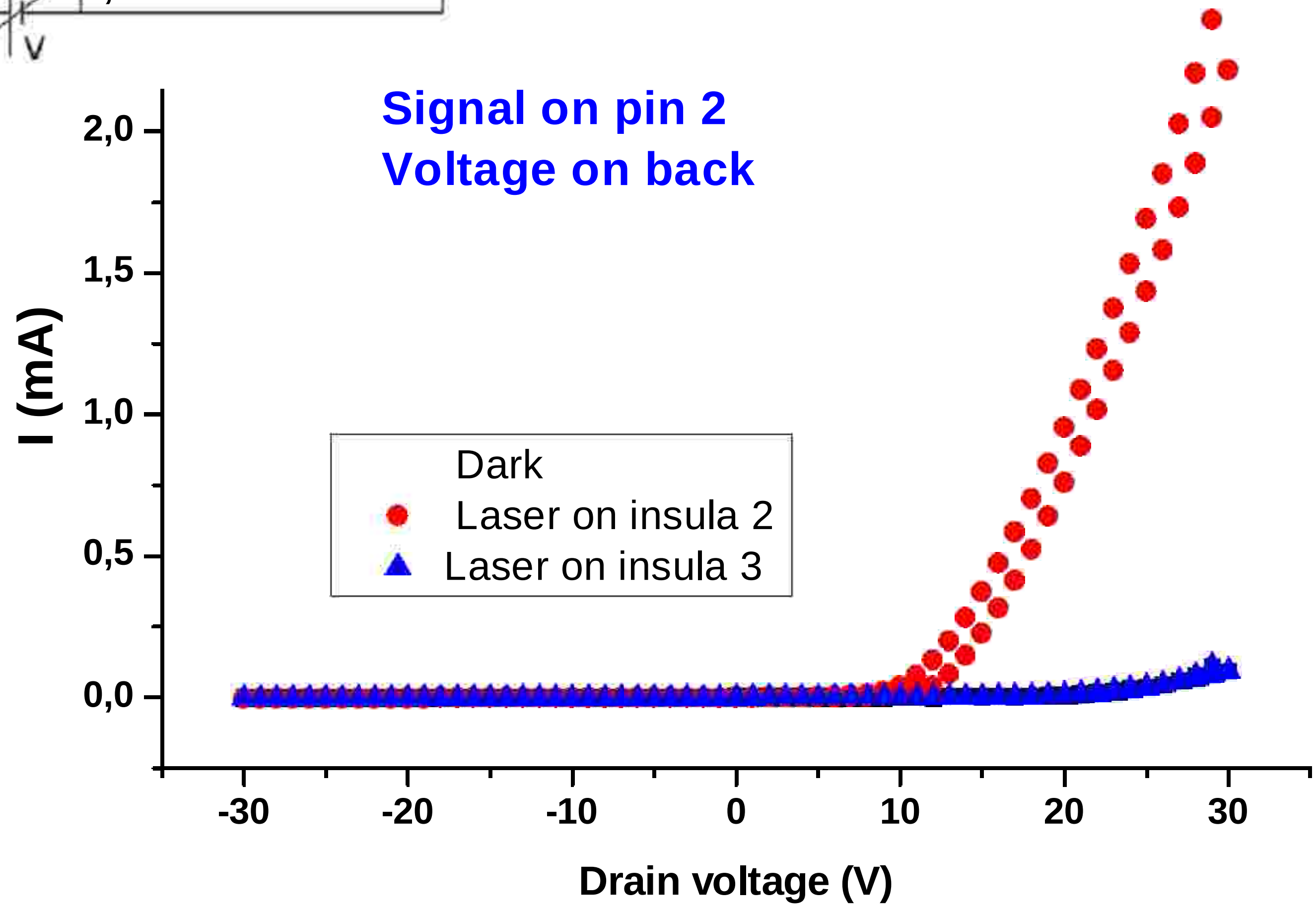




Two insulae sample

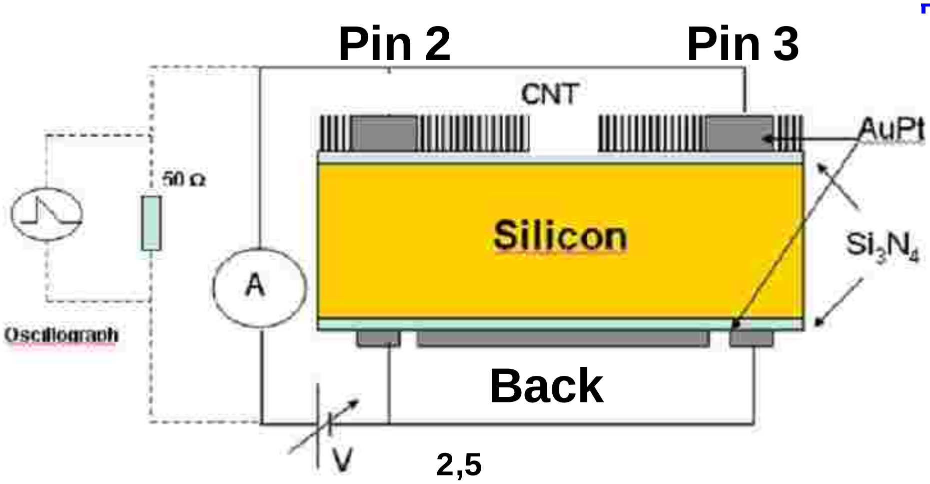
Scan with 650 nm laser

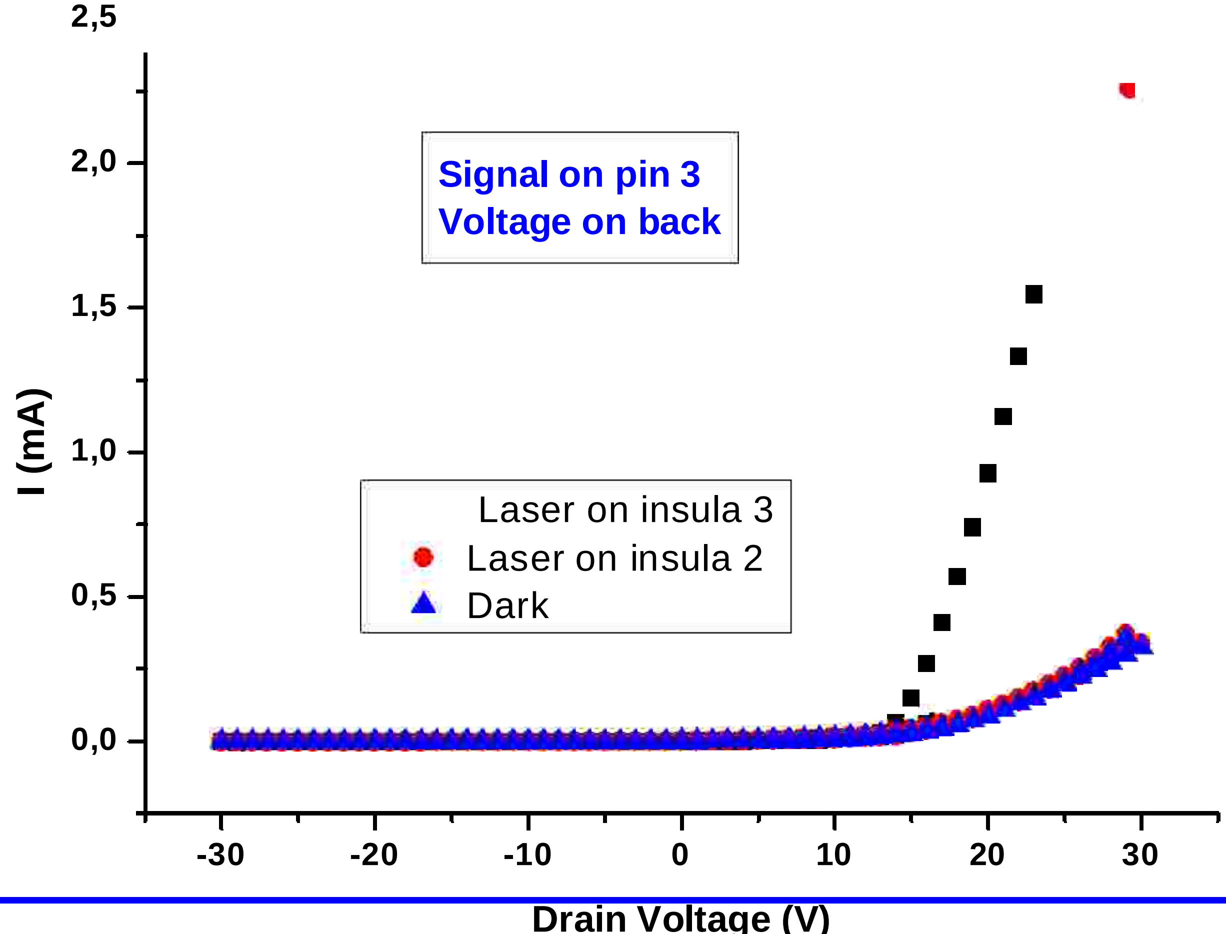




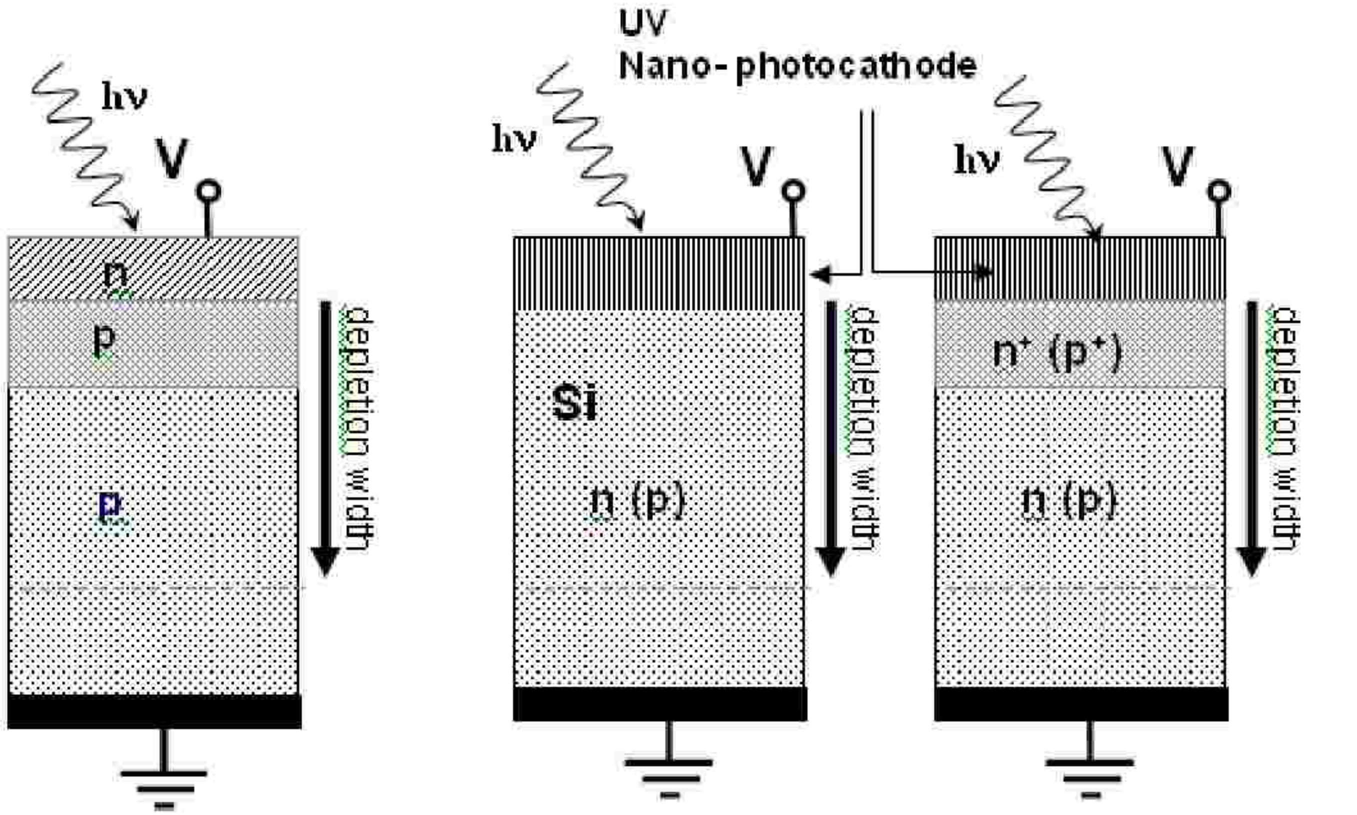
Two insulae sample

Scan with 650 nm laser





A possible detector layout

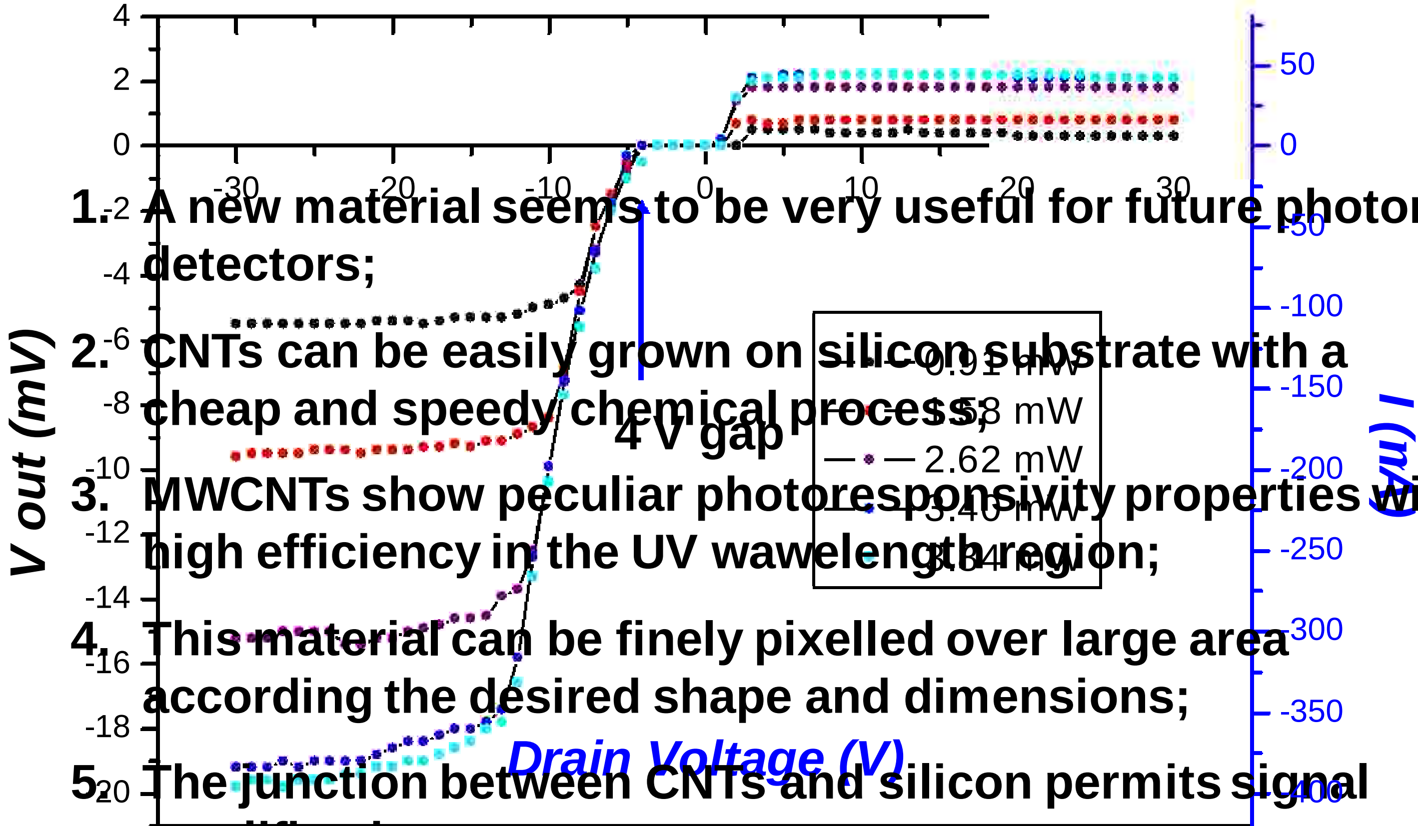


a) 2009- Silicon photomultiplier
(Principle structure)

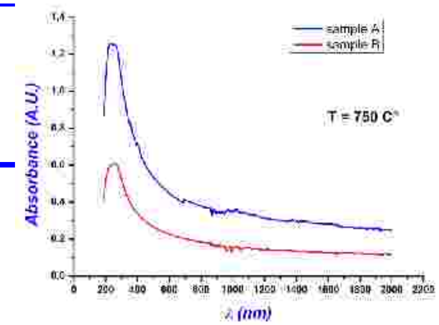
b) Nano-Silicon diode
(base structure for study)

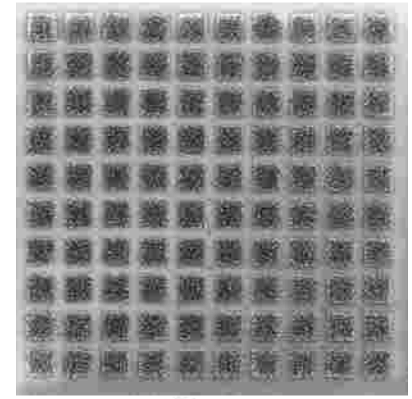
c) N-SiPM → 201(1?)
(final structure – main objective)

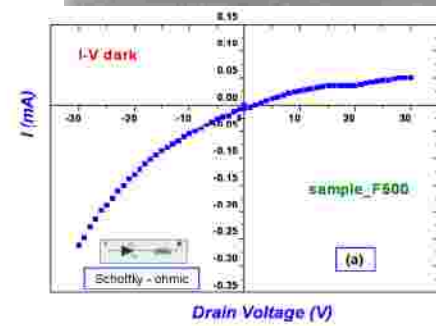
Conclusion



1. A new material seems to be very useful for future photon detectors;
2. CNTs can be easily grown on silicon substrate with a cheap and speedy chemical process;
3. MWCNTs show peculiar photoresponsivity properties with high efficiency in the UV wavelength region;
4. This material can be finely pixelled over large area according the desired shape and dimensions;
5. The junction between CNTs and silicon permits signal amplification

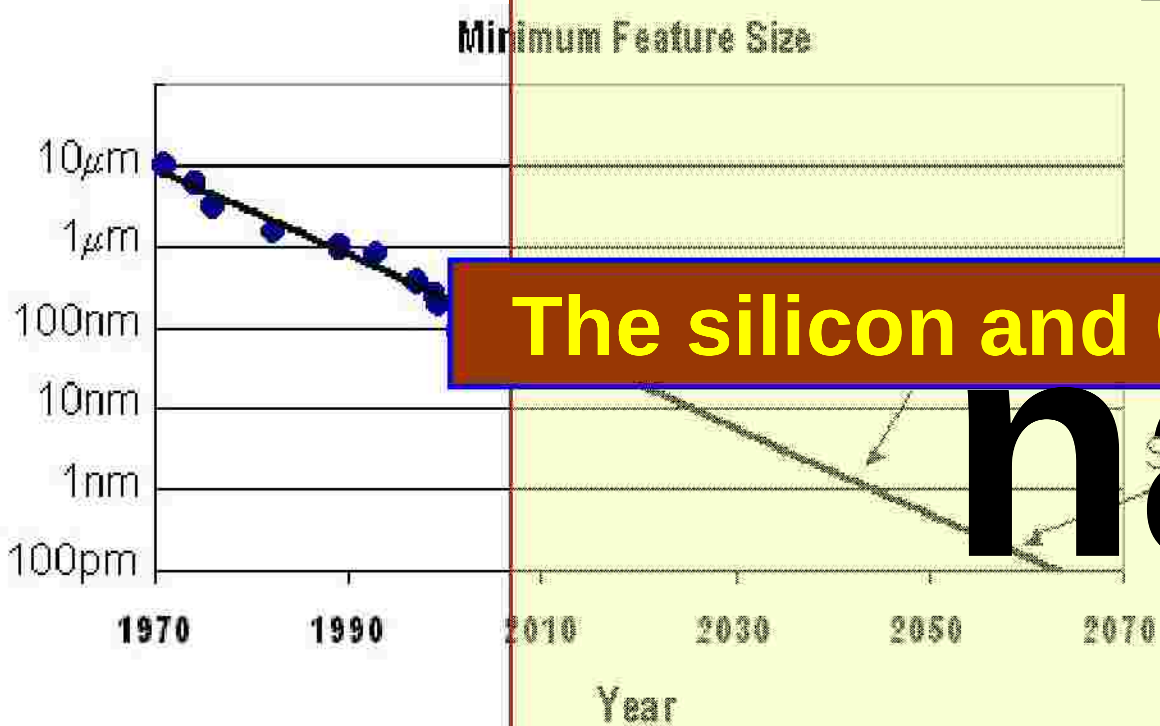






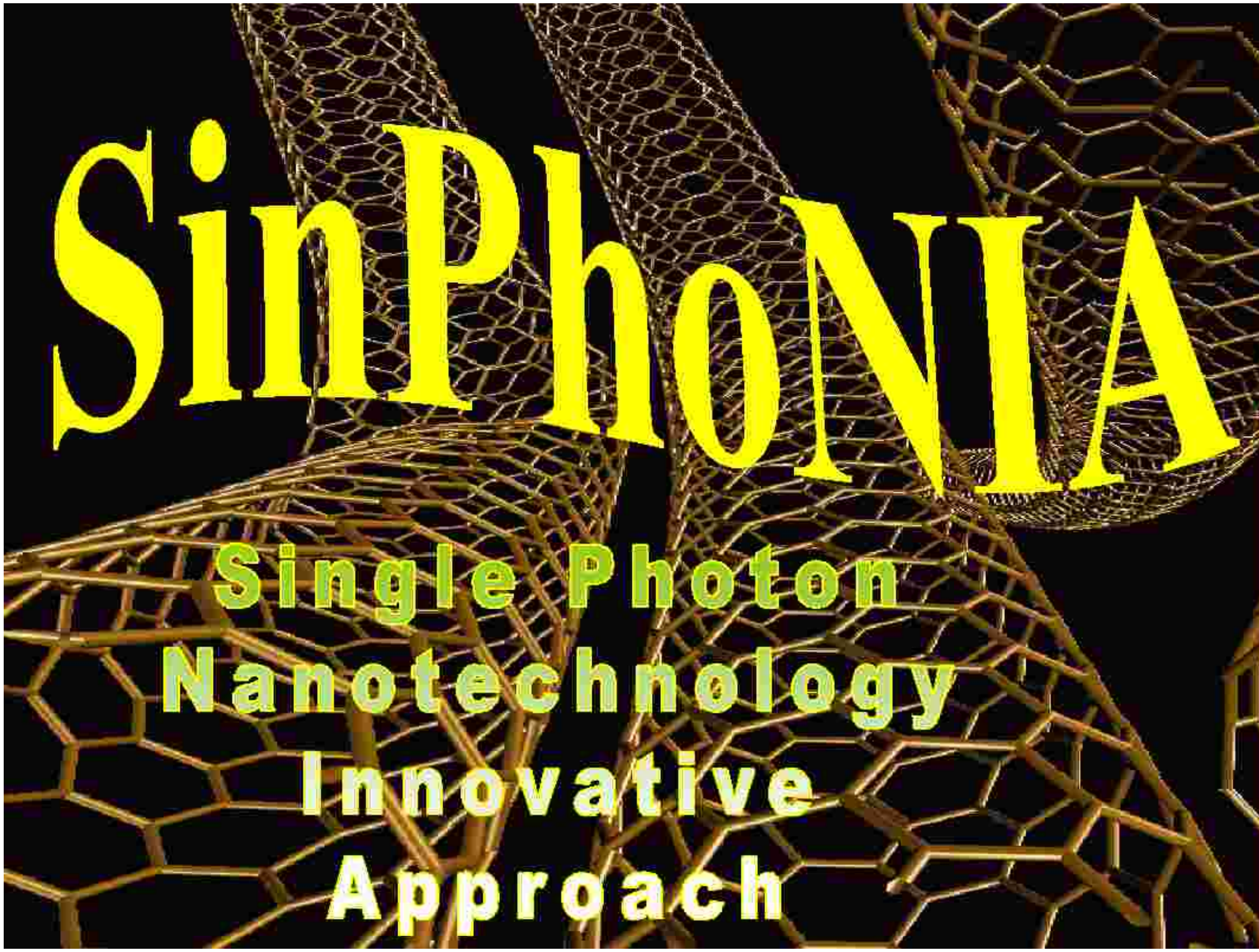
The SinPhoNIA collaboration is working to produce a single photon detector with the combined use of Silicon and Carbon in the form of Nanotubes.

The SinPhoNIA experiment



The nano world

The silicon and CNT world



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Thank you for your attention

Michelangelo Ambrosio -