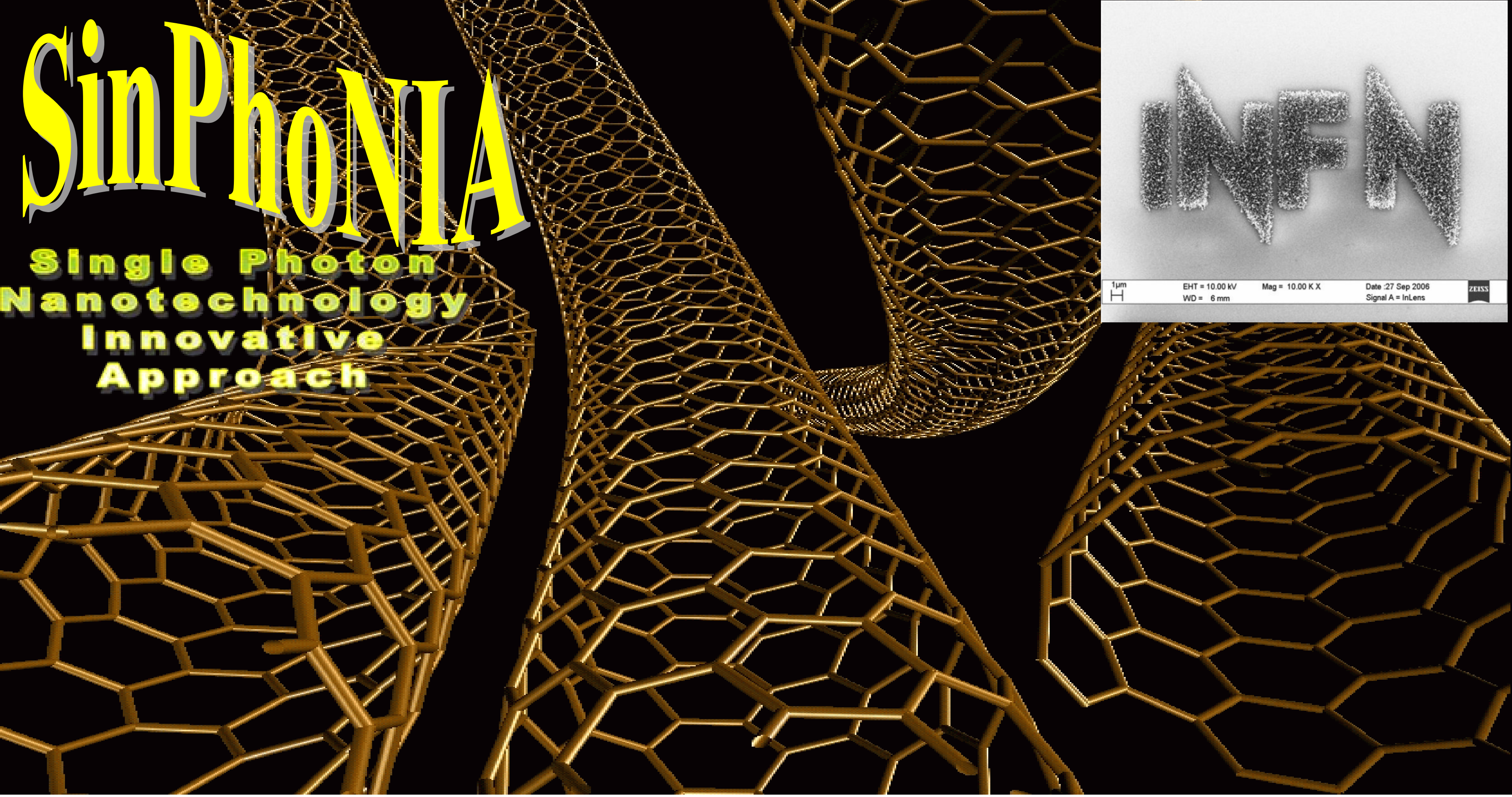



INFN Istituto Nazionale di Fisica Nucleare

http://sinphonia.na.infn.it/index.htm

# Progress in the realization of a SiC photodetector

Carla Aramo

6th NDIP Conference - Lyon _ July 4-8, 2011

New Developments In Photodetection

Palais des Congrès, Aix-les-Bains - France, **June 15-20, 2008**

5TH NDIP CONFERENCE

**From far Infrared to Gamma rays**

Opening session:

# Nanotechnology: A New Era for Photodetection?

Highlight


**Abstract**

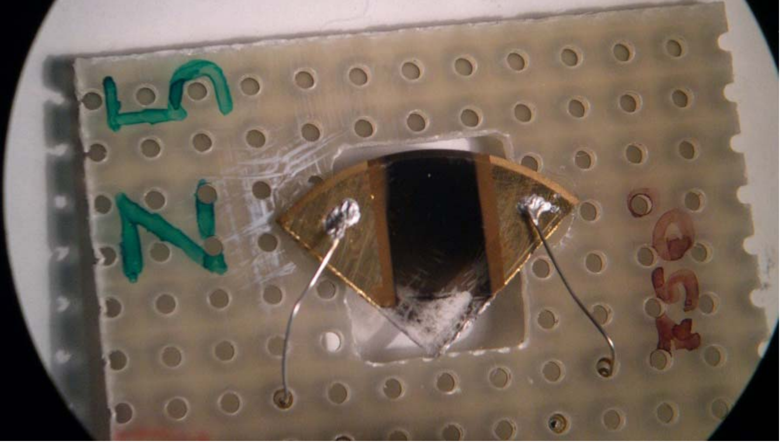
Nowadays we live in the so-called "Silicon Era", in which devices based on the silicon technology permeate all aspects of our daily life. One can simply think how much silicon is in the everyday household objects, gadgets, and appliances.

The impact of silicon technology has been very relevant in the photodetection as well. It enabled to design Large or Very Large Scale Integration devices, in particular microchips and pixelled detectors like the Silicon Photo Multiplier made of micrometric channels grouped in $mm^2$ pixels. However, on the horizon, the recent development of nanotechnologies is opening a new direction in the design of submicron photodevices, owing to the capability to deal with individual molecules of compounds or to chemically grow various kinds of materials.

Among them, carbon compounds appear to be the most promising materials being chemically very similar to silicon, abundant and easy to handle. In particular, carbon nanotubes (CNT) are a very intriguing new form of material, whose properties are worldwide being studied providing important results.

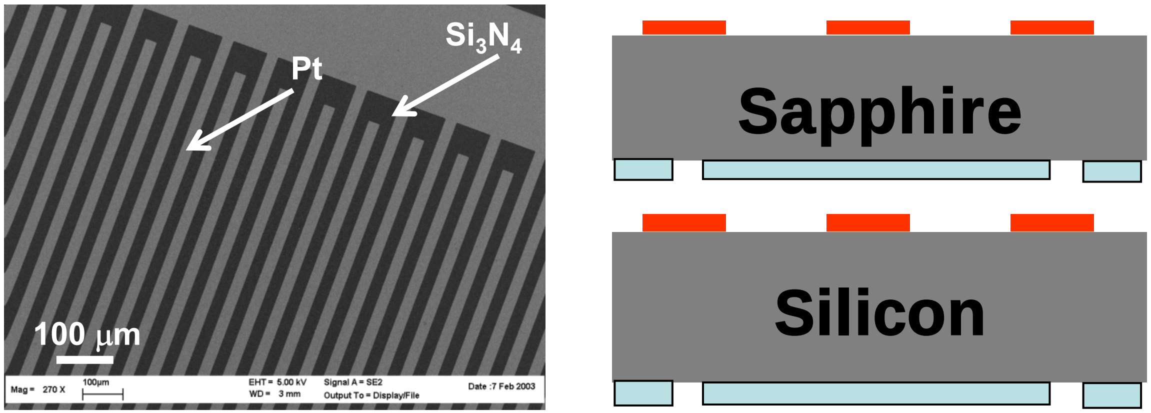
The photoelectric effects observed on carbon nanotubes indicate the possibility to build photodetectors based on CNTs inducing many people to claim that we are at the beginning of a Post Silicon Era or of the Carbon Era.

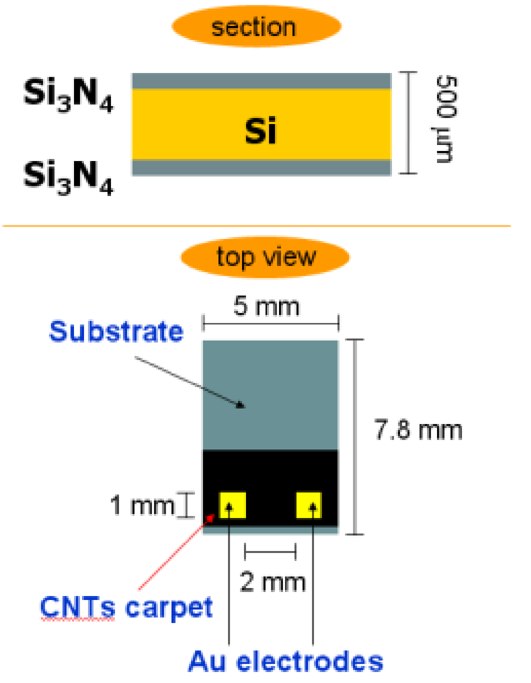
In this paper, we report on the most important achievements obtained on the application of nanotechnologies to photodetection and medical imaging, as well as to the development of radiation detectors for astro-particle physics experiments.

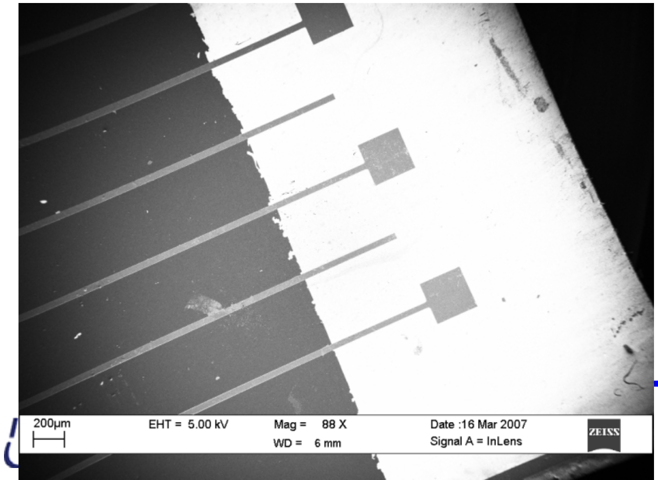


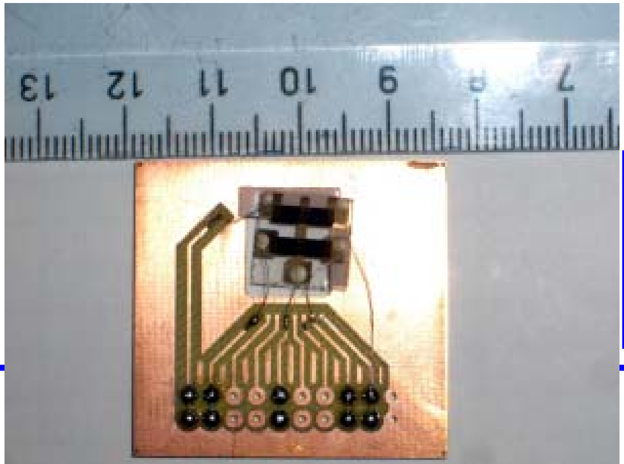
# GINT

(Gruppo INFN per le NanoTecnologie)



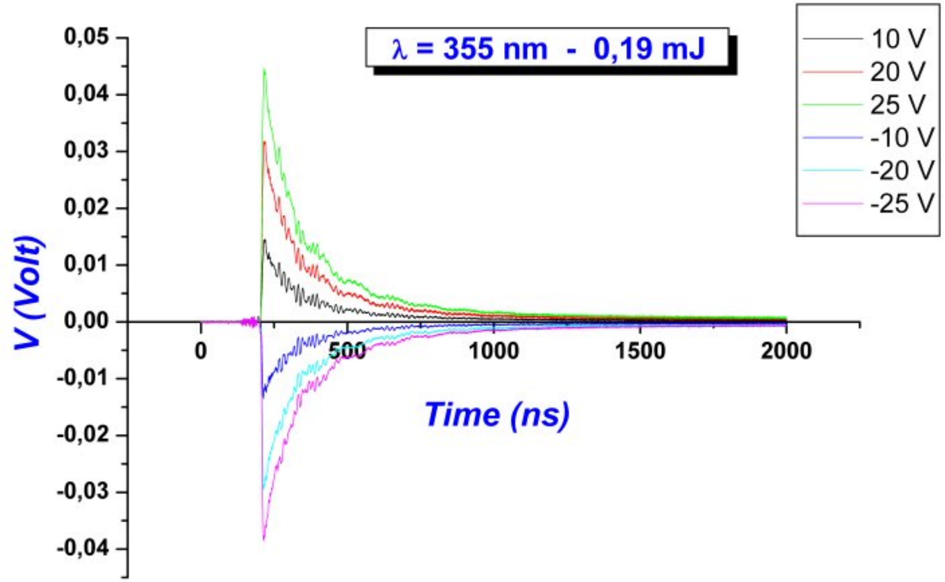



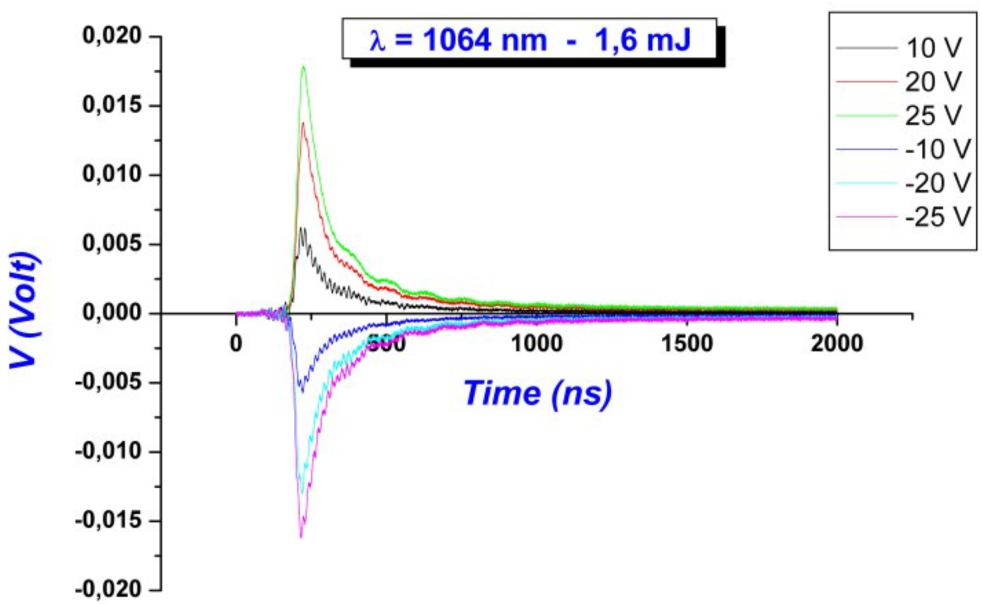



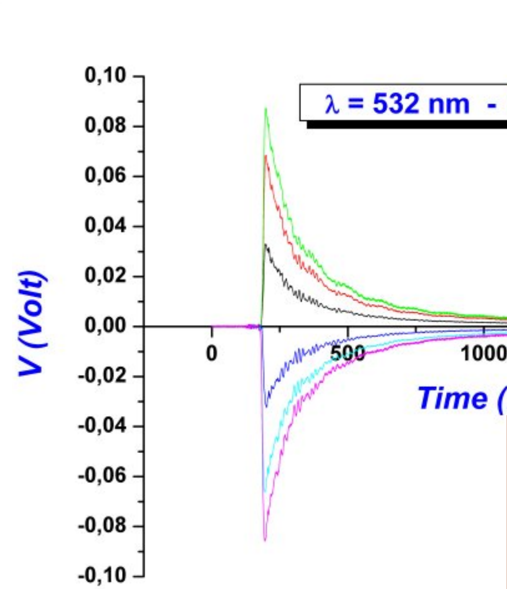



# Various kind of substrates

# Signals detected with the first carbon nanotube radiation detector



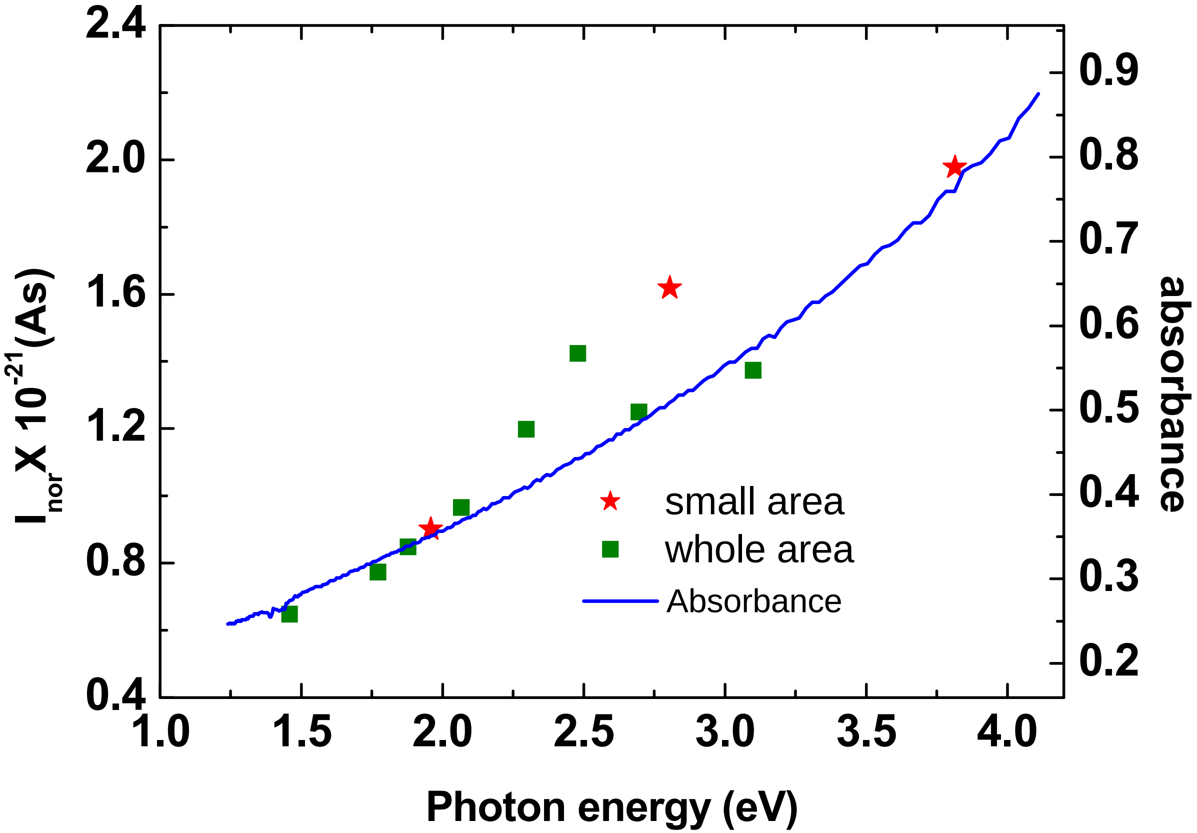





A. Ambrosio et al: ***"A prototype of a Carbon Nanotube microstrip radiation detector"***, **Nuclear Instruments and Methods in Physics Research A 589 (2008) 398–403**

# Photocurrent vs λ

GINT
(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**

# Scientific production - papers

A. Ambrosio et al: ***"Development of Carbon Nanotube based radiation detectors"***, V C I 2007 , The **11th Vienna Conference on Instrumentation**, Vienna, Austria – February 19-24, 2007

M. Ambrosio et al: ***"Nanotechnology: a New ERA for Photodetection?",*** OPENING TALK della 5th **NDIP Conference, Aix-Les-Bains**, 15-20 June 2008

M. Ambrosio et al: "***New Photon Detectors made of Multi Wall Carbon Nanotubes", IEEE Dresden*** 2008, 19-25 October 2008, Germany

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**

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

A. Tinti et al: ***"Electrical analysis of carbon nanostructures/silicon heterojunctions designed for radiation detection", Nuclear Instruments and Methods in Physics Research A 629 (2011), 377-381***

# Carbon Nanotubes (CNTs)

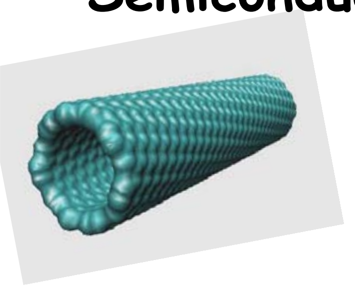
## Molecular Nanowires ($d \sim 1$ nm, $l \sim 1$ μm)

### SWNTs

Single Graphene Sheets ($d \approx 0.7 \div 3$ nm, $l \approx$ μ-range)

$\notin \mathbb{N}$ |n-m|/3 $\in \mathbb{N}$

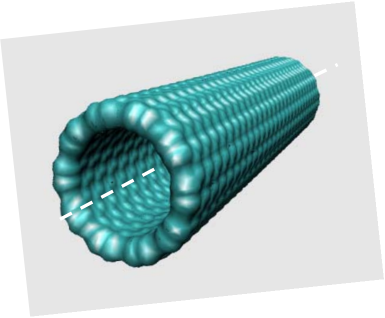
**Semiconductor**



*Channel (FETs),*

*Luminescence*

**Metal**



*Ballistic Conduction,*

*e-wave guides, SETs*

### MWNTs

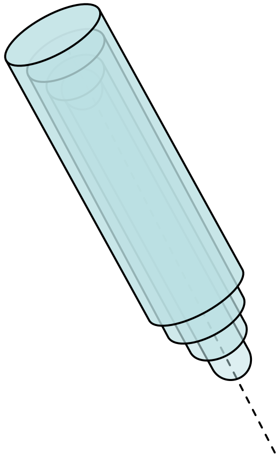
Coaxial graphene sheets

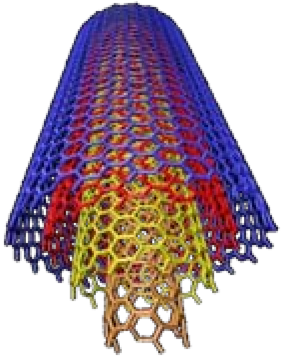
($d \approx 2 \div 100$ nm, $l \approx$ μ-range

($d^{out} \approx 20_{AD}, 100_{CVD}$ nm)

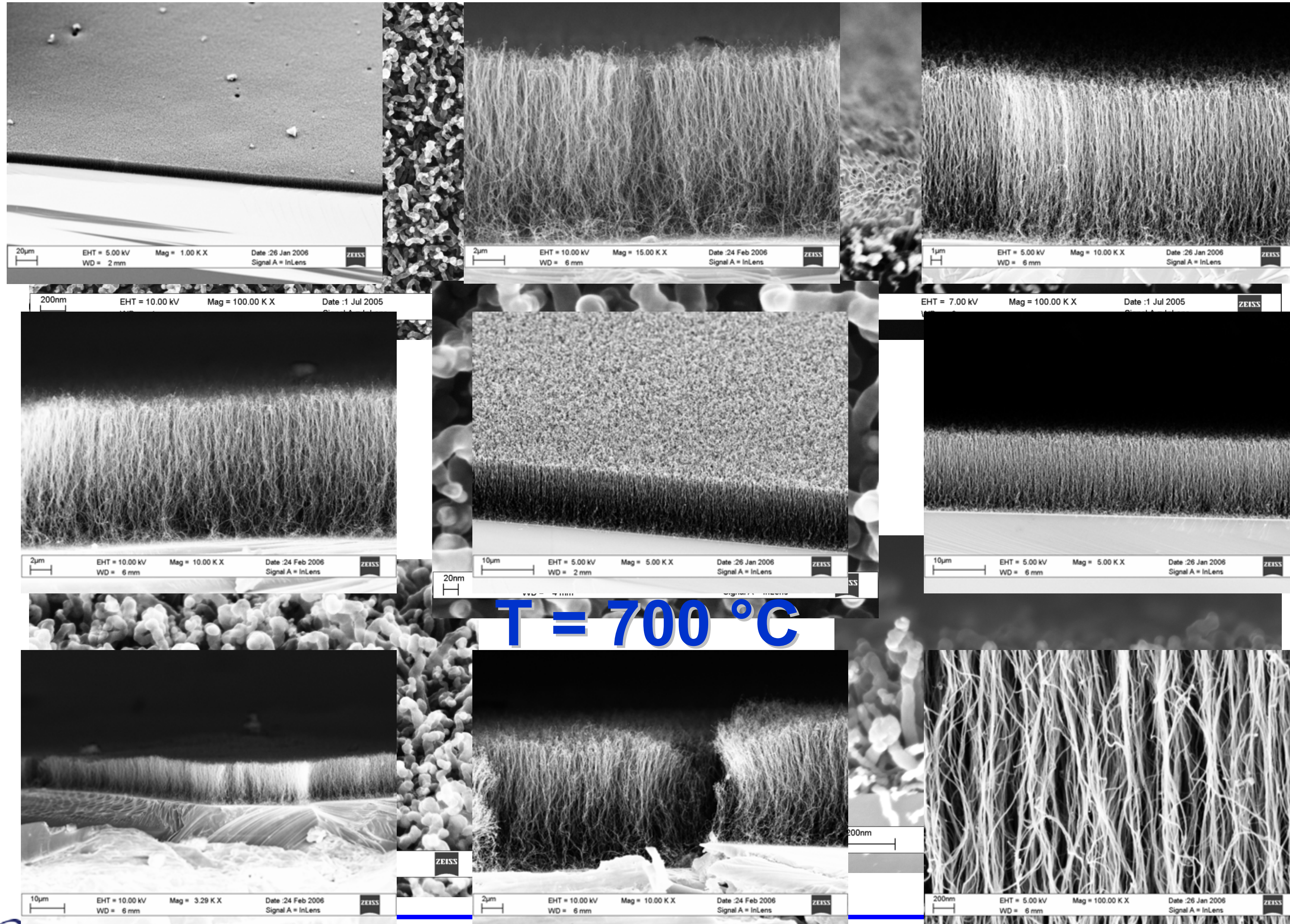
*Vias*

*Nanocomposites*

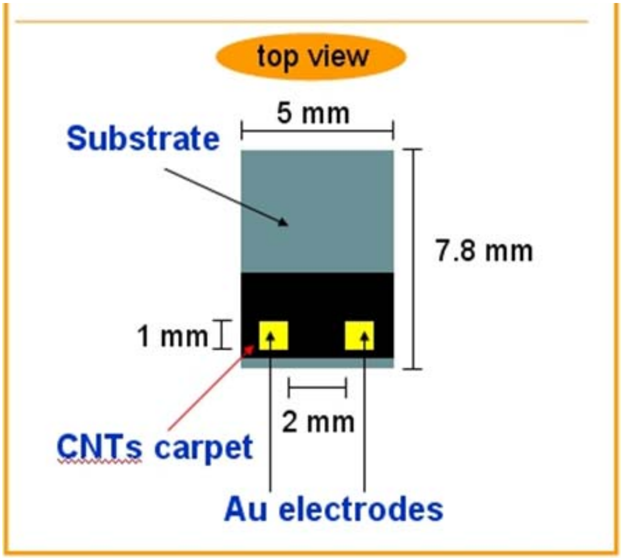


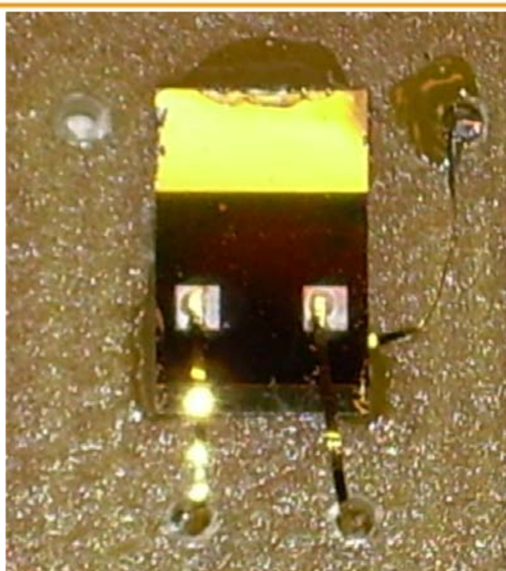


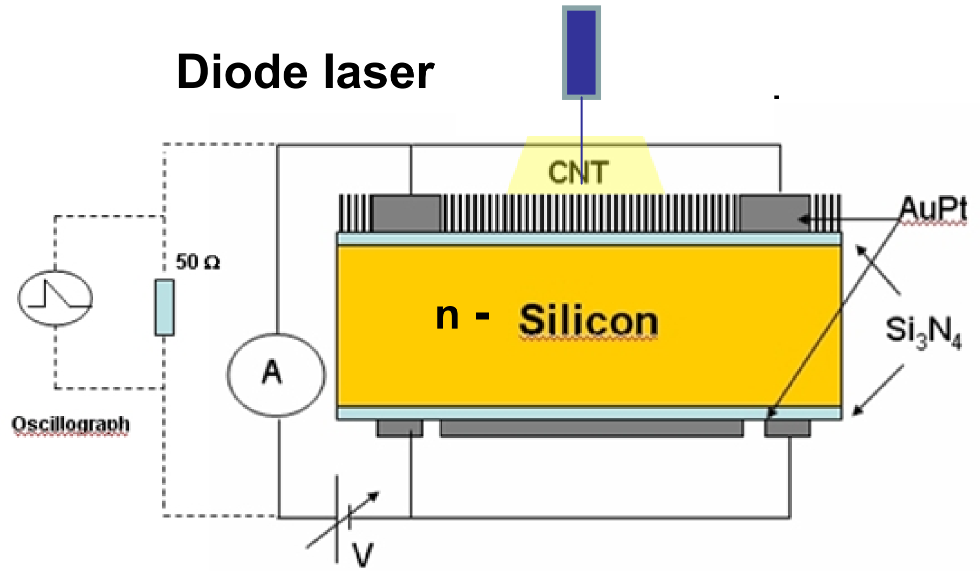
# Nanotube production: SEM images

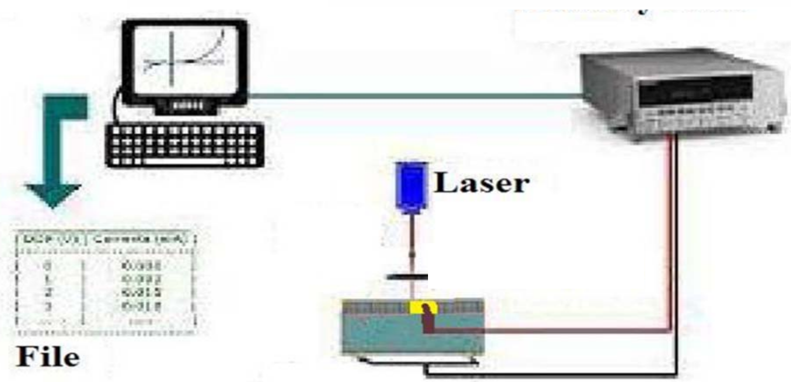


# SiC radiation detector



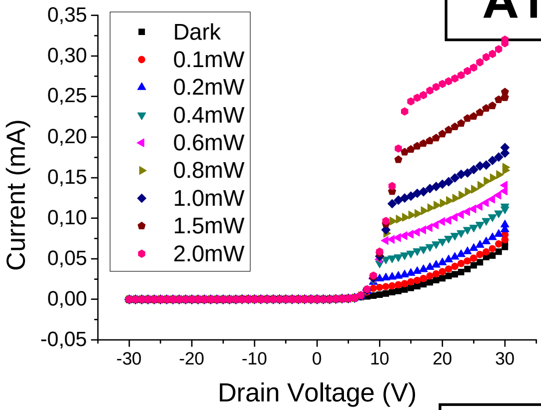


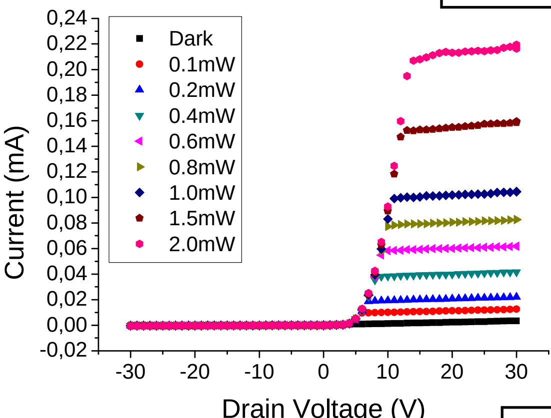
# Room temperature

**T = 500 °C**
**λ = 650 nm**

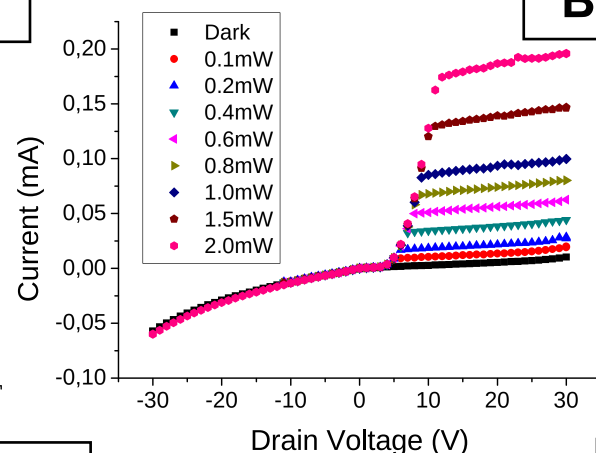
A1



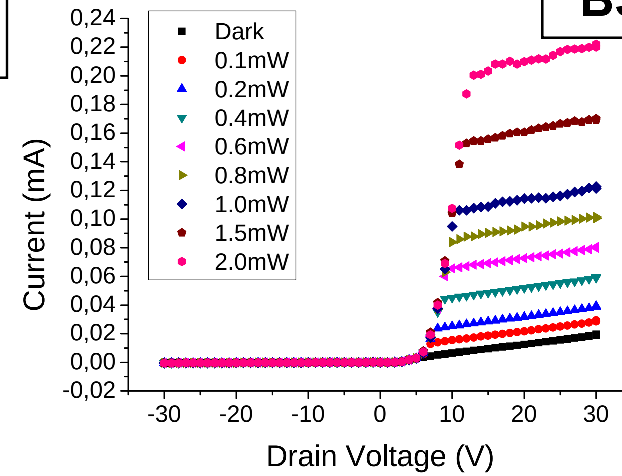

B1



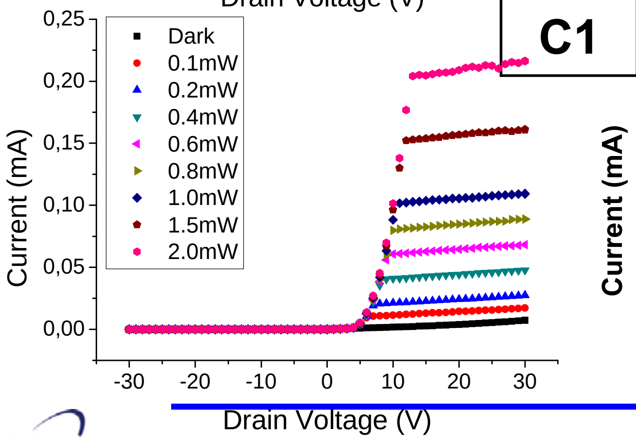

B2



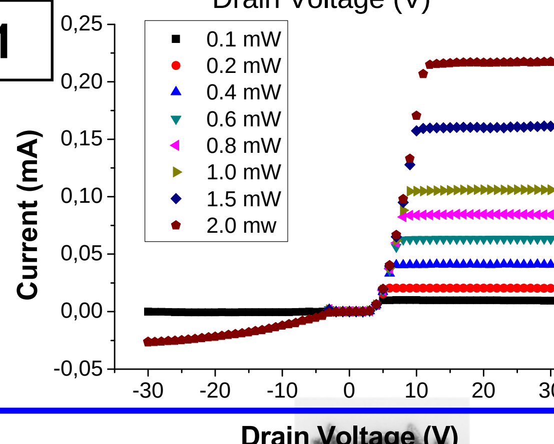

B3




C1




C2

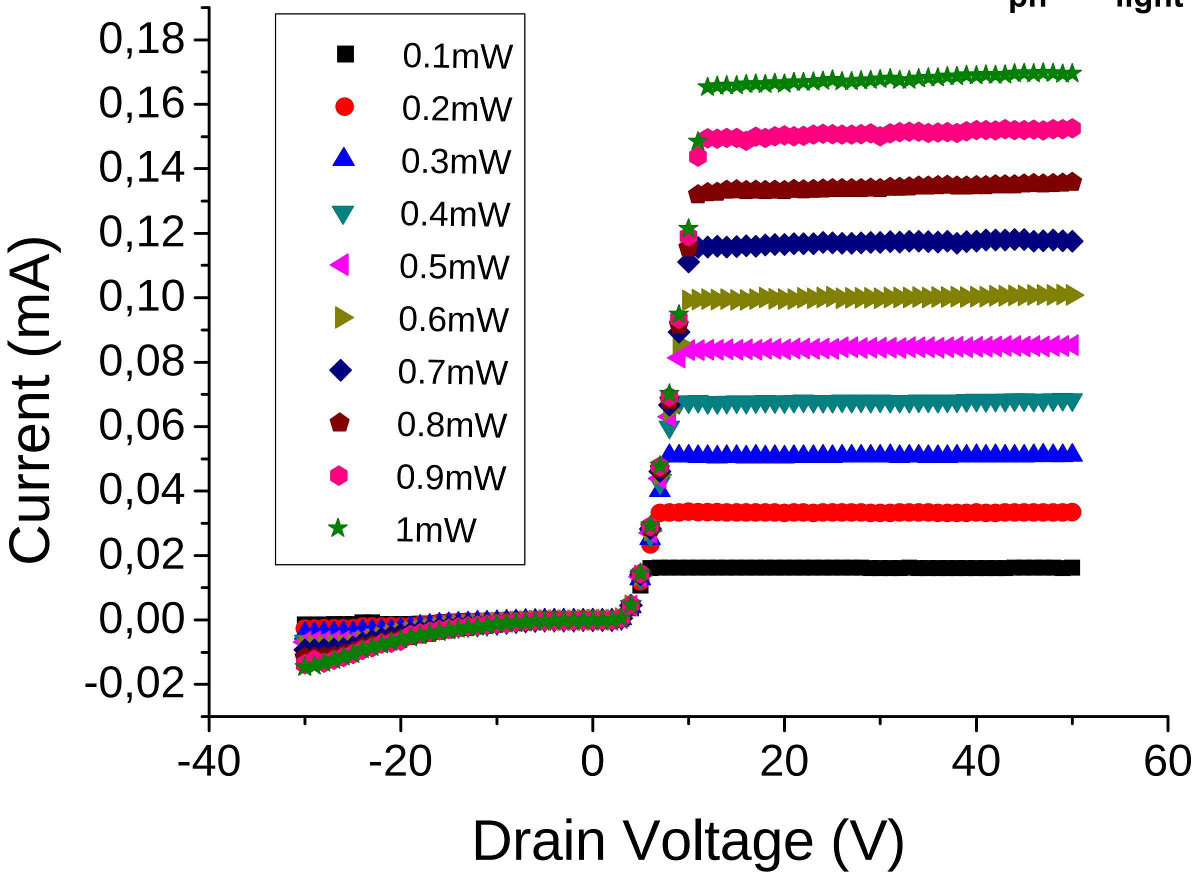



**Nanotubes growth on a silicon substrate may create a diode-like junction with surprising photoresponsivity properties.**

# I-V plot of C2 detector @ $\lambda$=785 nm

With this architecture the charge generated inside CNTs by radiation can be collected trough the silicon substrate without great attenuation.

Photocurrent $I_{ph} = I_{light} - I_{dark}$




**The sample operates as a diode with a very low reverse current and a direct current proportional to light intensity.**

**The junction shows a threshold of 2.5 V, after that the current increases quite linearly until a large plateau in which current value is very stable.**

# Study of heterojunction Si-CNT

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

## Electrical analysis of carbon nanostructures/silicon heterojunctions designed for radiation detection

A. Tinti [a,*], F. Righetti [a], T. Ligonzo [a], A. Valentini [a], E. Nappi [a], A. Ambrosio [b], M. Ambrosio [c], C. Aramo [c], P. Maddalena [b], P. Castrucci [d], M. Scarselli [d], M. De Crescenzi [d], E. Fiandrini [e], V. Grossi [f], S. Santucci [f], M. Passacantando [f]

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[b] *CNR-SPIN U.O.S. di Napoli e Dipartimento di Scienze Fisiche, Universitá degli Studi di Napoli Federico II, Via Cintia 2, 80126 Napoli, Italy*
[c] *INFN, Sezione di Napoli, Via Cintia 2, 80125 Napoli, Italy*
[d] *Dipartimento di Fisica, Università degli Studi di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy*
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[f] *Dipartimento di Fisica, Università degli Studi dell'Aquila, Via Vetoio 10, 67100 Coppito, L'Aquila, Italy*

**Nuclear Instruments and Methods in Physics Research A 629 (2011), 377-381**

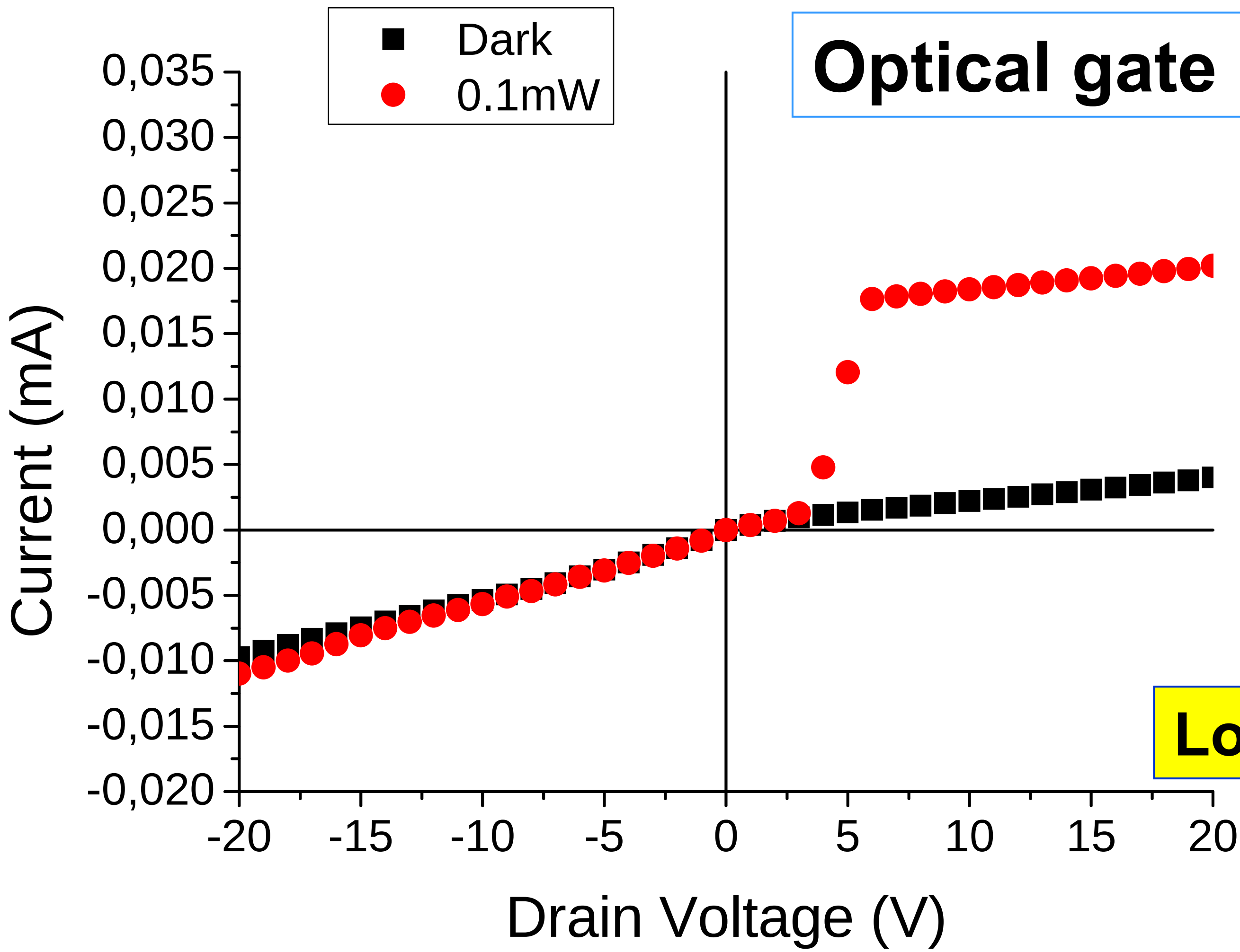
A B S T R A C T

A new class of radiation detectors based on carbon nanostructures as the active photosensitive element has been recently developed. In this scenario the optimization of the device, both in dark and on light irradiation, is a crucial point. Here, we report on electrical measurements performed in dark conditions on carbon nanofibers and nanotubes deposited on silicon substrates. Our experimental results were interpreted in terms of a multistep tunneling process occurring at the carbon nanostructures/silicon interface.



*Keywords:*

# Details of Si-CNT heterojunction



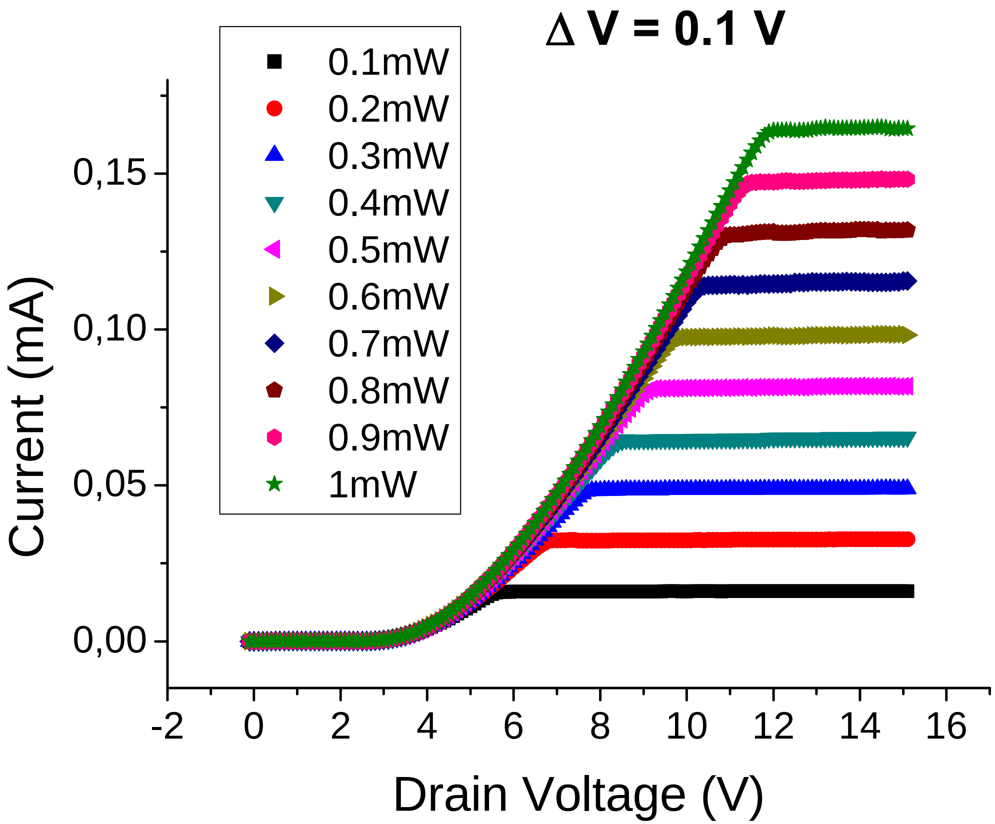

**Optical gate**

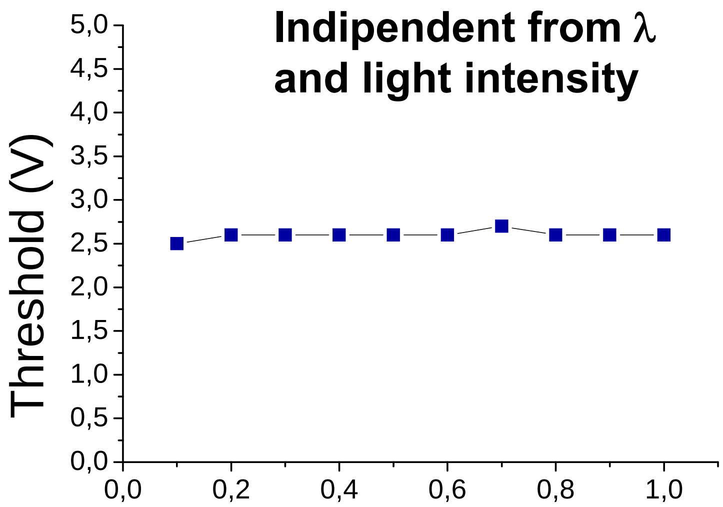
**Rectifying behaviour of Si-CNT heterojunction**

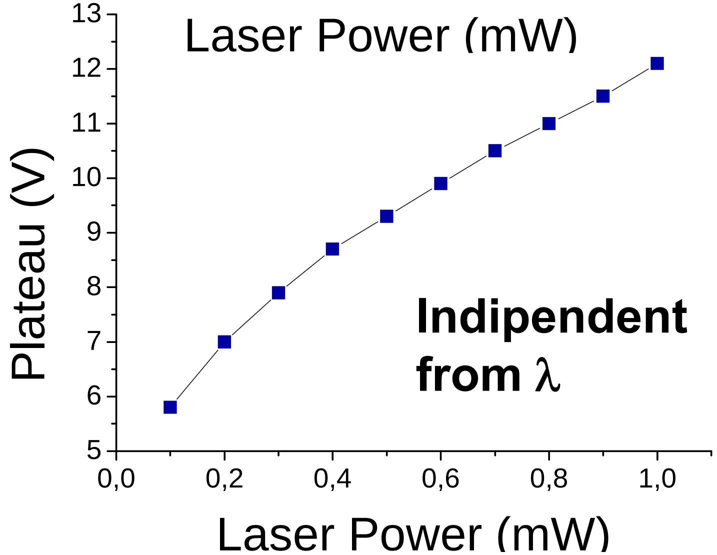
**Low dark current**

**Low noise detector**

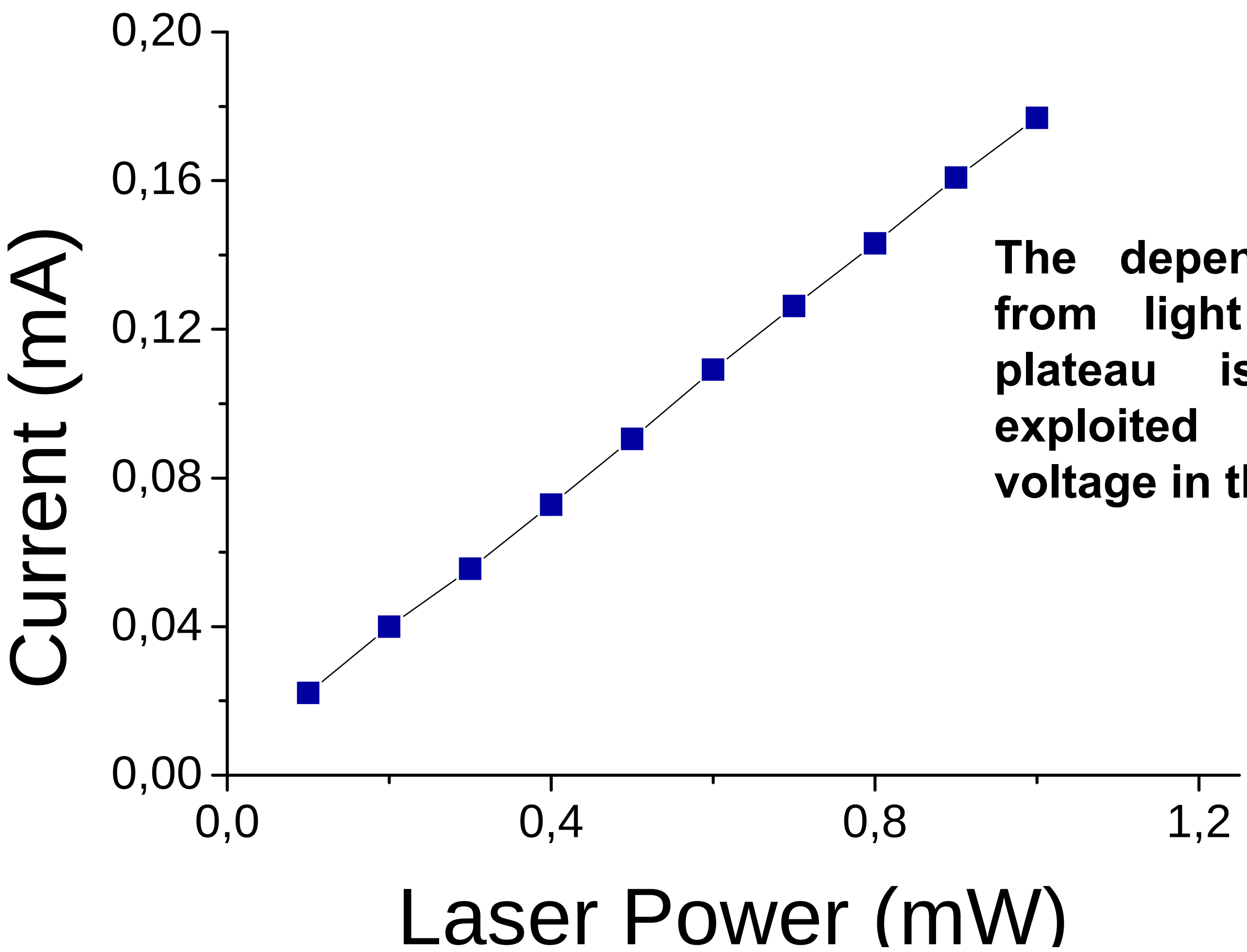
# Threshold and plateau @ 500 °C



# Linearity @ 785 nm and 25V

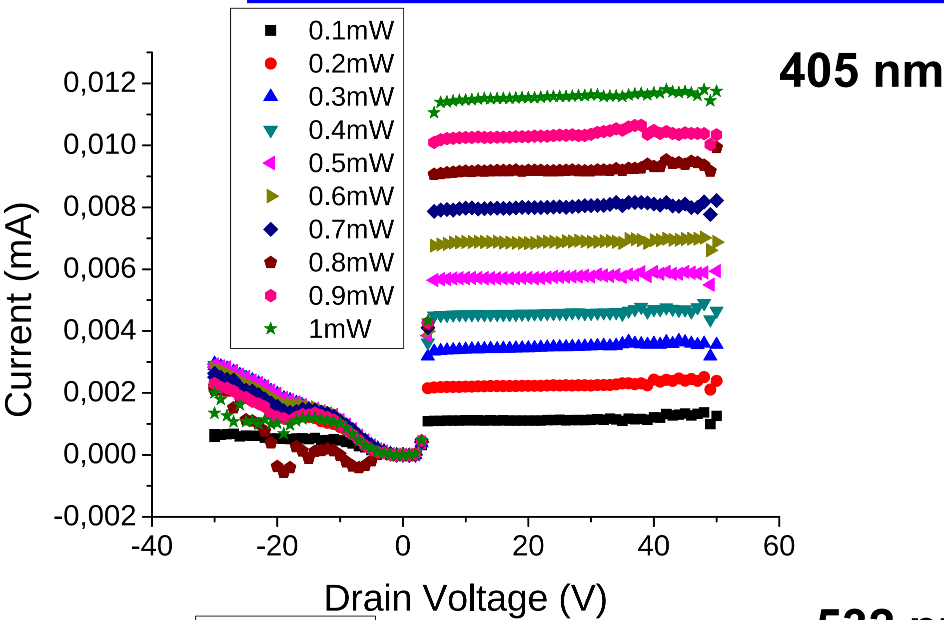


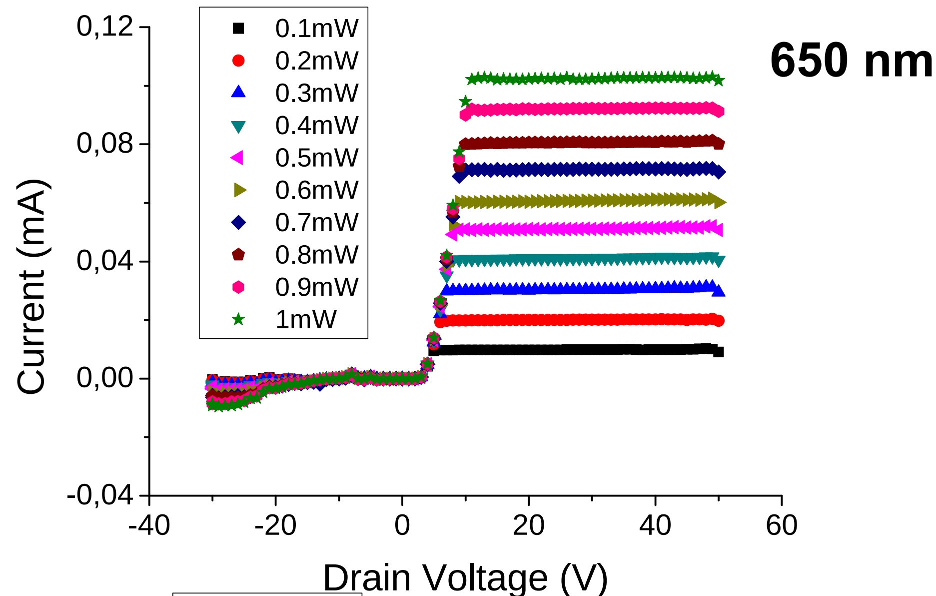

**C2 Detectors**

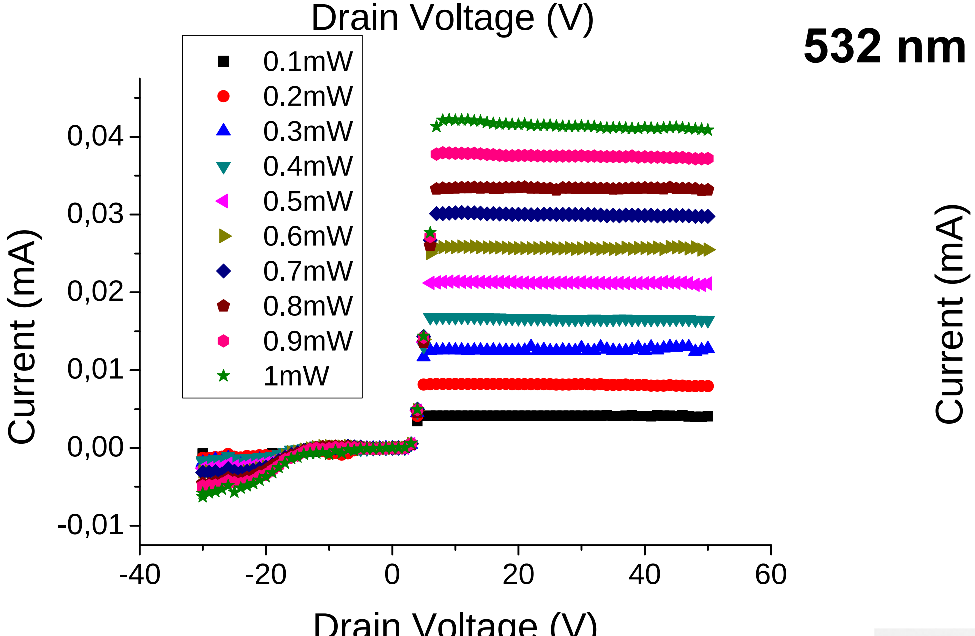
**The dependence of current from light intensity at the plateau is linear for all exploited intensities at all voltage in the analysed range.**

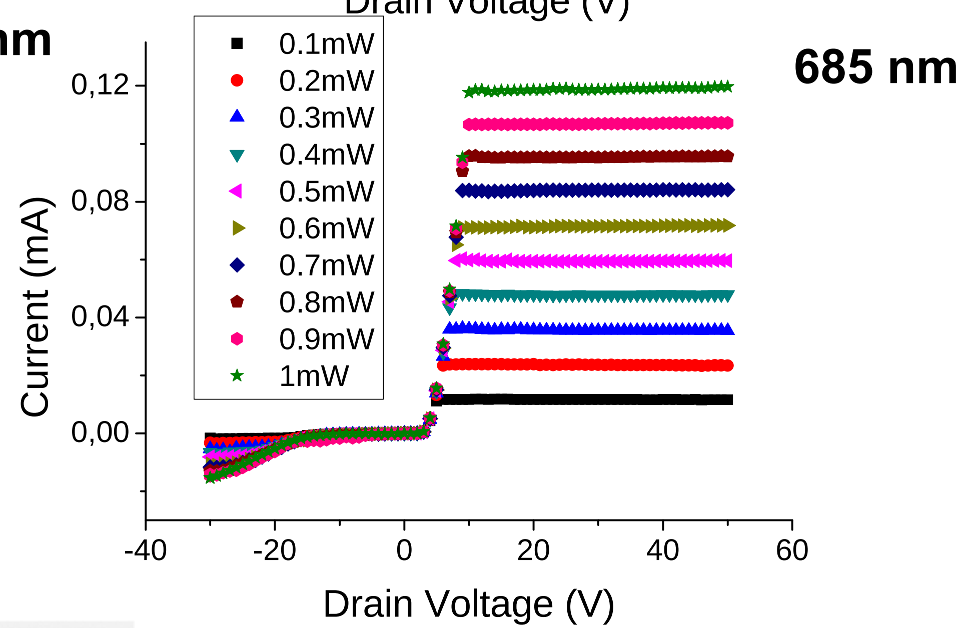
C2 Detectors

# λ and laser intensity dependence



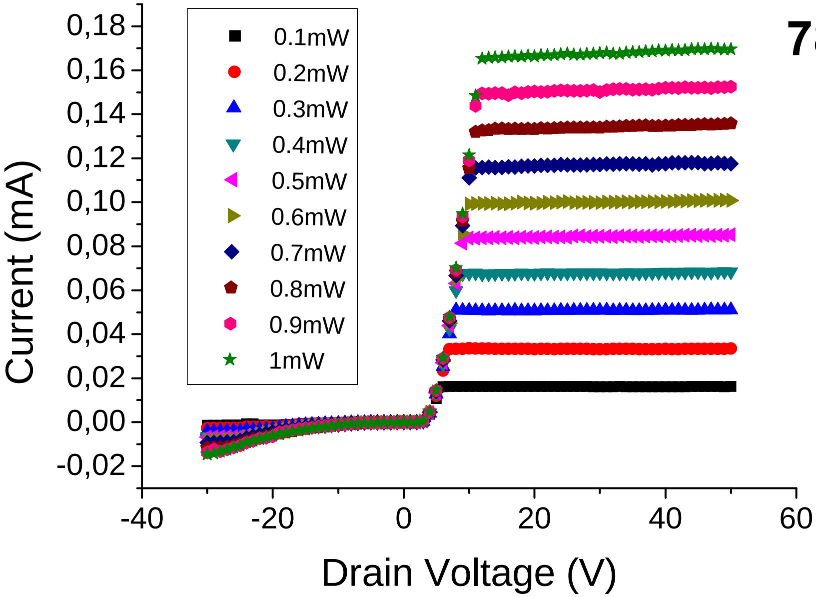



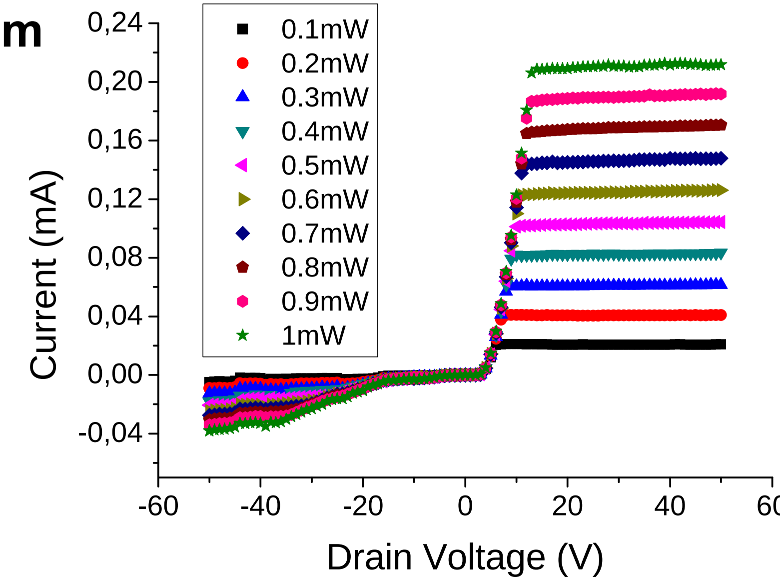
# C2 Detectors

# λ and laser intensity dependence

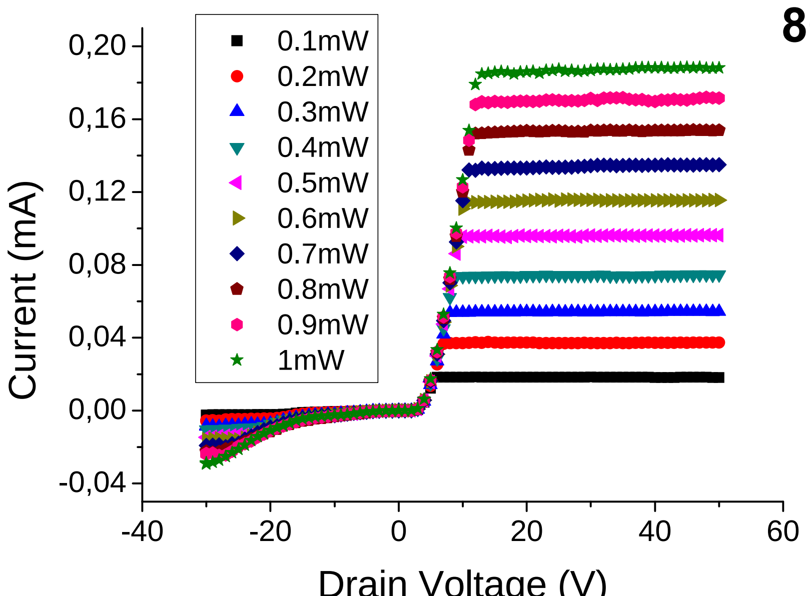
785 nm



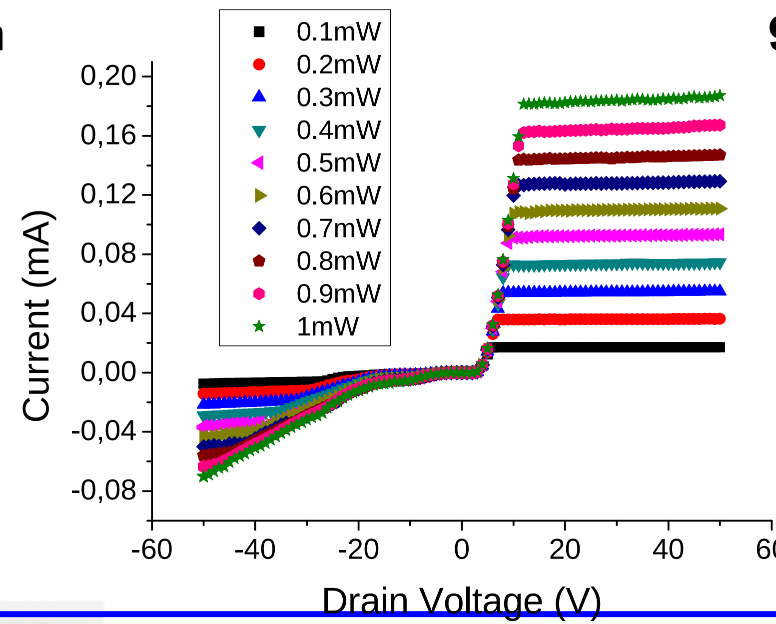

880 nm



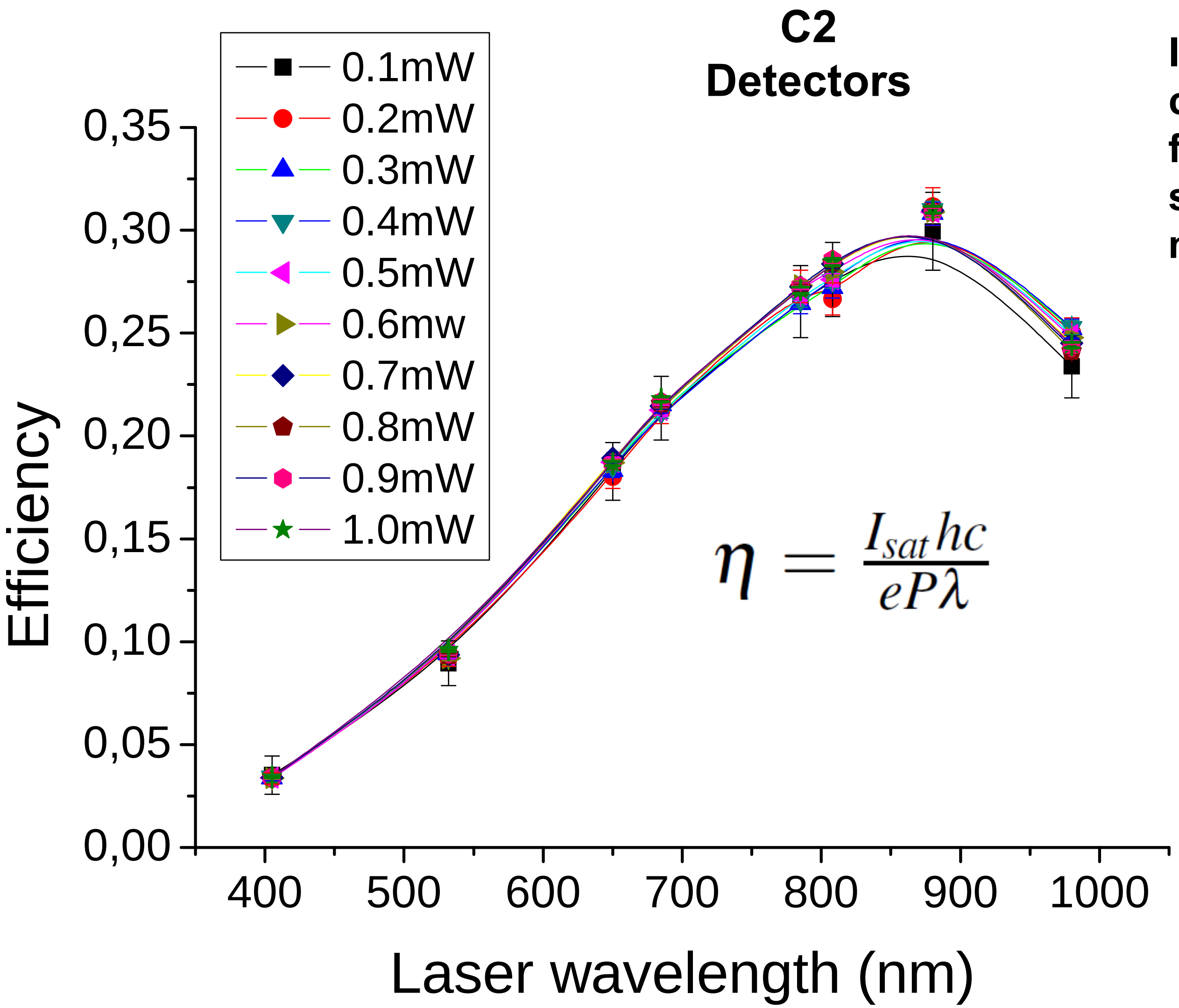

808 nm




980nm



# Conversion Efficiency @ 25V



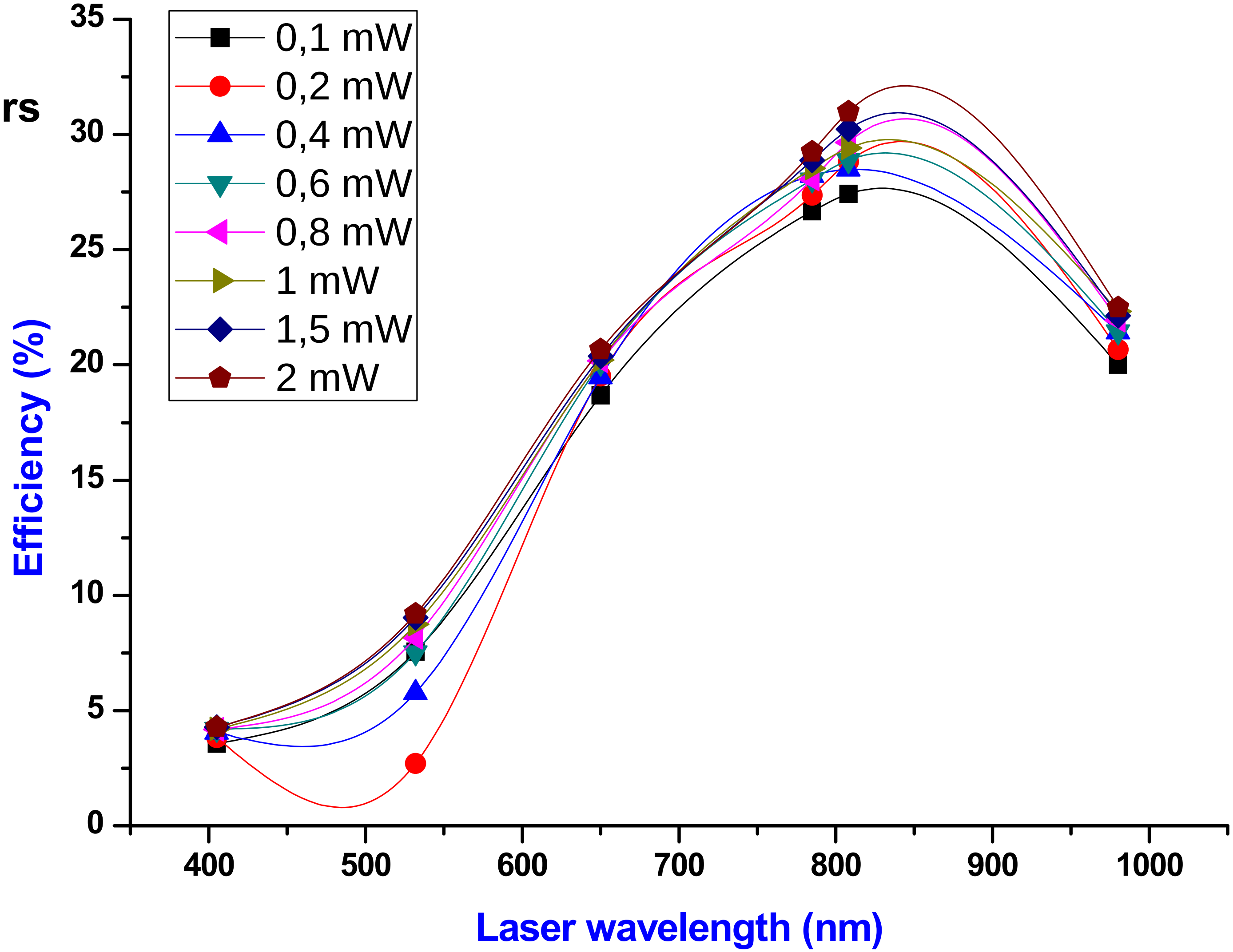

$$\eta = \frac{I_{sat}hc}{eP\lambda}$$

**In this measurement we cannot take into account the fraction of light reflected by surfaces, then we cannot measure quantum efficiency.**

**For each wavelength 20 measurements of photocurrent induced in the detector for various light intensities permit to estimate the mean value with combined errors of ratio between the number of drained charges and the number of incindent photons.**

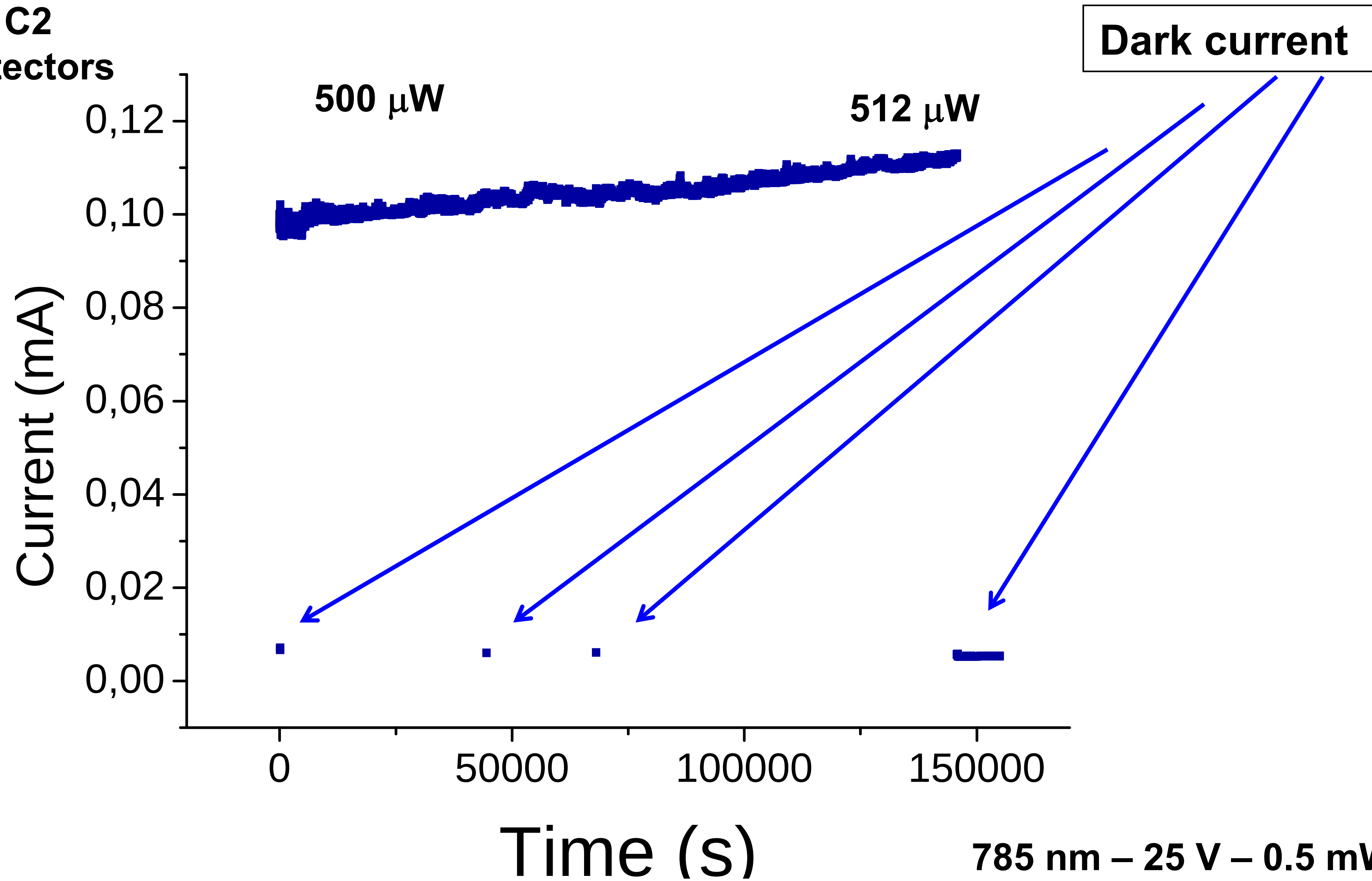
# Aging – 2 years ago

C2 Detectors



# Long term stability – 40 hours

**C2 Detectors**

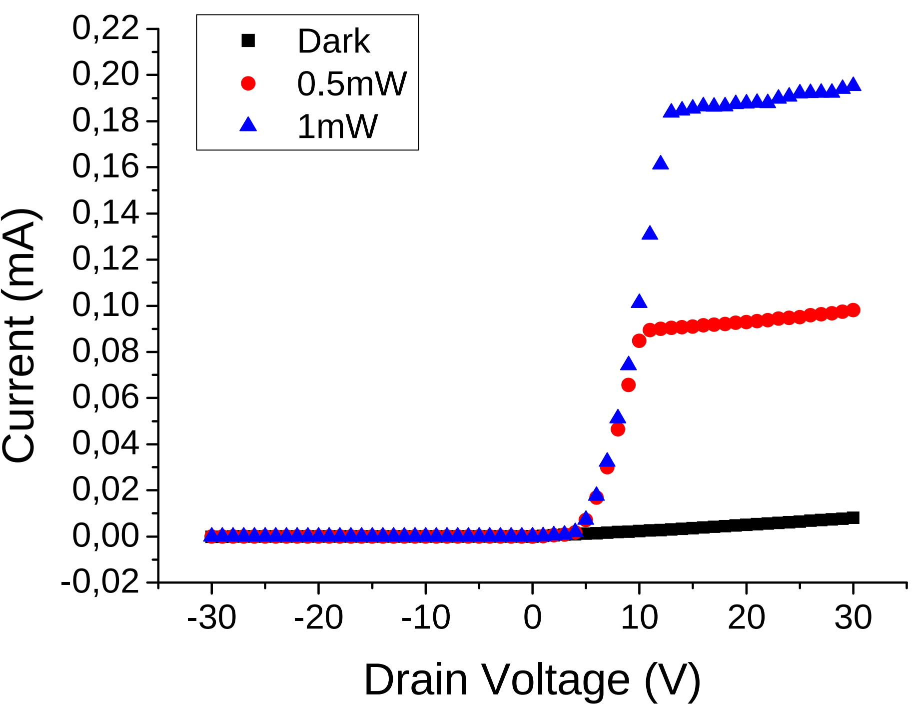



**785 nm – 25 V – 0.5 mW**

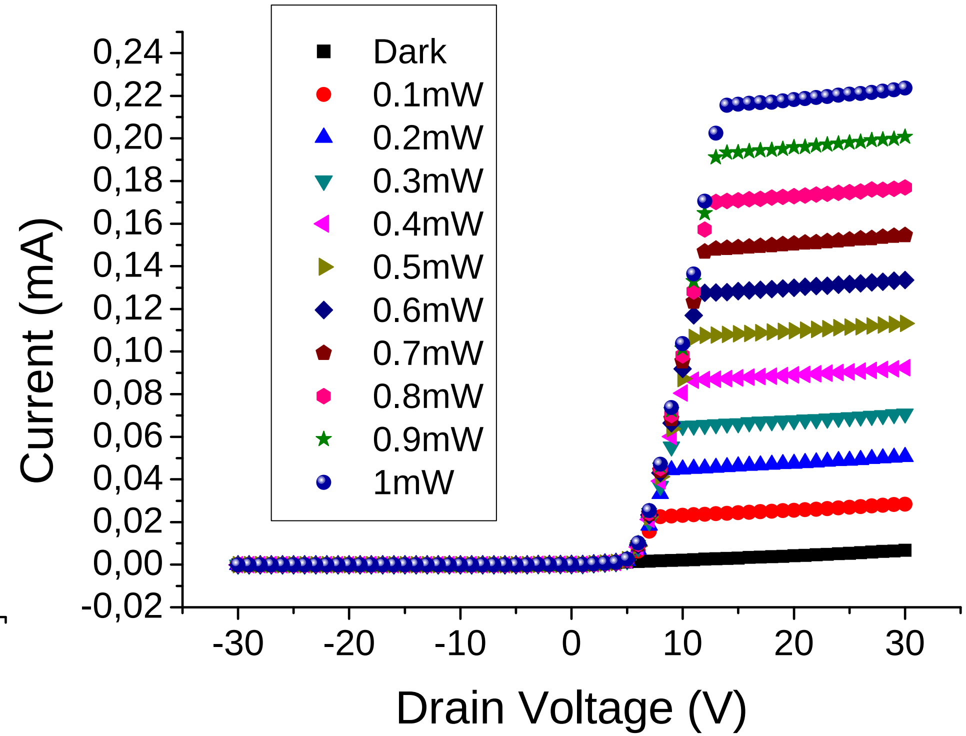
# Before and after the long term measurement

**C2 Detectors**

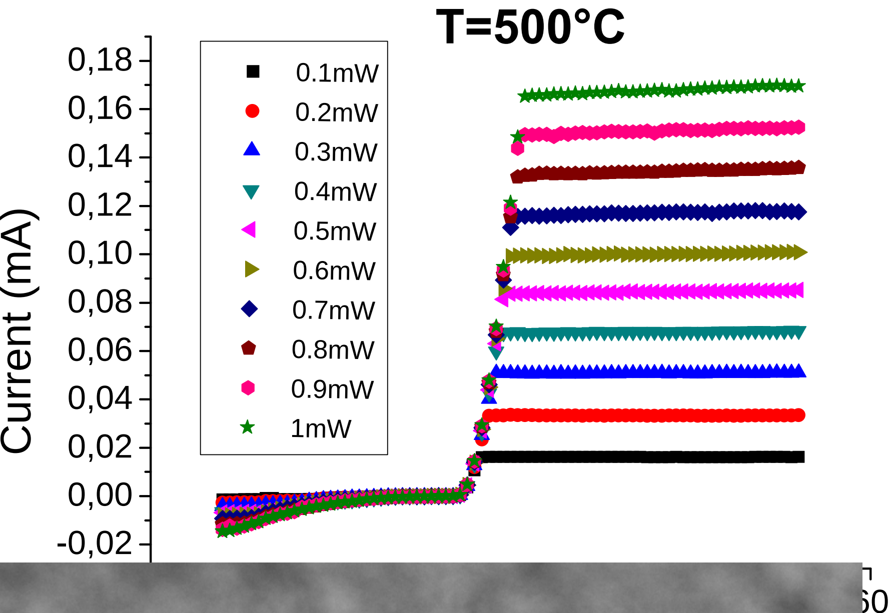
**Before**

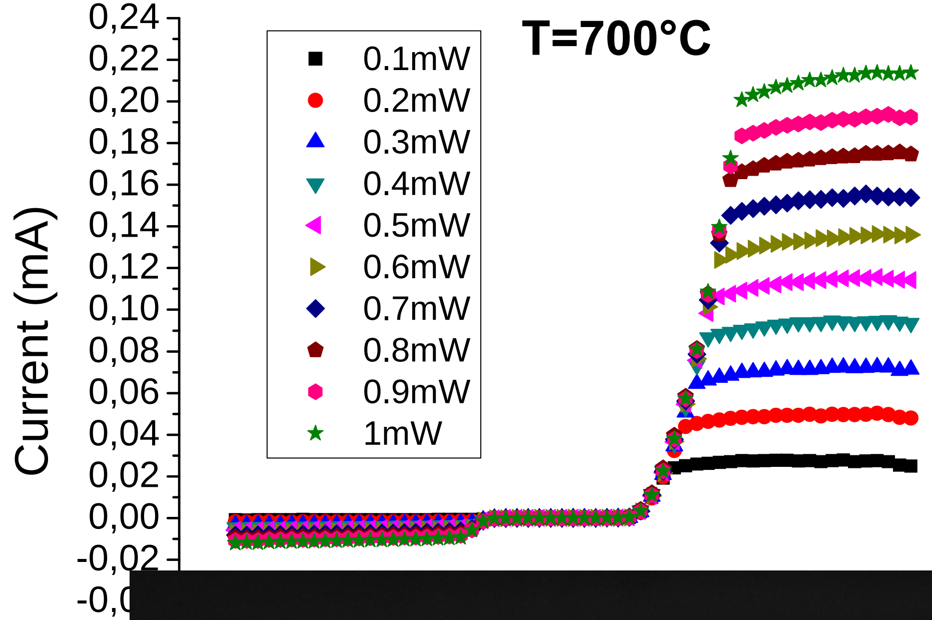


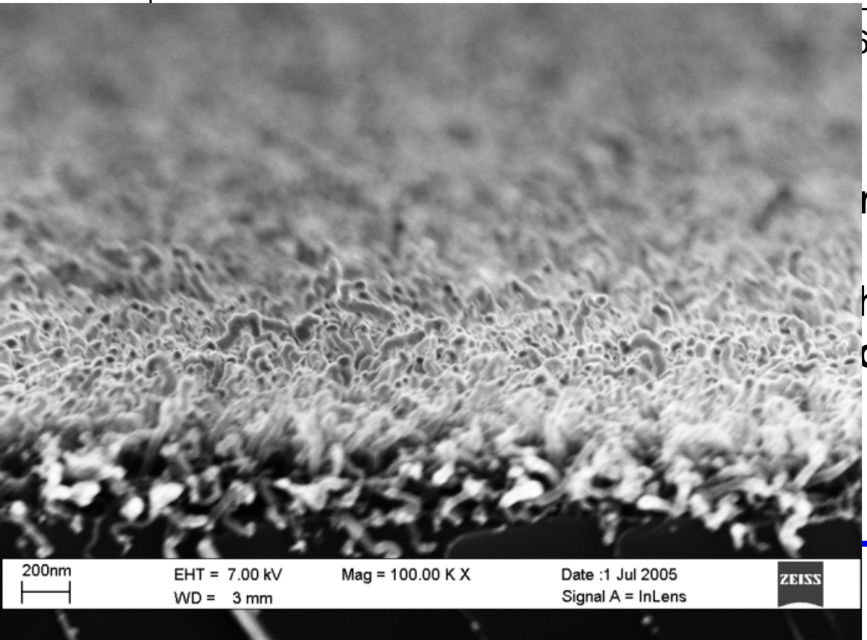

**After**



# Comparison between SiC growth at 500 °C and at 700 °C @ λ=785 nm

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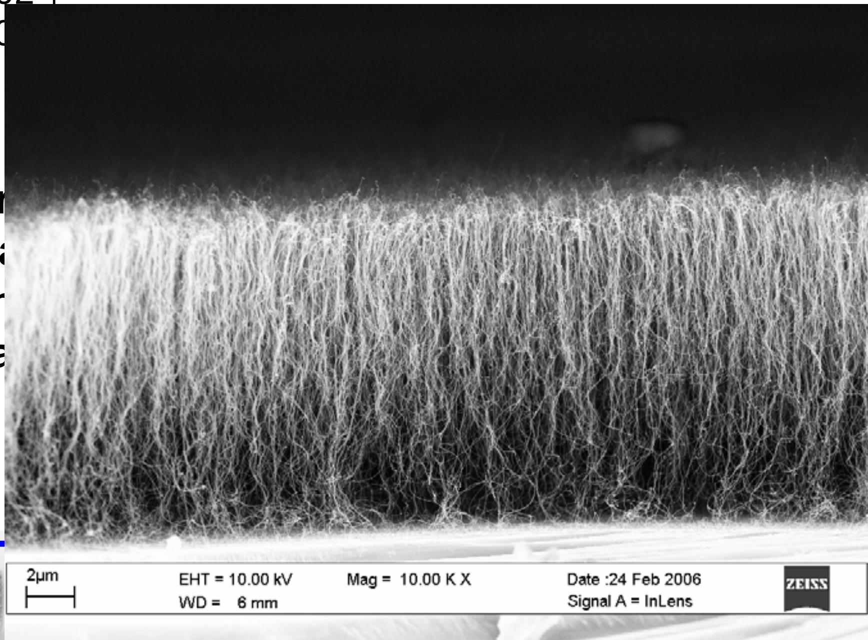
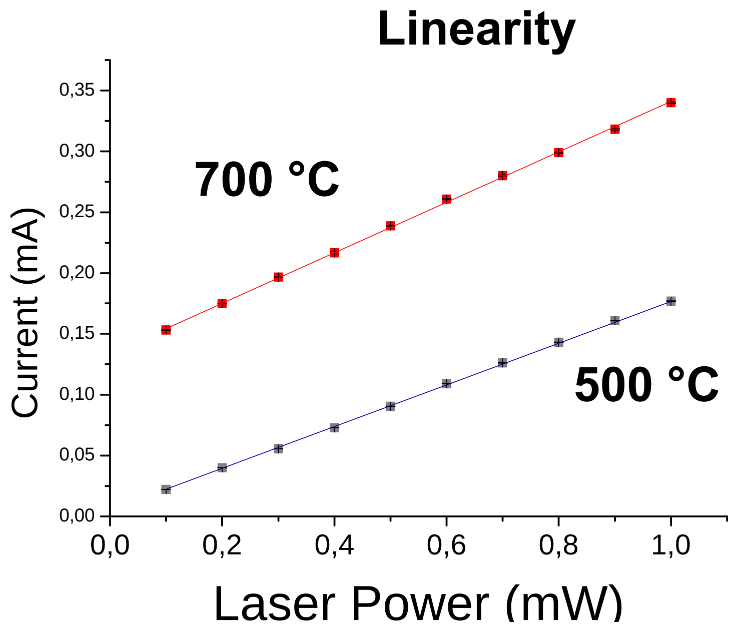
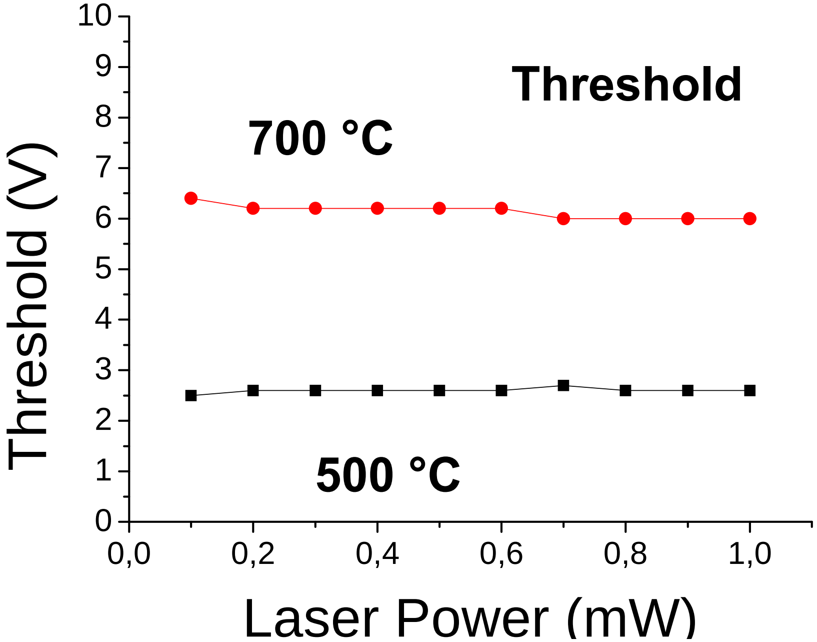
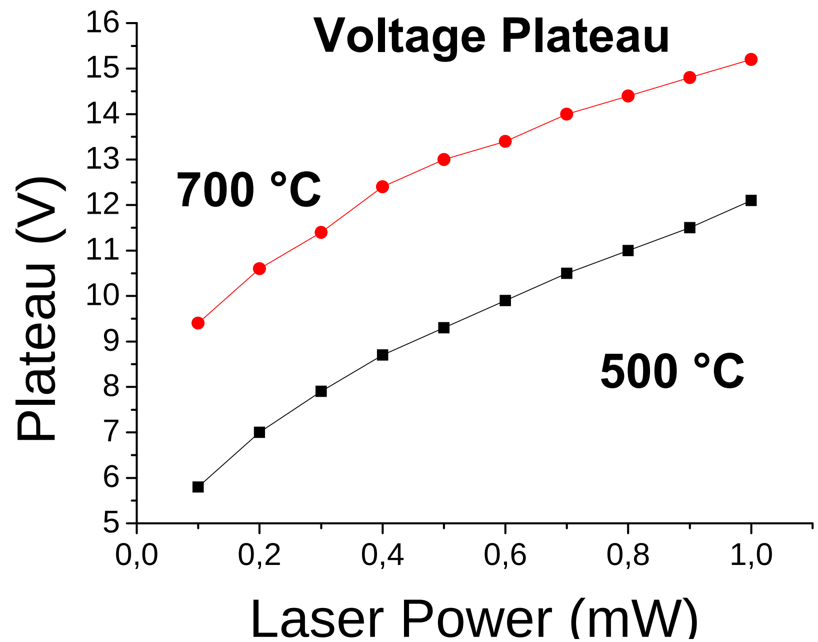


# T= 500 °C and T=700 °C @ λ=785 nm

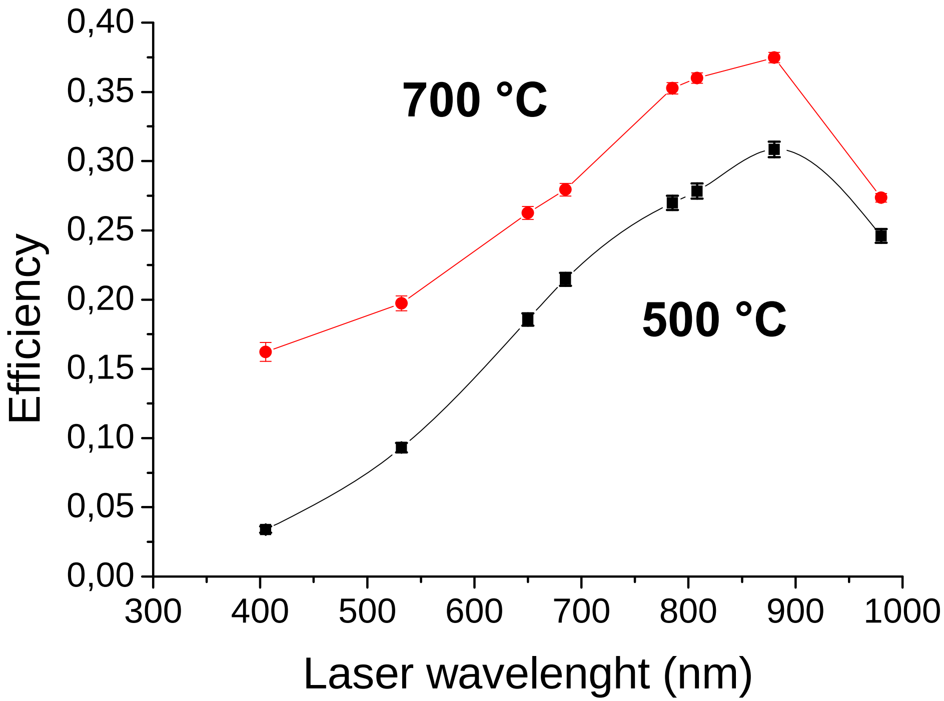
**The Silicon substrate is the same**

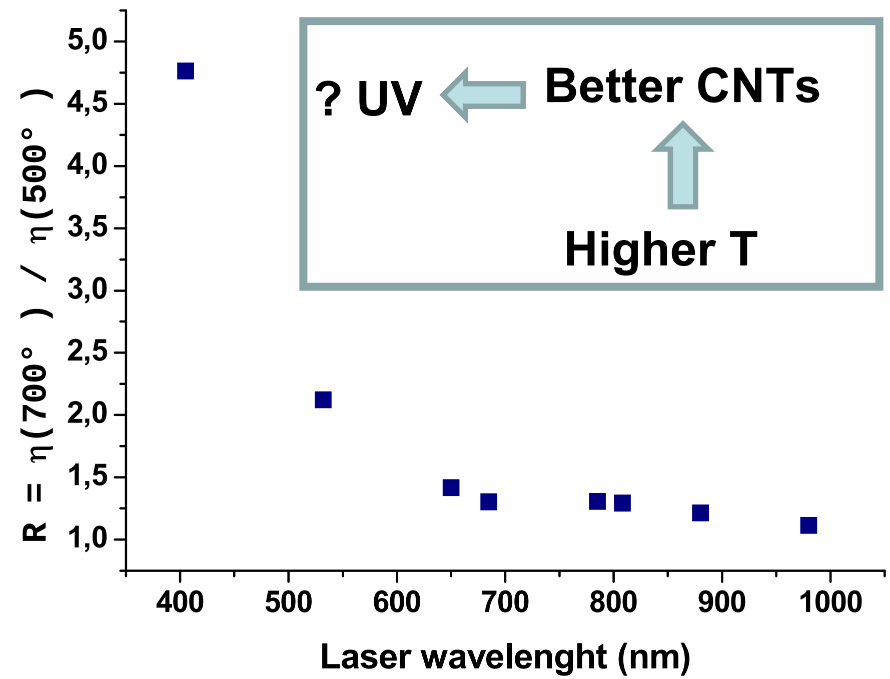


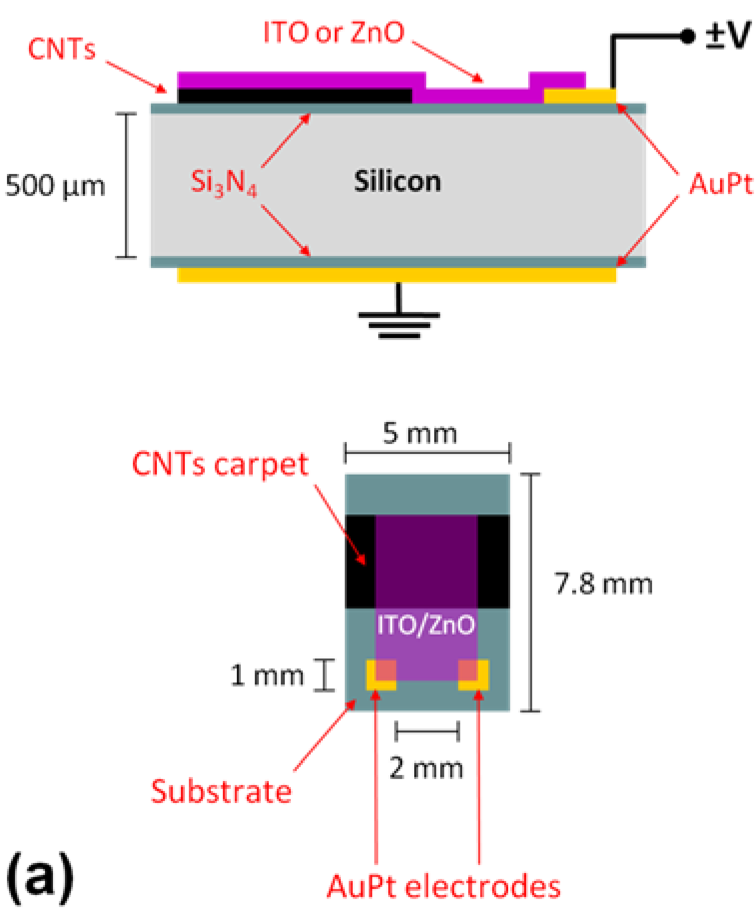
# The Silicon substrate is the same




**Note: all measurements have been performed without any kind of signal amplification.**

# Coating




**In order to obtain a CNTs coating, a thin film of a transparent conductive oxide (TCO), namely indium tin oxide (ITO) or zinc oxide (ZnO), is sputtered on the CNTs network so to partially cover the Au/Pt pads.**

**Optical properties of TCO films and their electrical resistivity ensured the formation of near ideal ohmic contact.**

**Results are equivalent.**

# Summary and outlook

A novel photon detector made of Silicon and CNT has been realized .

The main characteristics of this detector are:

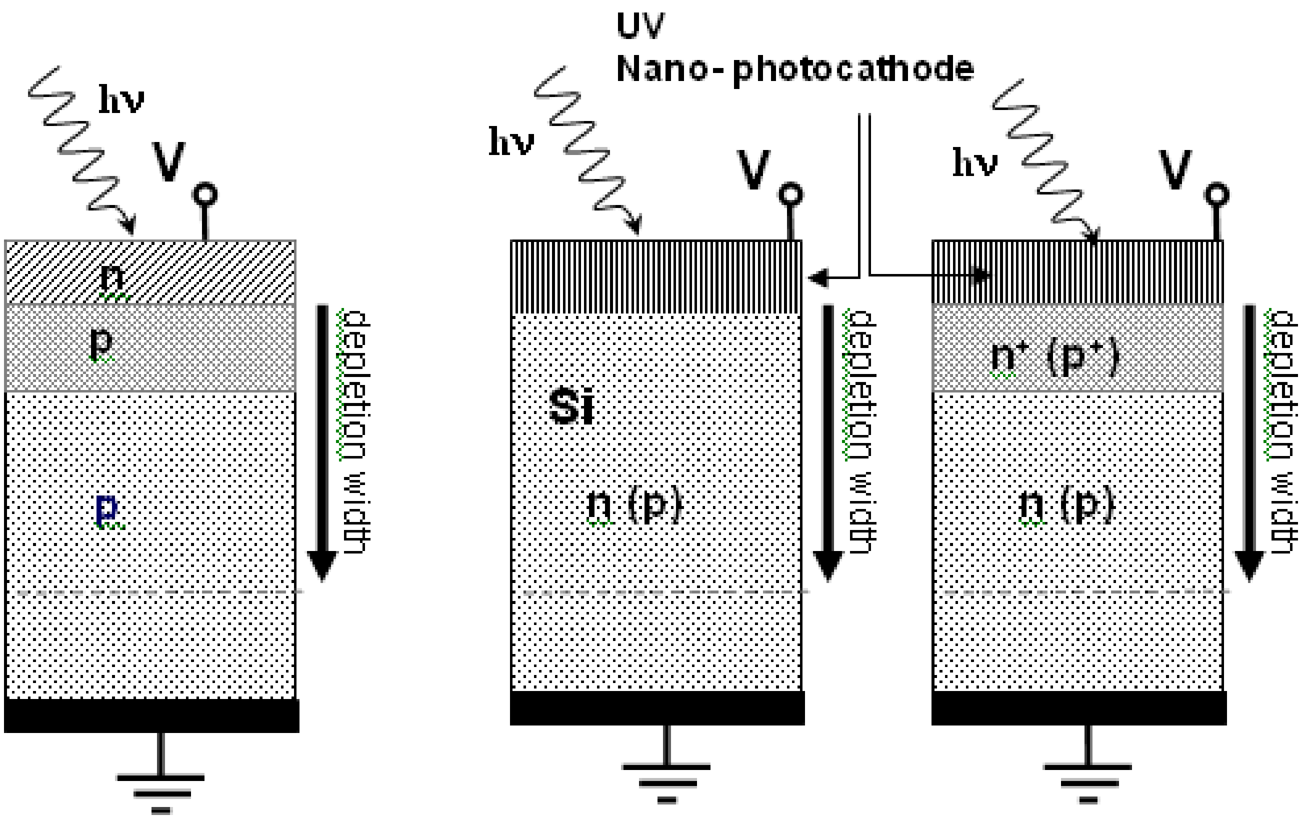
- Low threshold
- Low dark current
- Large plateau region
- High linearity
- Stable at room temperature
- Conversion efficiency depending from light wavelength and from CVD temperature

Coating of CNTs surface has bee obtained with a conductive layer of ITO
Detector aging is under investigation.

## OUTLOOK

Collaboration with FBK-IRST is in progress to obtain amplifying Silicon substrates structured as SiPM. The final purpose is to realize a highly pixelled single photon detector sensitive from UV to near IR.

# A possible final 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)

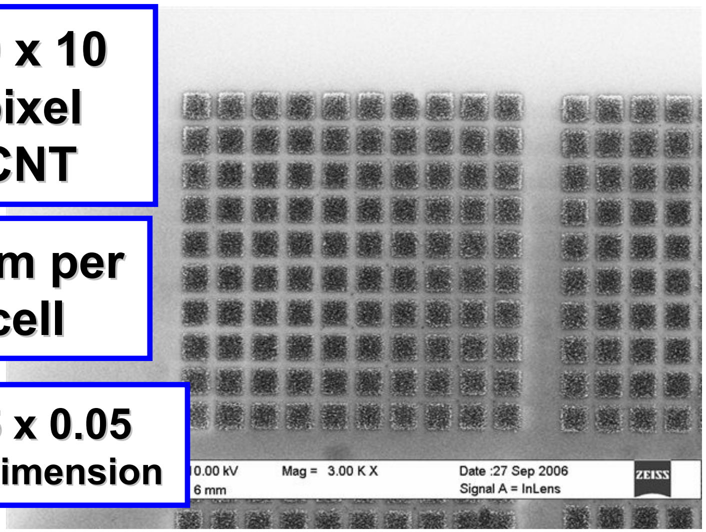
# Nano-pixelled photocathodes

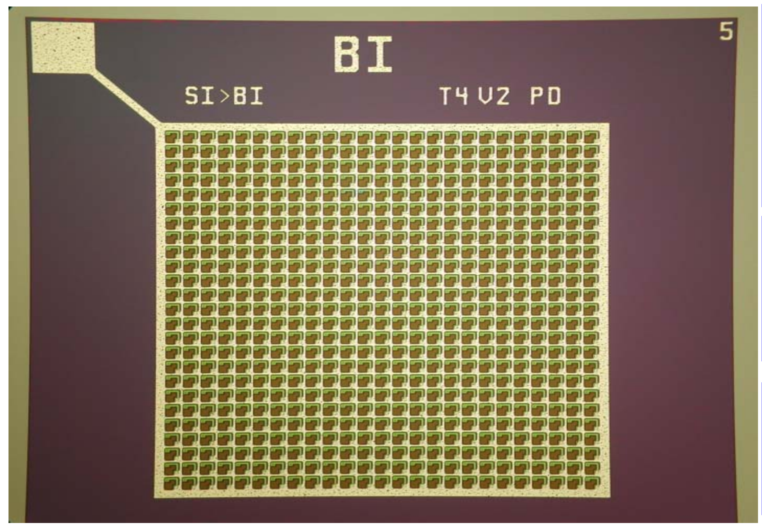
MWCNTs can be grown on different kind of substrates according the desired geometry. Nanolithography process allows to obtain finely pixelled elements over large surfaces.

**10 x 10 pixel CNT**

**4 μm per cell**

**0.05 x 0.05 $mm^2$ dimension**



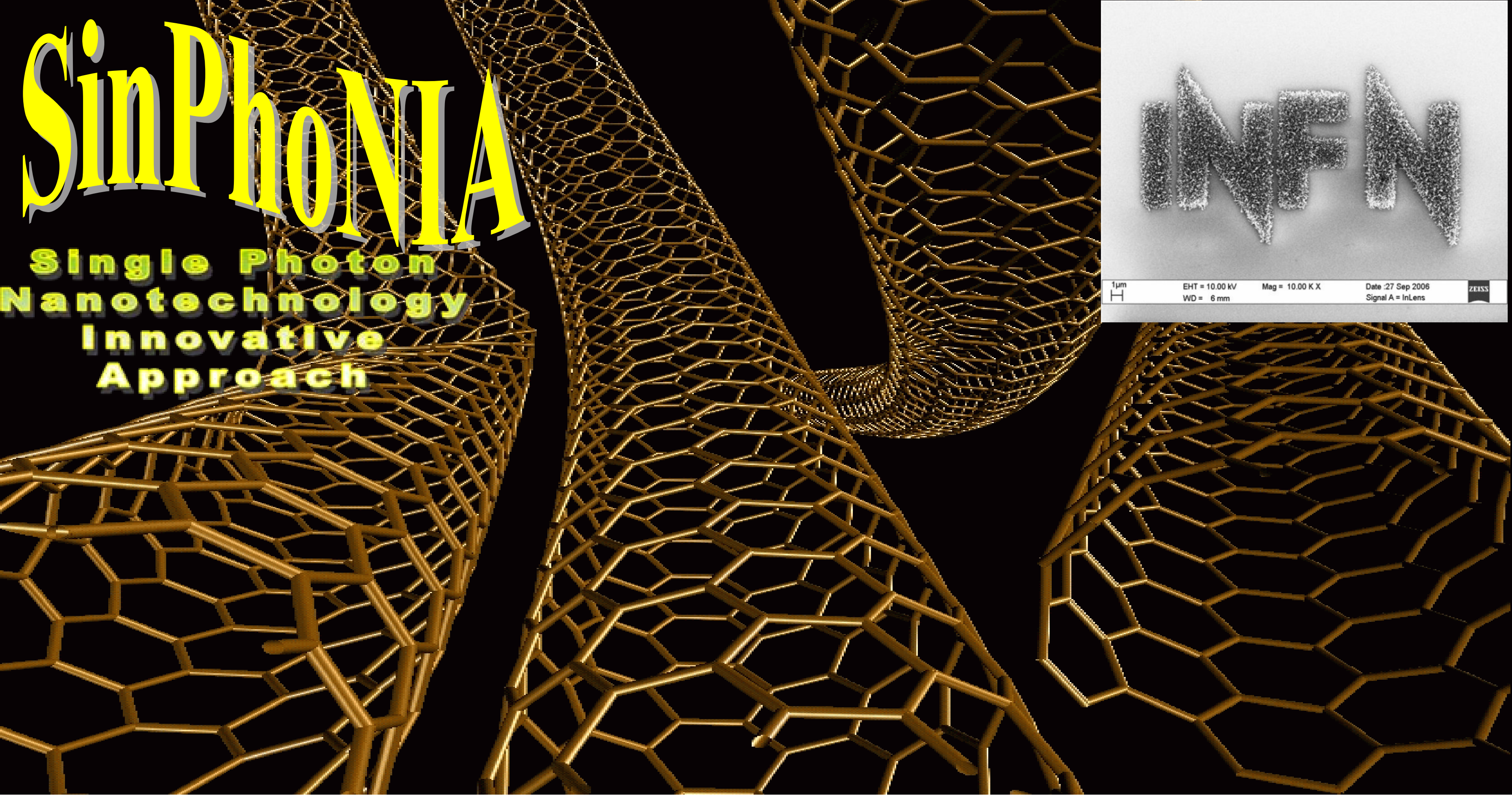




**25 x 25 pixel SiPM**

**40 μm per cell**

**1 x 1 $mm^2$ dimension**

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




INFN Istituto Nazionale di Fisica Nucleare

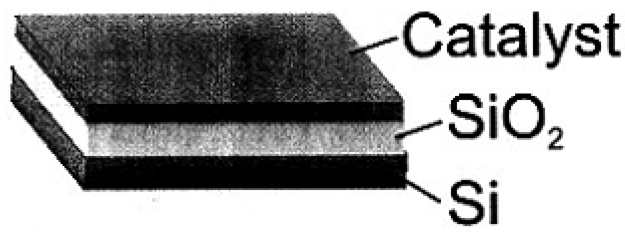
http://sinphonia.na.infn.it/index.htm

# Thank you for your attention

# Growth Mechanism of Carbon Nanotubes (CVD and PECVD)

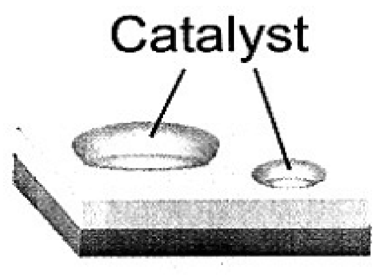
Substrate

**Ni** Catalyst deposition



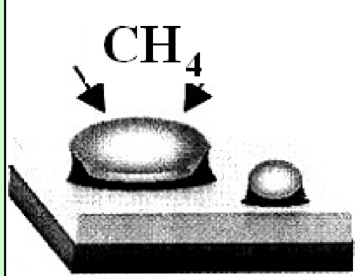

Ni Clusters formation

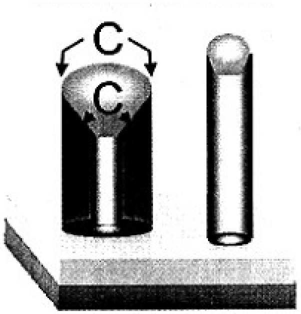
480 - 650 C°
$10^{-5}$ torr
10 - 45 min




CVD or rf PECVD

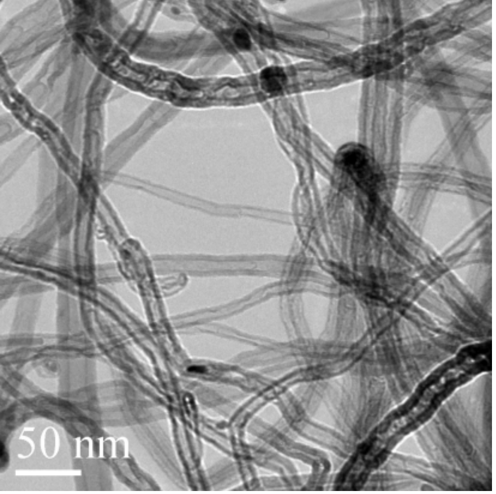
500 - 750 C°
1 torr
$C_2H_2$
or
$CH_4$
+ $NH_3$

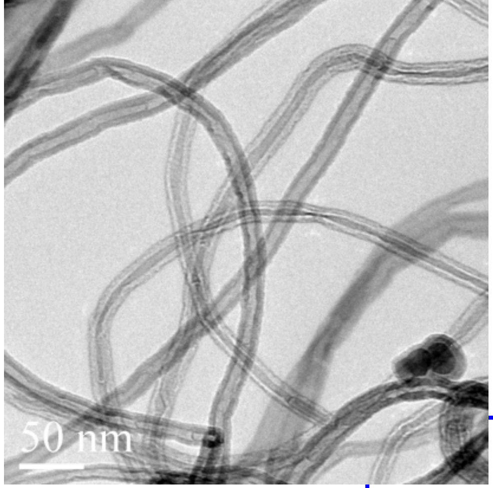


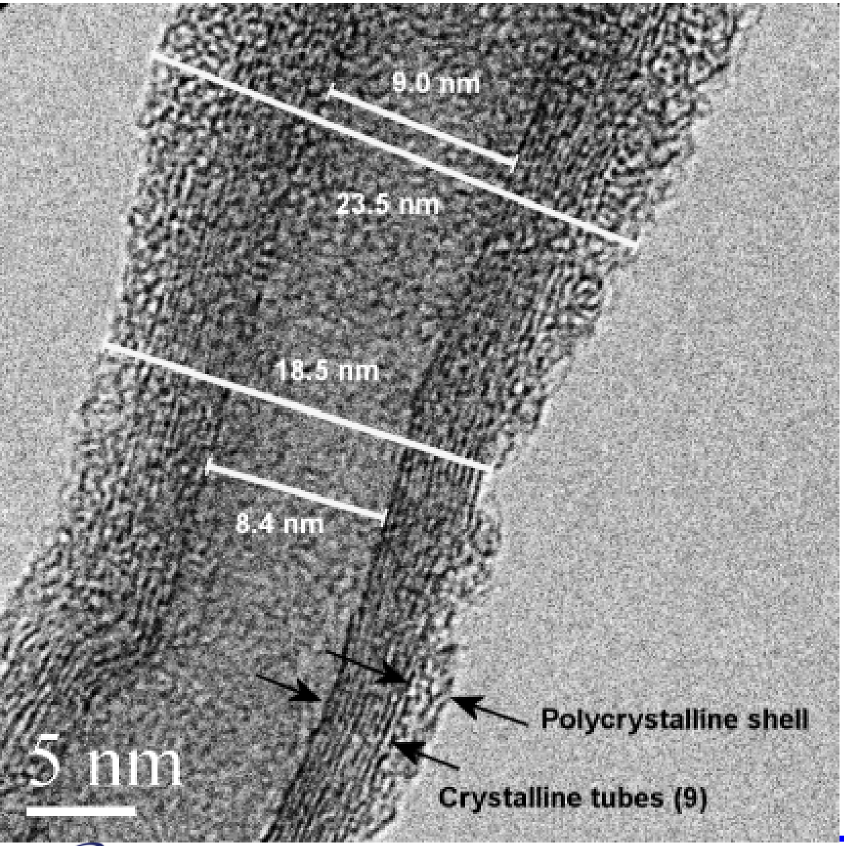



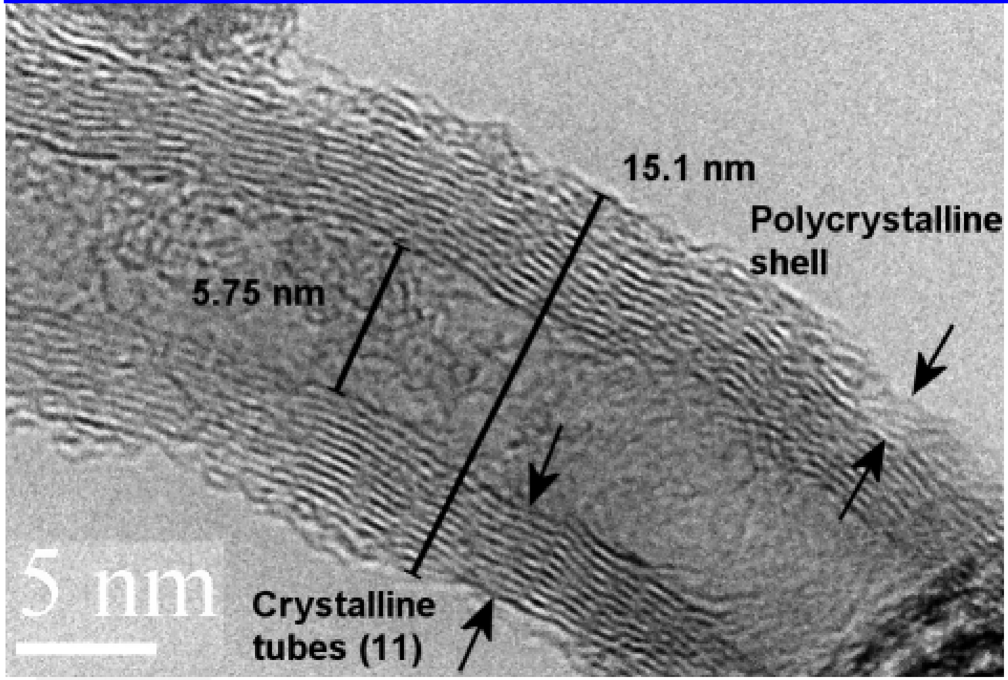
# CNT Characteristics

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

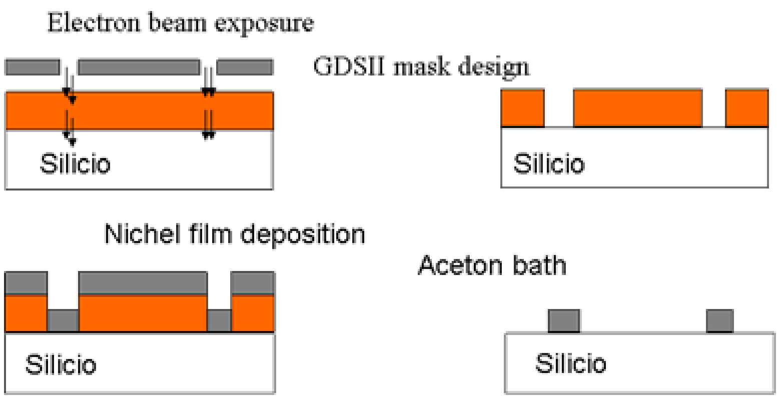


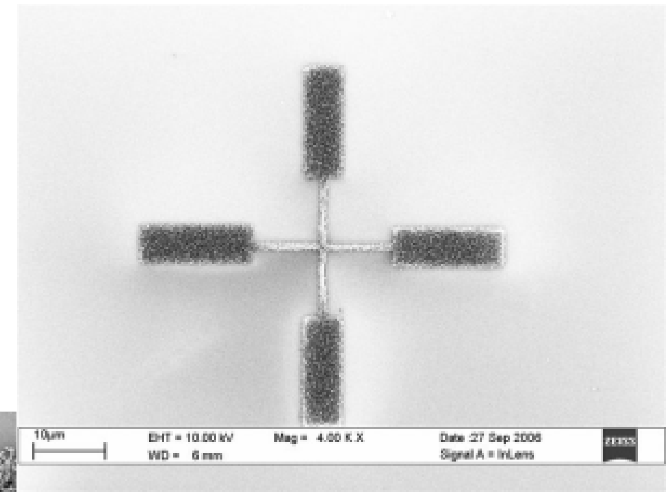



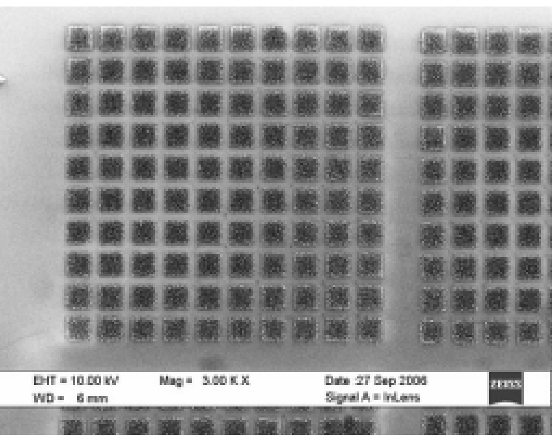



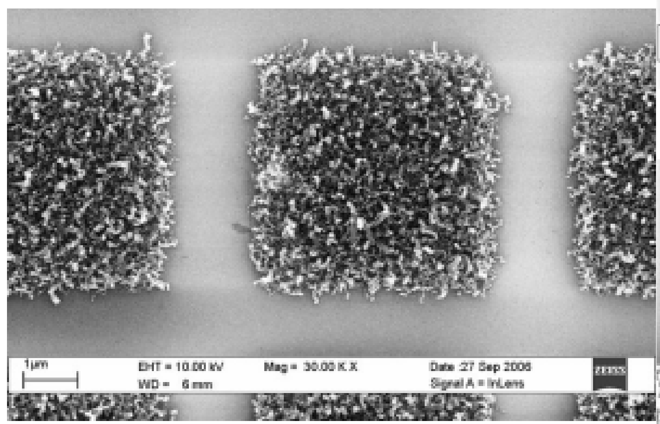
# Nanolithography and patternization

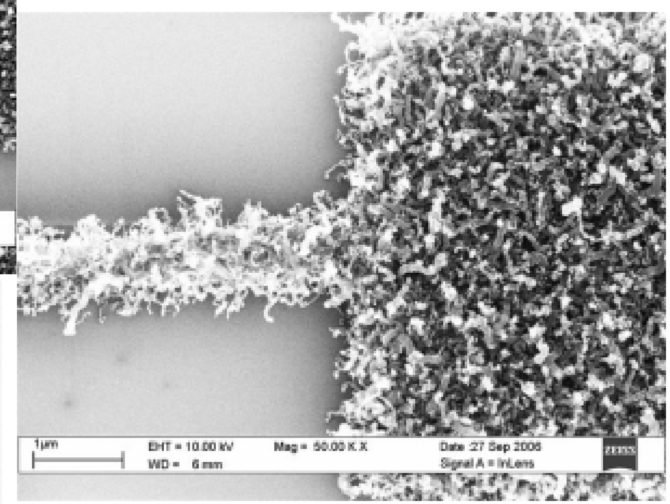


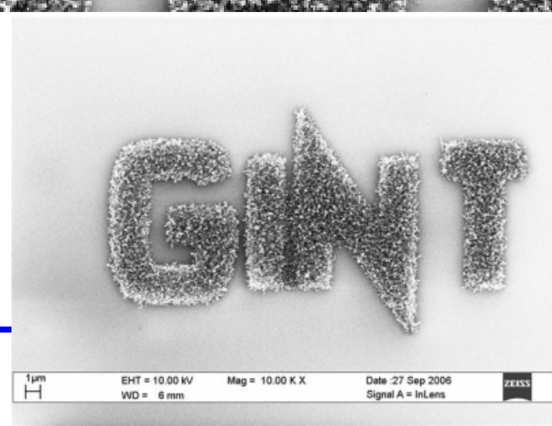


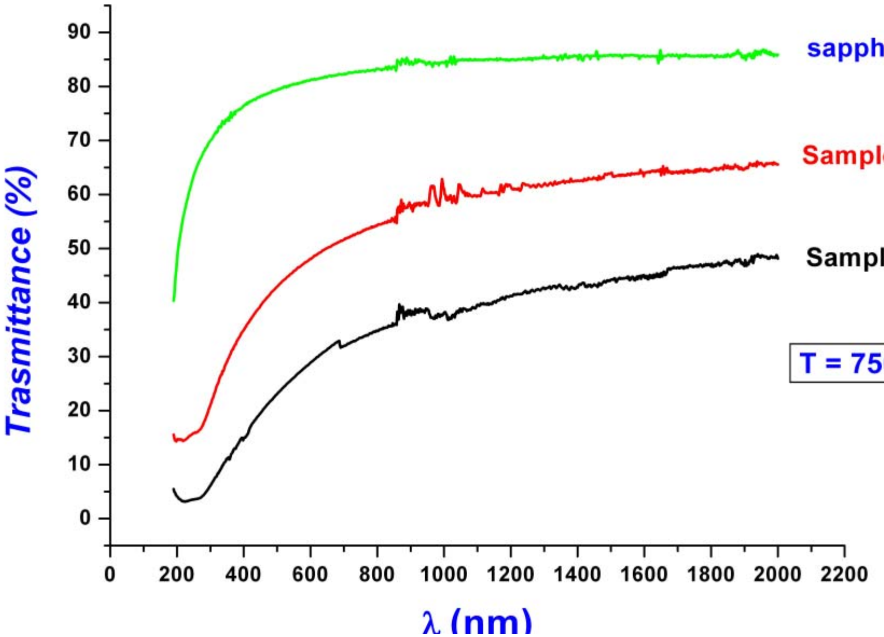




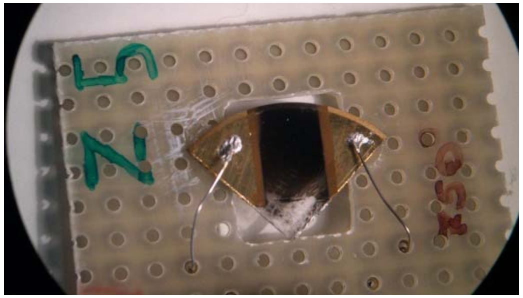


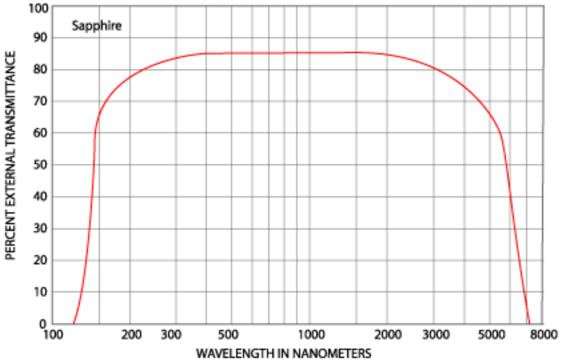


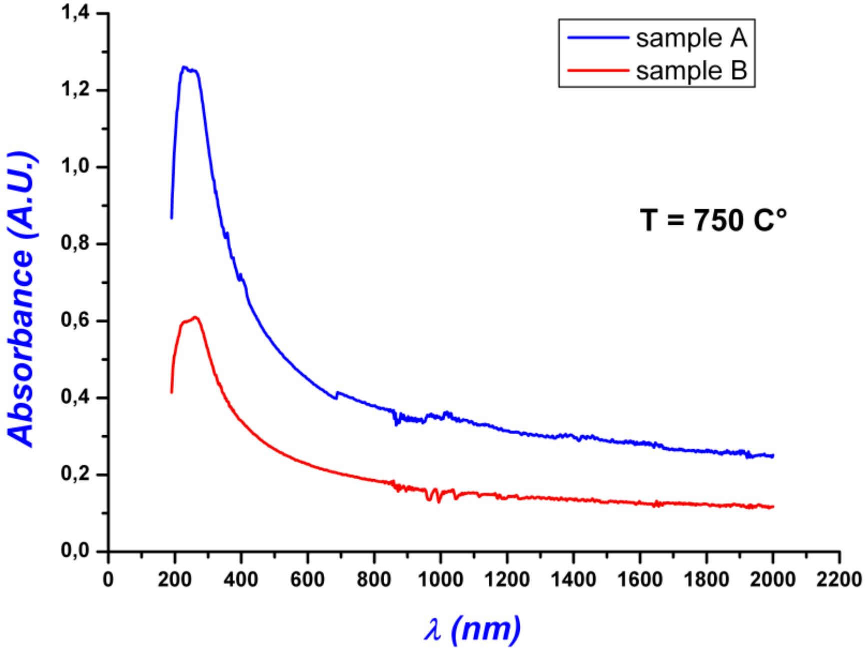




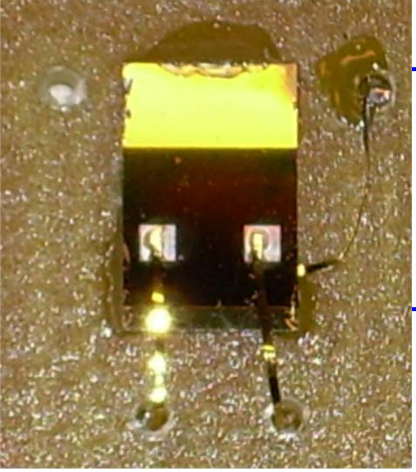

GINT
(Gruppo INFN per le NanoTecnologie)



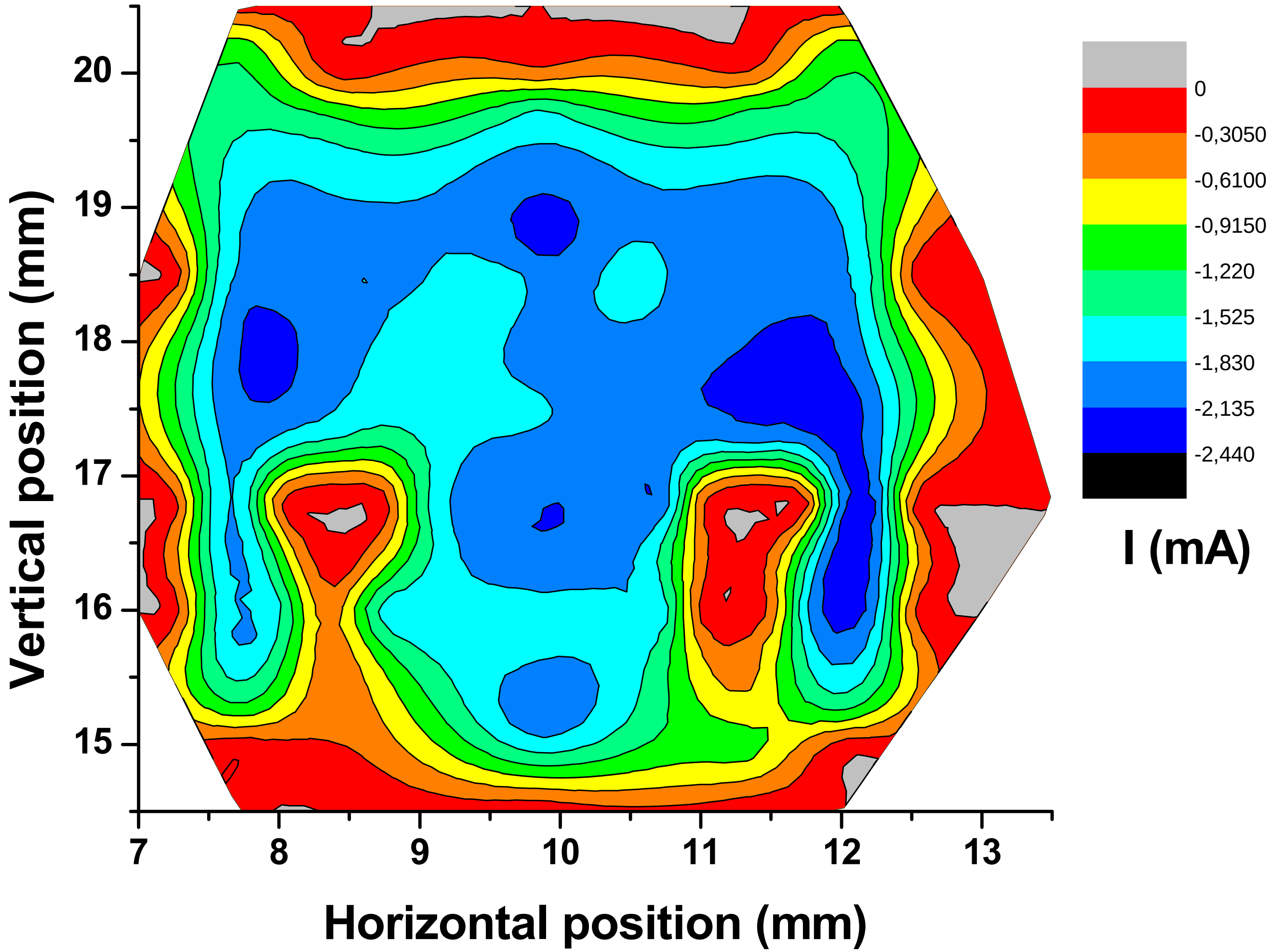


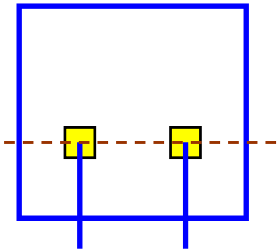

# CNT absorbance
## ($log_{10}$ 1/T)

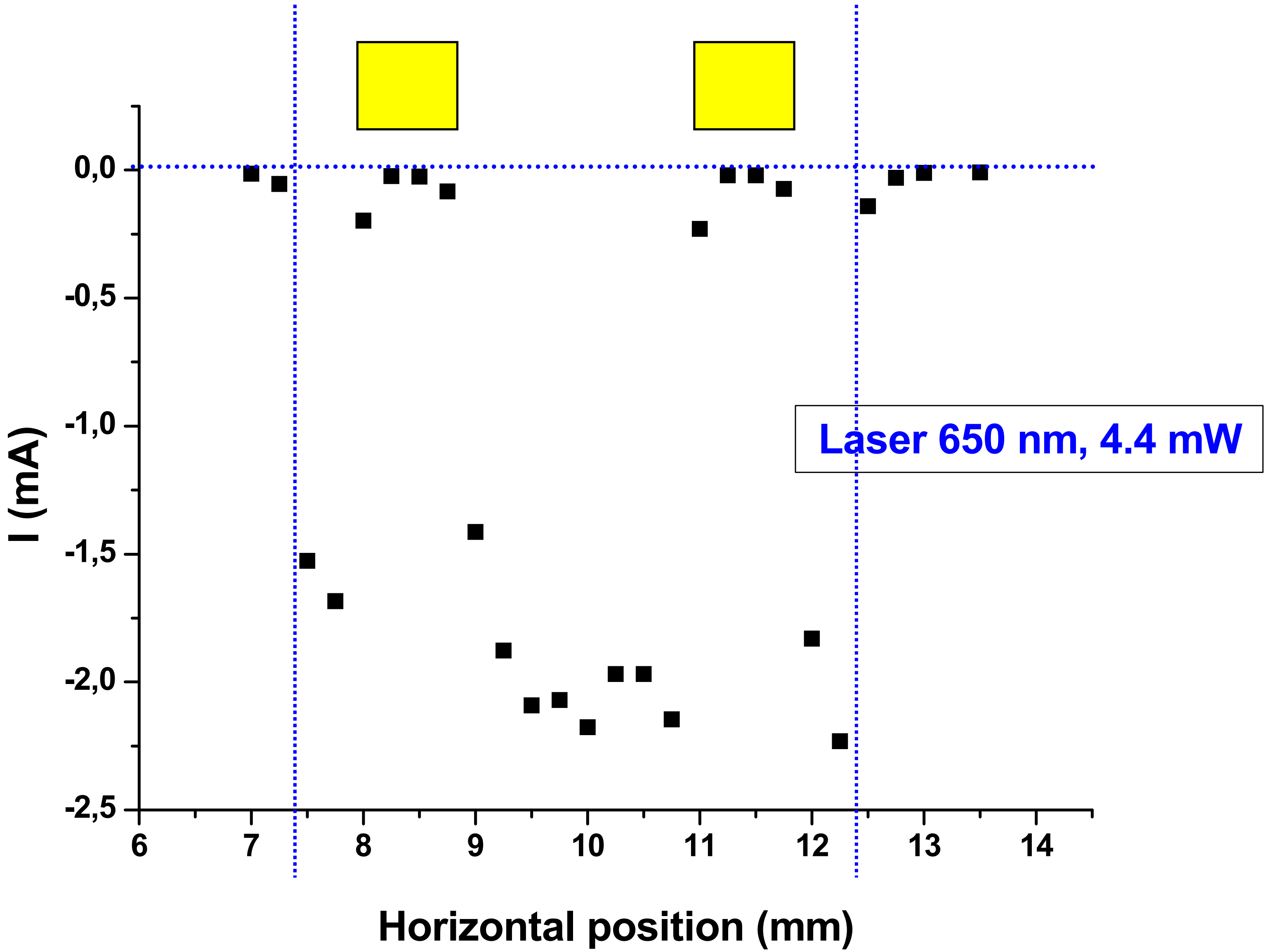


# Map of detector surface

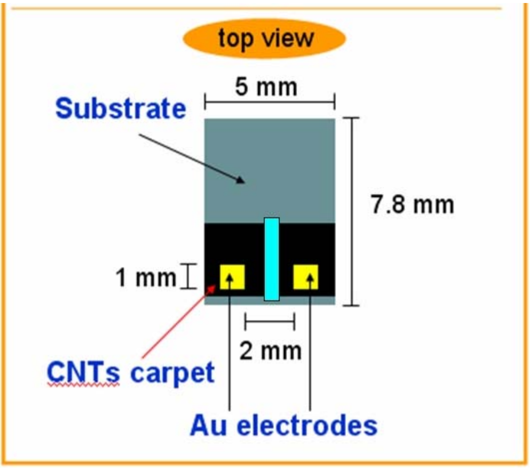


# Linear scan

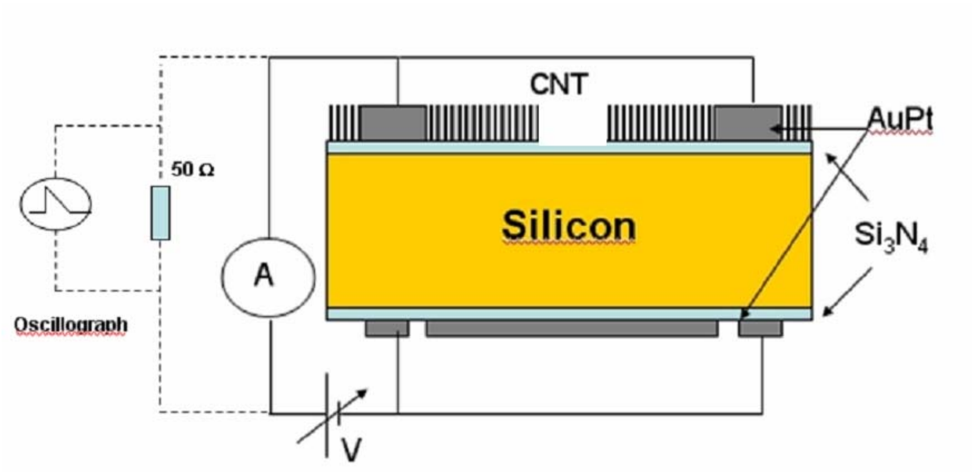


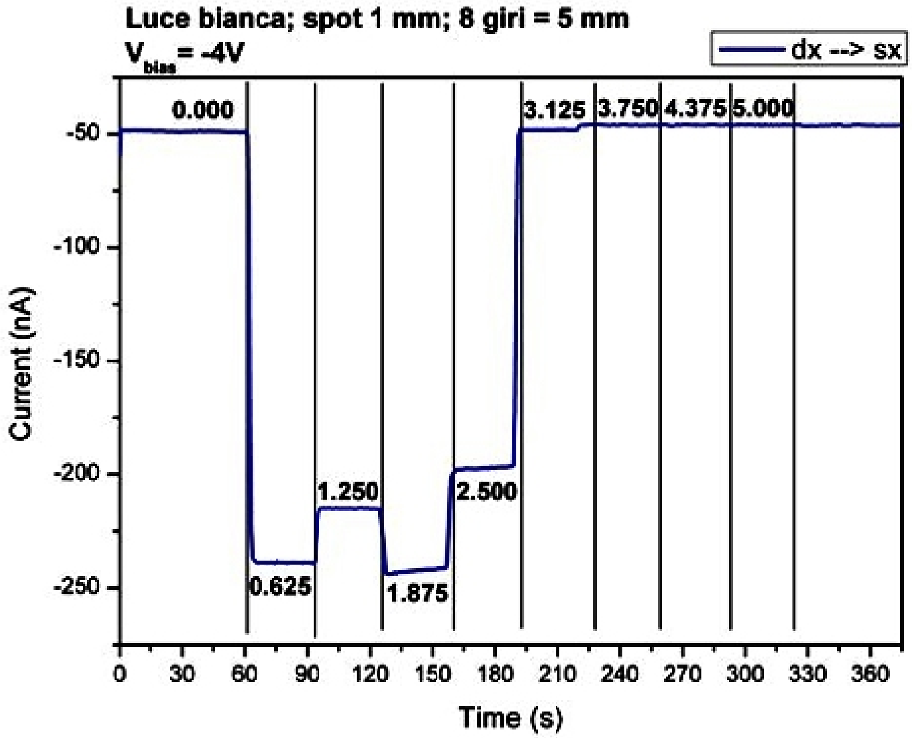

0,0
-0,5
-1,0
-1,5
-2,0
-2,5
I (mA)
6
7
8
9
10
11
12
13
14
Horizontal position (mm)
Laser 650 nm, 4.4 mW

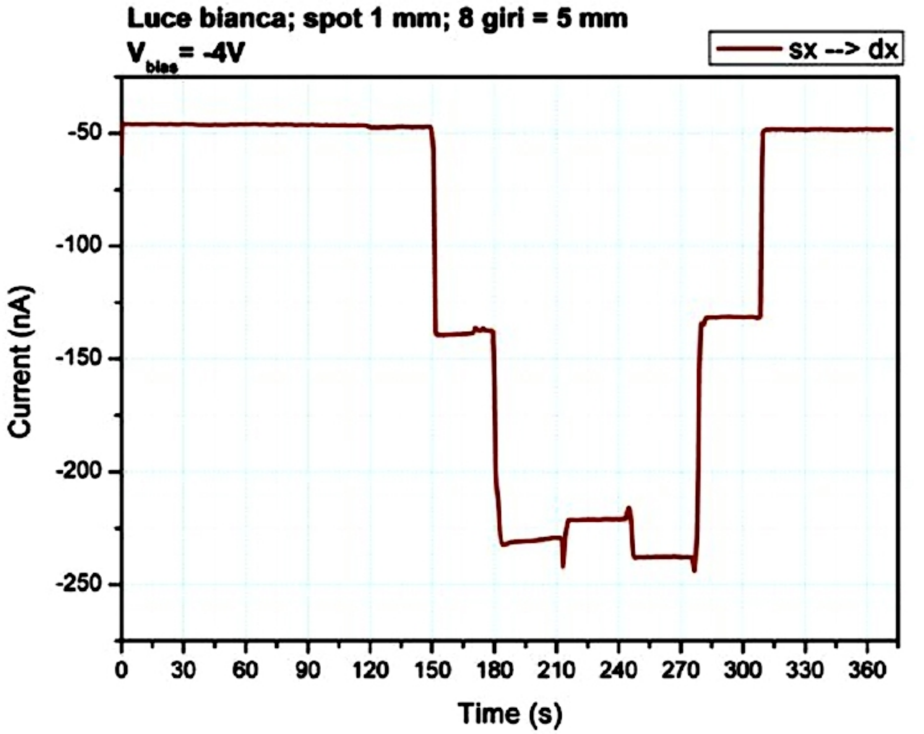
# Two insulae sample

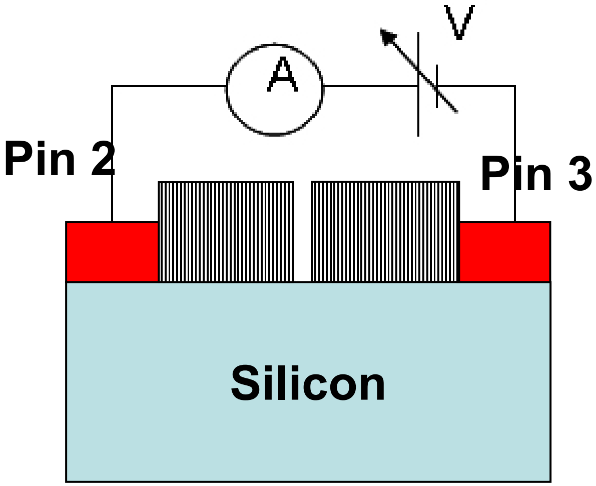



**Scan with optical fiber**



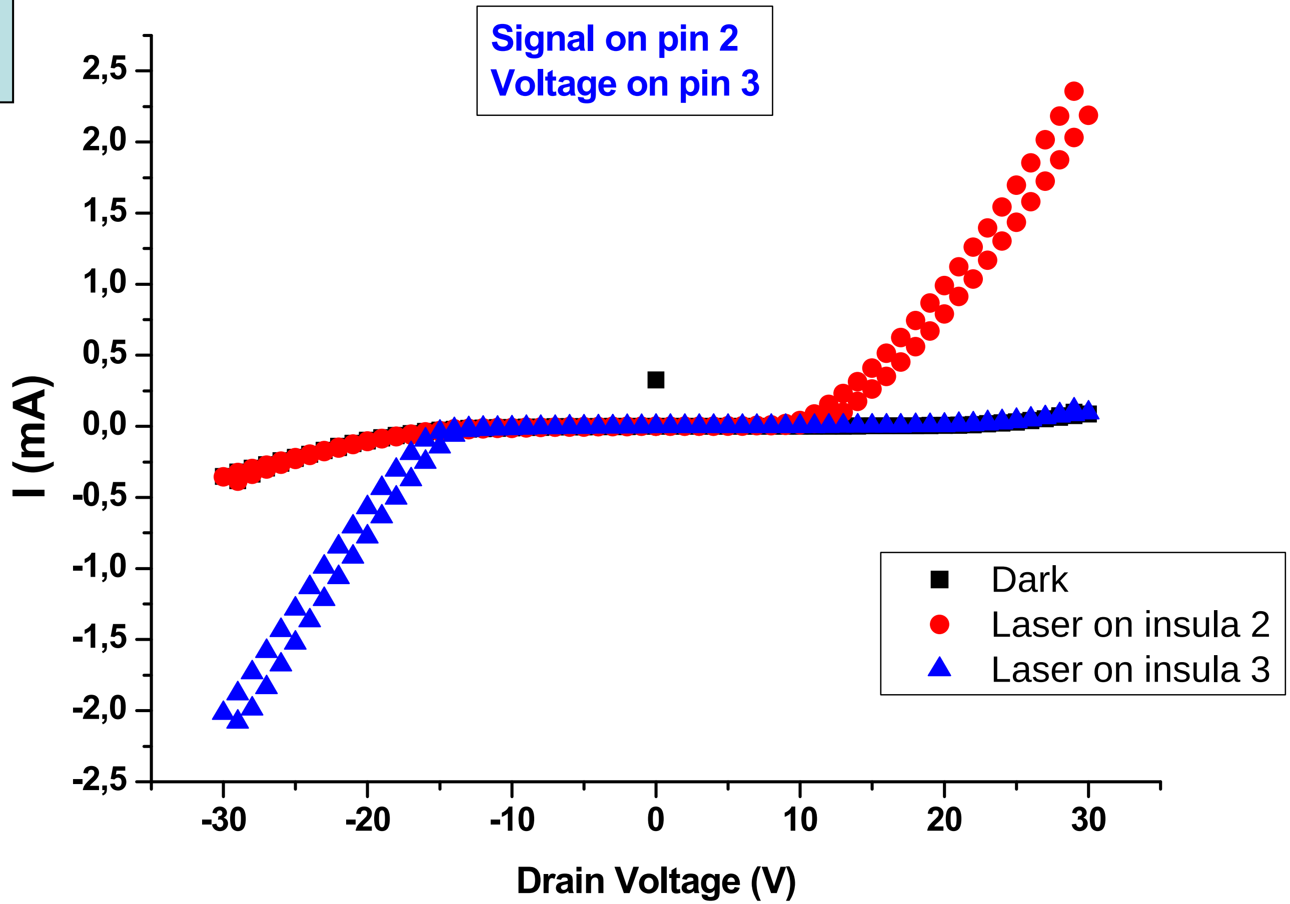





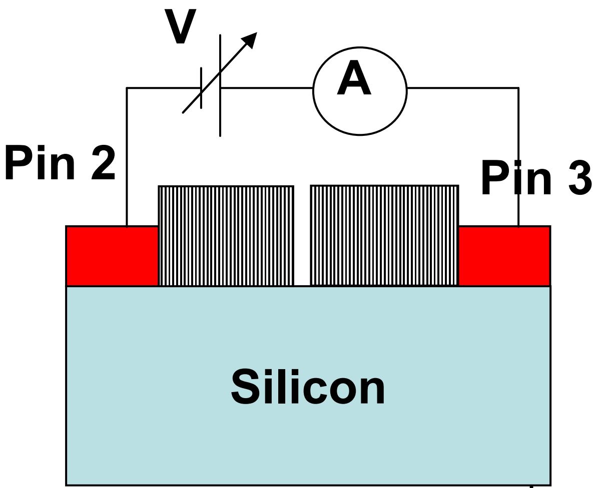

# Two insulae sample

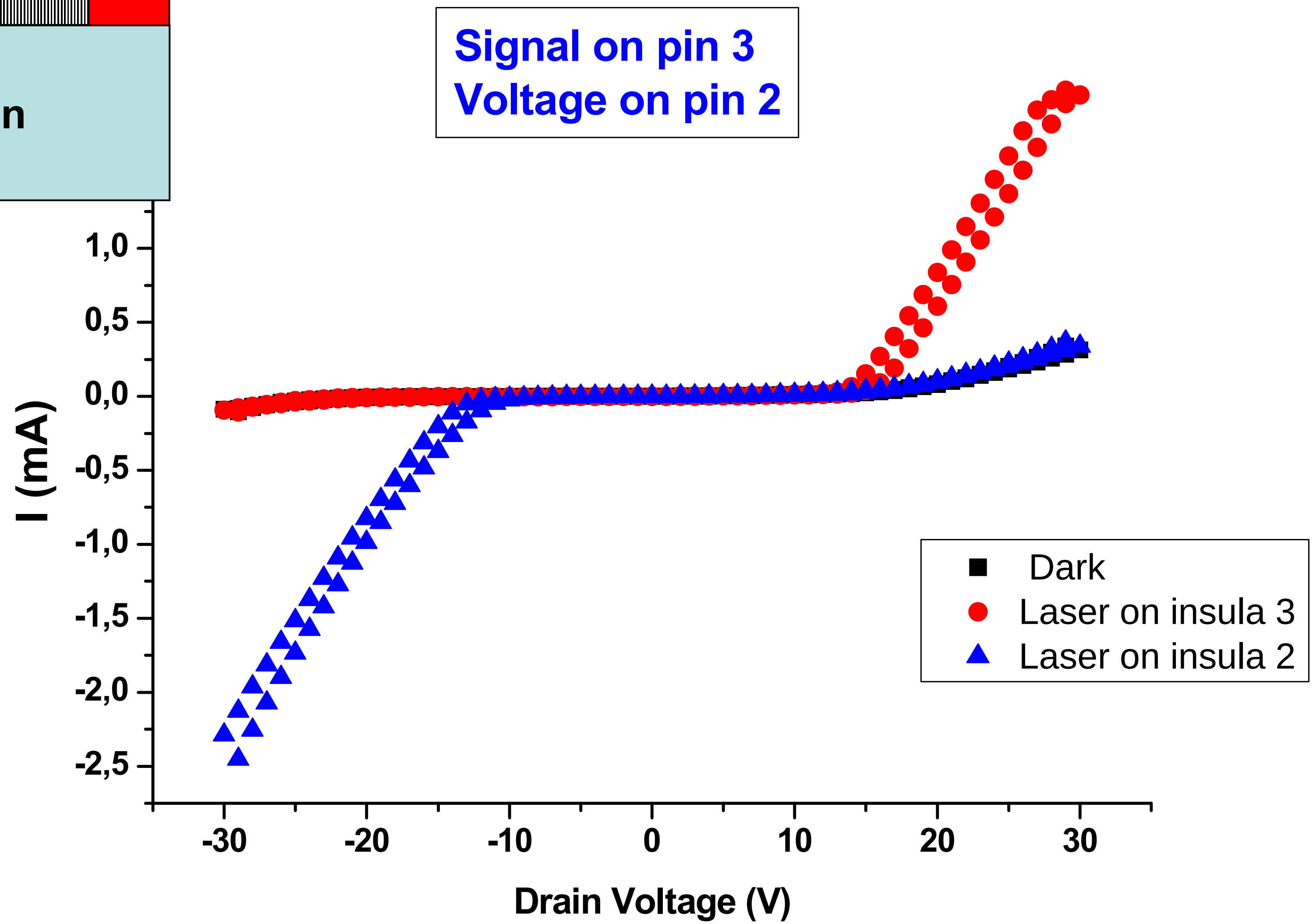
**Scan with 650 nm laser**



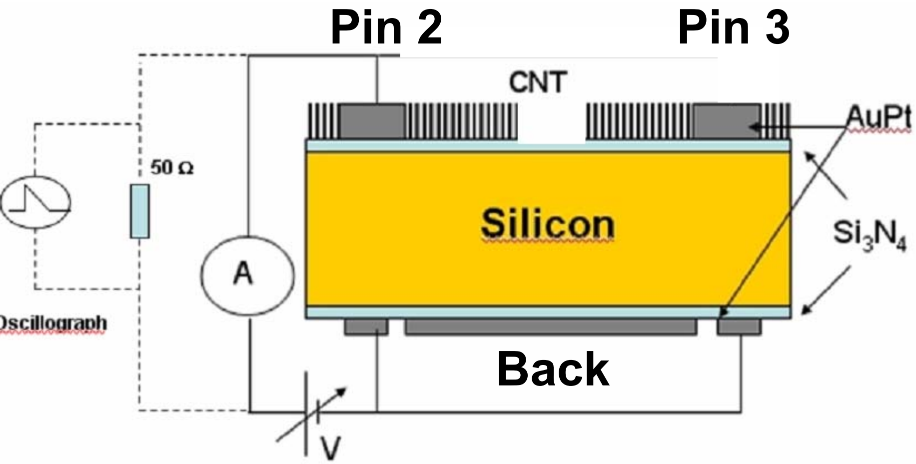
# Two insulae sample

**Scan with 650 nm laser**



# Two insulae sample




**Scan with 650 nm laser**