Use of Multi-Walled Carbon Nanotubes for UV radiation detection
A new nanostructured material: CARBON

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

The Post-Silicon ERA

This material is CARBON in the form of NANOTUBES
What is CNT?

A Carbon Nanotube is a single graphene sheet rolled up to form an empty cylinder. The \textbf{electronic properties} of one of these nano-objects depend on the chiral vector of the tube, representing the versus of the rolling in terms of the unit vectors of the hexagonal graphene lattice.

Figure 5. Chiral vector for CNT characterization (adapted from Wilderer, 1998, p. 59)
Carbon Nanotubes (CNTs)

Molecular Nanowires ($d \sim 1 \text{ nm}, l \sim 1 \text{ µm}$)

**SWNTs**
- Single Graphene Sheets
- $(d \approx 0.7 \div 3 \text{ nm}, L \approx \text{µm-range})$
  - $\in N$

**MWNTs**
- Coaxial graphene sheets
- $(d \approx 2 \div 100 \text{ nm},
  (d_{out} \approx 20_{\text{AD}}, 100_{\text{CVD}} \text{ nm})$
- $L \approx \mu\text{m-range}$
  - $\notin N$

**Semiconductor**
- Channel (FETs), Luminescence
- Semiconductor CNT contribute to the fotoresponsivity, while the metallic CNT are necessary in order to extract the charges

**Metal**
- Ballistic Conduction, $e$-wave guides, SETs
Development of radiation detectors based on carbon nanotubes
GEOMETRY
and
SUBSTRATES

Sapphire

Comb-like electrodes

Electrodes

Microstrip

Sapphire

Si$_3$N$_4$

Silicon

Aluminium

Quartz

GINT

(Gruppo INFN per le NanoTecnologie)
Radiation detector made of Multi-Walled Carbon Nanotubes

Signals detected with the first carbon nanotube radiation detector

\[ \lambda = 355 \text{ nm} - 0.19 \text{ mJ} \]
Signal comparison at different wavelengths

\( \lambda = 532 \text{ nm} - 0.46 \text{ mJ} \)

\( \lambda = 1064 \text{ nm} - 1.6 \text{ mJ} \)

\( V_{\text{Drain}} = 25 \text{ V} \)
Collected electrons / incident photons

No signal amplification
No CNT annealing.....
as cast MWCNT
CNT absorbance

\( \log_{10} \frac{1}{T} \)

T = 750 °C
Photocurrent normalized to the number of photons $I_{\text{nor}}$ 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
The main problem

Signal generated inside CNTs is collected by means of electrodes in a plane orthogonal to the nanotube axis. The charge must migrate by tunneling and has a great probability to be re-absorbed.

The efficiency of such device is very low.
A different architecture under test

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

With this architecture the charge generated inside CNTs by radiation can be collected through the silicon substrate without great attenuation.
The answer of detector to a pulsed red light
Measured photocurrent

The graph shows the dependence of the drain voltage ($V_{\text{drain}}$) in millivolts ($\text{mV}$) on the drain voltage in volts ($\text{V}$) for different conditions: dark, light, and dark plus light. The colors represent the conditions:

- **Blue**: dark
- **Red**: light
- **Purple**: dark plus light

The graph indicates a nonlinear relationship between the drain voltage and the drain voltage, with different behaviors under each condition.
Conversion efficiency

Collected electrons / incident photons

$E^{-06}$

Conversion efficiency

Sapphire

Graph showing collected electrons per incident photon as a function of drain voltage at different powers and wavelengths.

- $\lambda = 355$ nm
- $\lambda = 532$ nm
- $\lambda = 1064$ nm

Drain Voltage (V)

Collected electrons / incident photons

- 3.84 mW
- 3.40 mW
- 2.62 mW
- 1.58 mW
- 0.91 mW

Comb-to-comb pattern
Conclusion

- CNTs demonstrate important photoconductive properties;

- The maximum sensitivity is in the UV region;

- The first microstrip detector made of multi-walled carbon nanotubes grown on sapphire substrate have been realized.
Next ...

- Study of new architecture with CNTs grown on silicon substrate;
- Charge amplification inside the silicon substrate;
- Nanotubes coating
Development of UV Single Photon Detector based on Carbon Nanotubes

Funded by INFN for the 2009 – 2011 three-year period