Sviluppo di un fotomoltiplicatore a valanga basato su giunzione nanotubi di carbonio/Si

SCAPho-Silicon Carbon Avalance Photodetector

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Collaborations

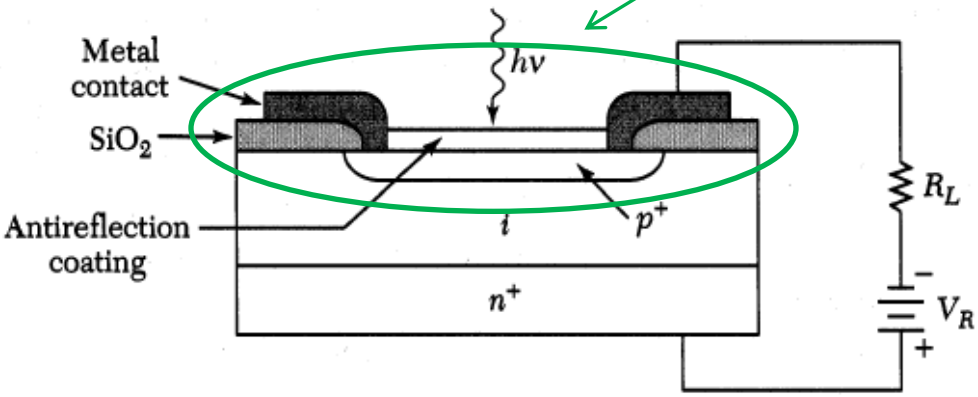
Fondazione Bruno Kessler Trento-Italy
ISM-CNR Frascati-Italy

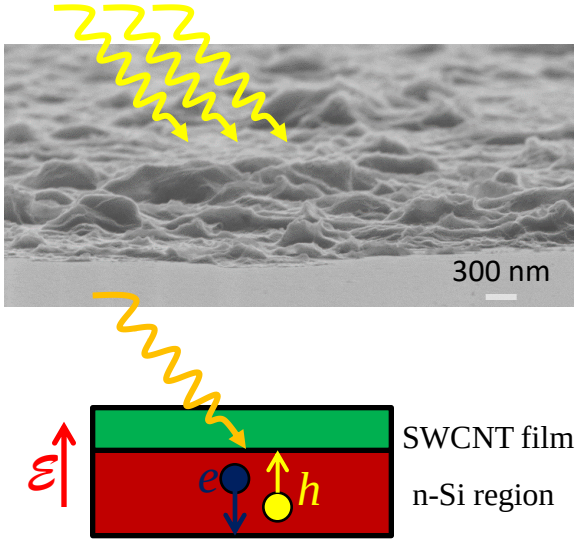
Photodetectors

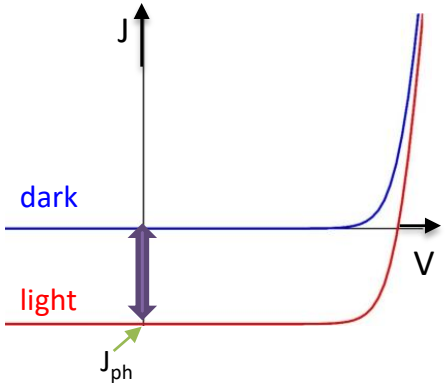
p-n semiconducting or metal Schottky junction

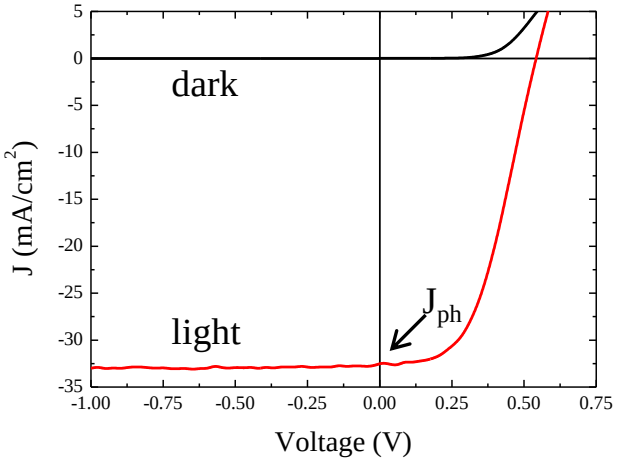
-Antireflection coating
-Thin (semitransparent) upper layer
-Conductive electrodes to collect the photogenerated charges

Substitution with a Single Walled Carbon Nanotube (SWCNT) thin film



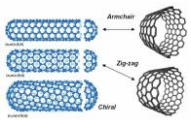






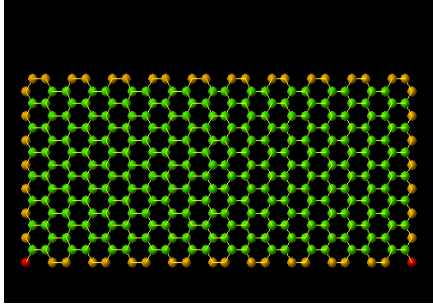
1-
Low-cost
Rapid
Room-temperature process
Versatile deposition method
Scalable tecnique
Highly reproducible
SWCNT random networks

Realization and properties of CNT films



metallic

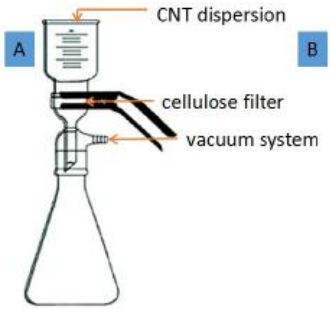
Non metallic

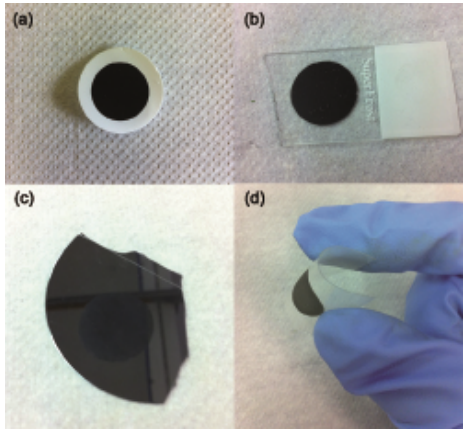


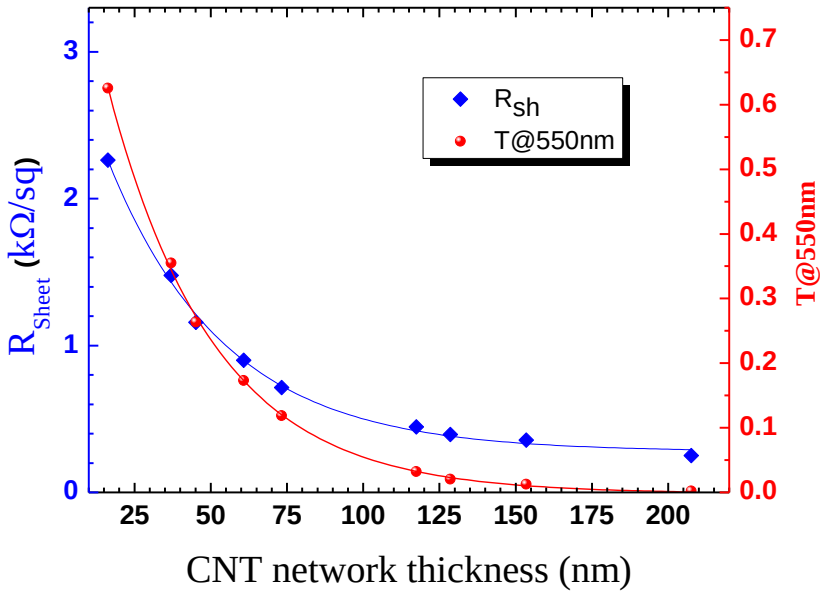
2- SWCNT thin films are conductive and semitransparent

Optical transmittance and electrical conductivity are two competing parameters both depending on the film thickness and the metallic CNT concentration

- Aqueous suspension of SWCNTS and anionic surfactant (SDS)
- Well dispersed suspension (ultrasonication and ultracentrifugation)
- Vacuum filtration process on cellulose filter
- Dry-transfer printing deposition method

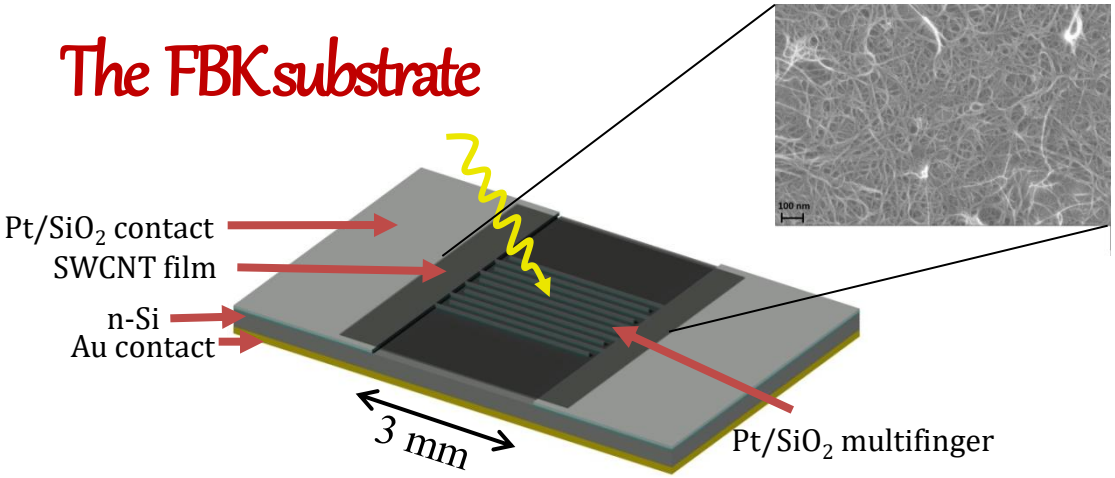


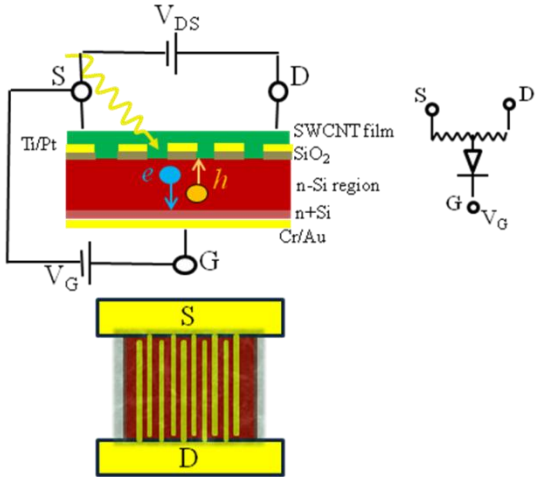




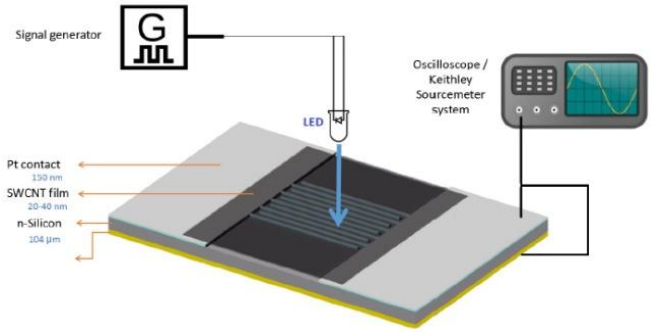
The SWCNT/n-Si device

The FBK substrate

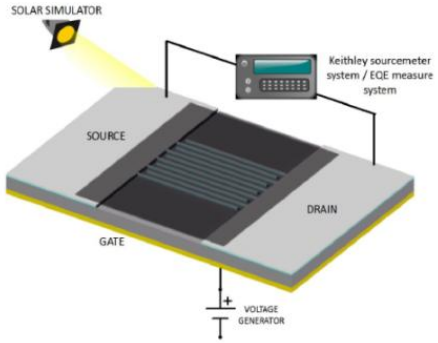




Two possible configurations for two and three teminal measurements

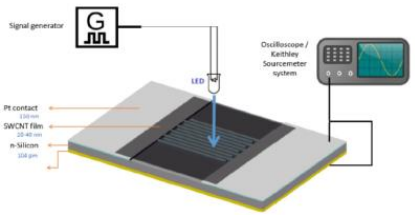


Two teminals



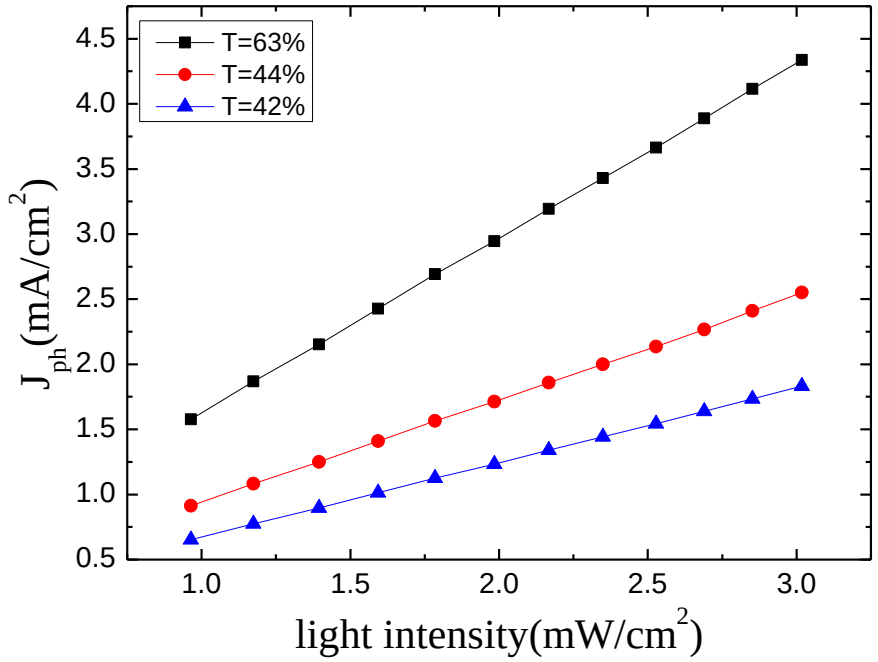
Three teminals

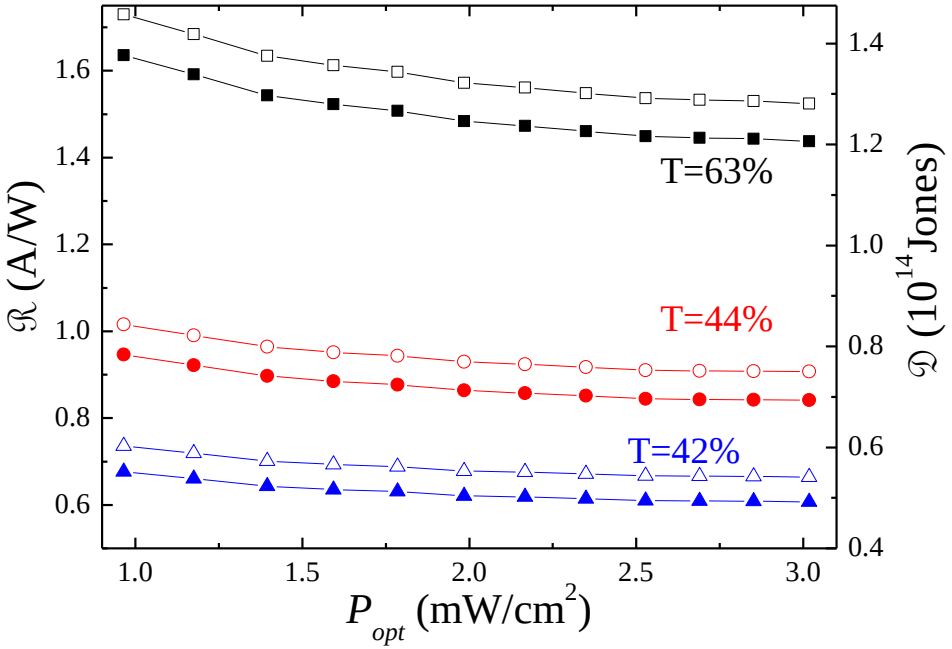
Two teminals



Main results of SWCNT/Si photodetectors

Linearity with the incident power density
High responsivity and detectivity





$$J_{ph} \propto P_{in}$$

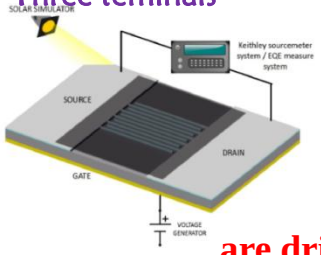
$$\mathcal{R} = \frac{I_{ph} - I_0}{P_{opt}}$$

The Responsivity measures the PD input-output gain

$$\mathcal{D} = \sqrt{\frac{A}{2eI_0}}\mathcal{R}$$

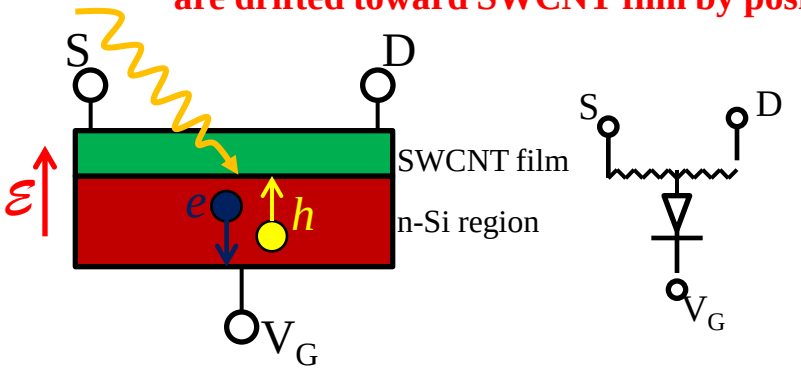
The Detectivity measures the ability of a PD to detect small signals

Three teminals

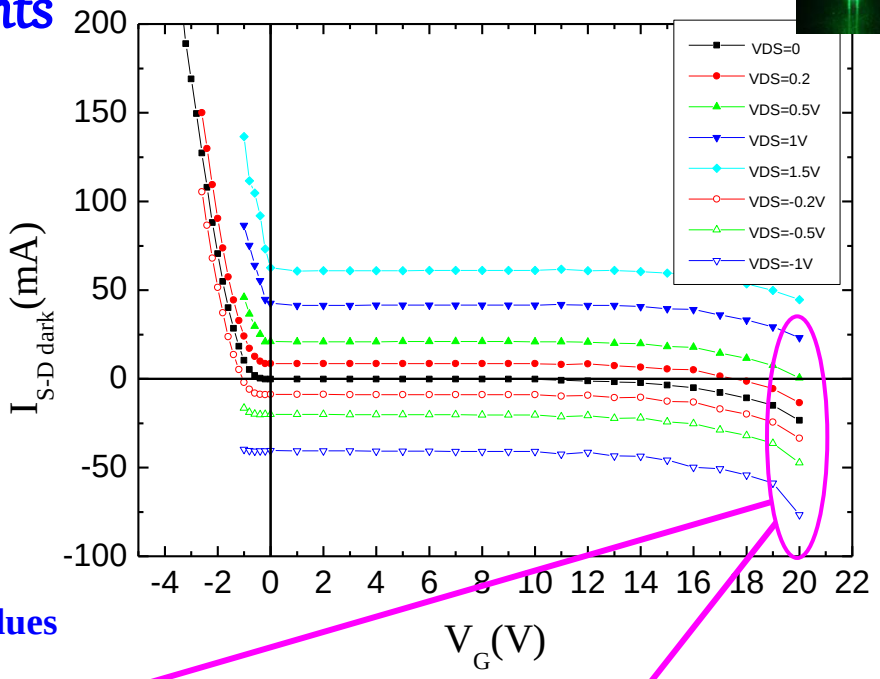


Three terminals measurements

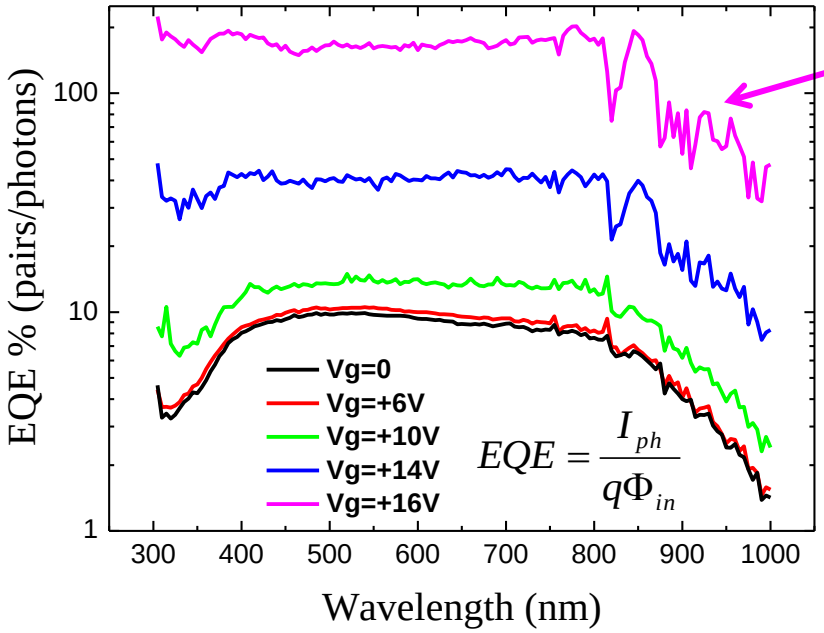
AVALANCE PHOTODETECTOR
Photogenerated charges inside Si
are drifted toward SWCNT film by positive gate

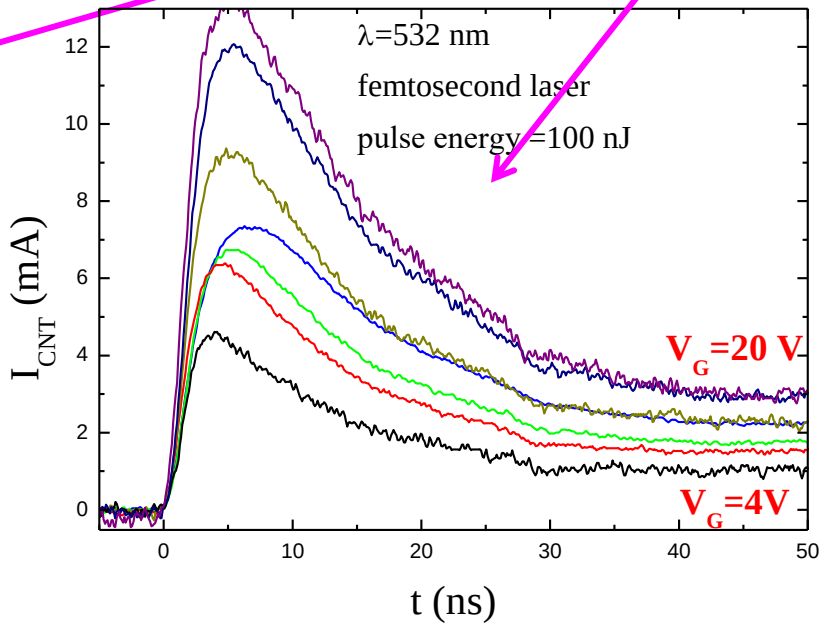


The gate voltage affects the light detection



EQE and responsivity increase far above the 2 terminals values

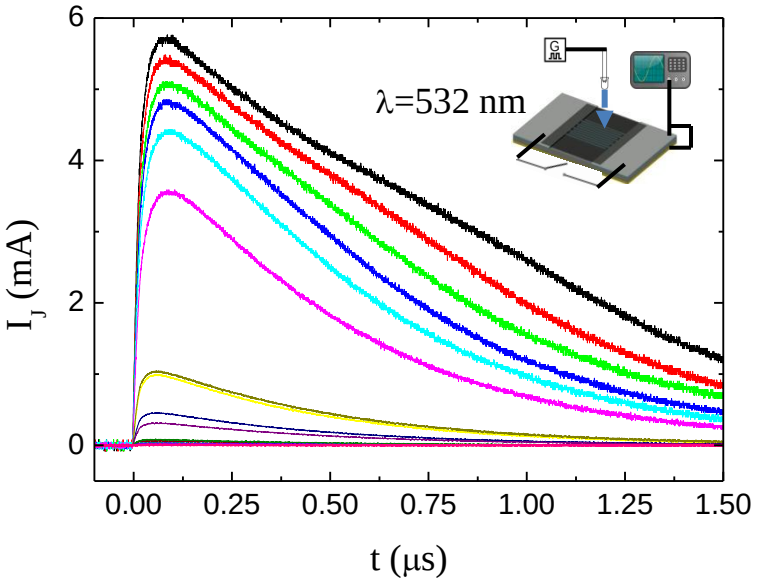




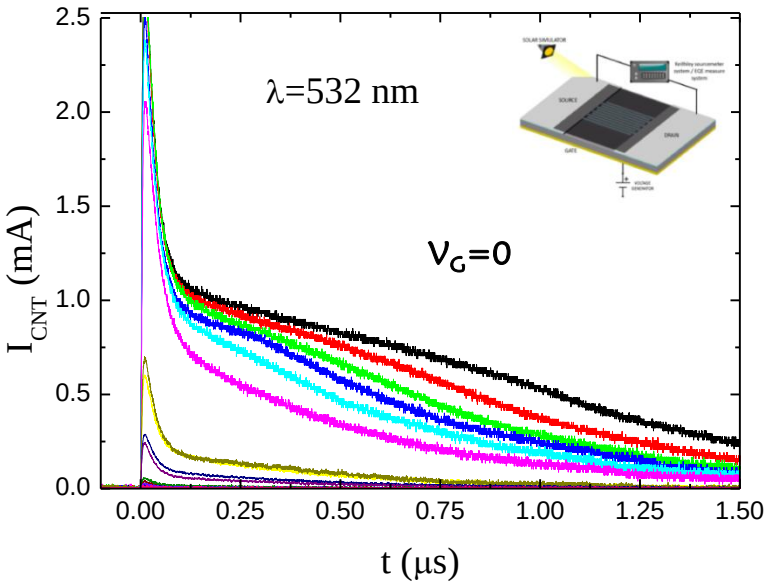
M. Salvato et al. IEEE Trans on Nanotechnology 837,17, 2018

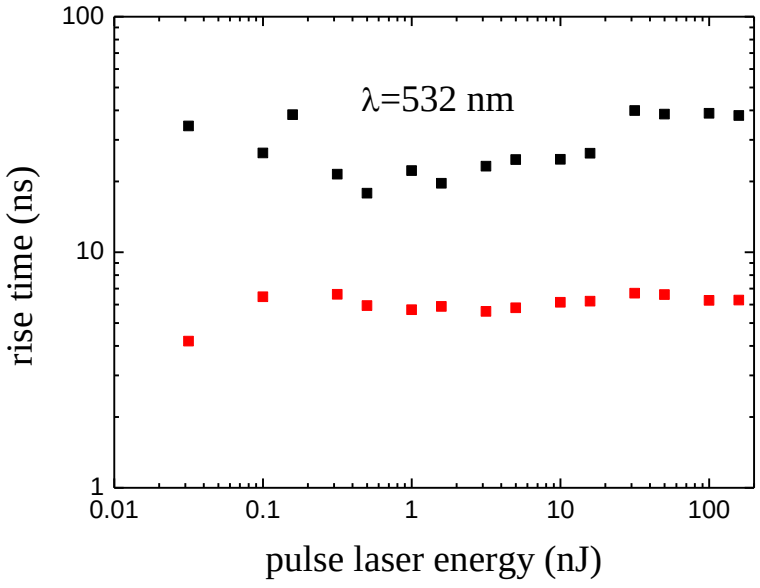
Three terminals vs. two terminals configuration using Pulsed laser 40 fs, 31 pJ-1μJ

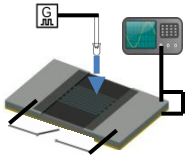
Two teminals



Three teminals

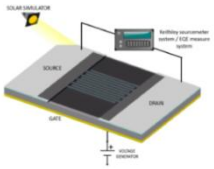




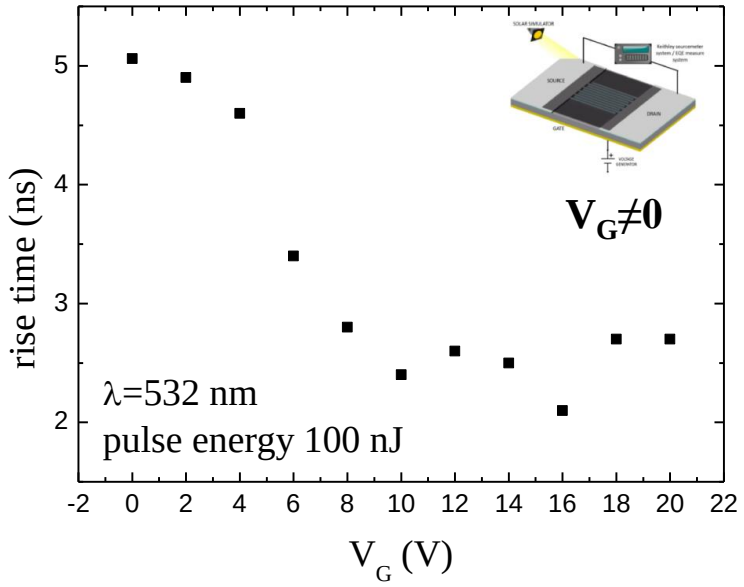


Two teminals

Three teminals



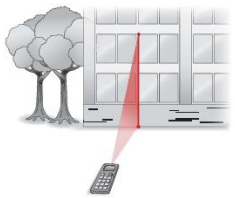
V_G=0



Our photodetector vs. not polarized commercial APD

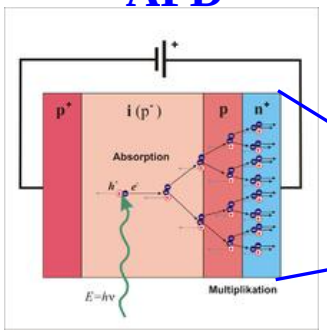
	Active area	Responsivity	Breakdown voltage	Dark current	Capacitance	Rise time	Spectral range	Gain $V>V_B$ D
Hamamatsu Si APD S12053	0.8 mm^2	0.5 A/W	200 V	0.5 nA	5 pF	1.5 ns	300 nm-1000 nm	10^5
Osi Optoelectronics HR020 series	0.2 mm^2	0.45 A/W	15 V	0.06 nA	1.8 pF	0.8 ns	400 nm-1000 nm	
Our SWCNT/Si detectors	9 mm^2	1.2 A/W	20 V	<1 nA	5 nF	3-5 ns	300 nm-1000 nm	Not meas.

SWCNT junctions as candidates for Avalance PhotoDetectors (APD)
and possibly for Multi Pixel Photo Counters (MPPC)
for single photon detection

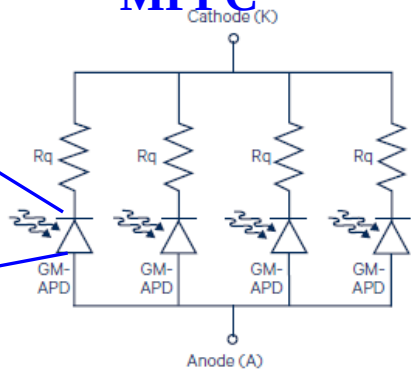


Optical rangefinders

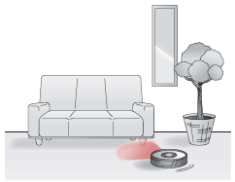
APD



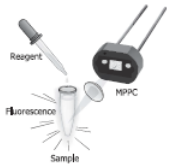
MPPC



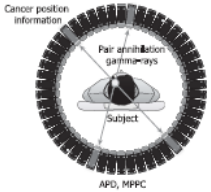
LIDAR



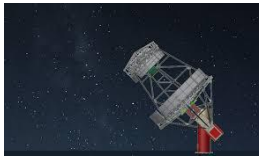
Obstacle detection



Fluorescent measurements



PET-NMR facilities

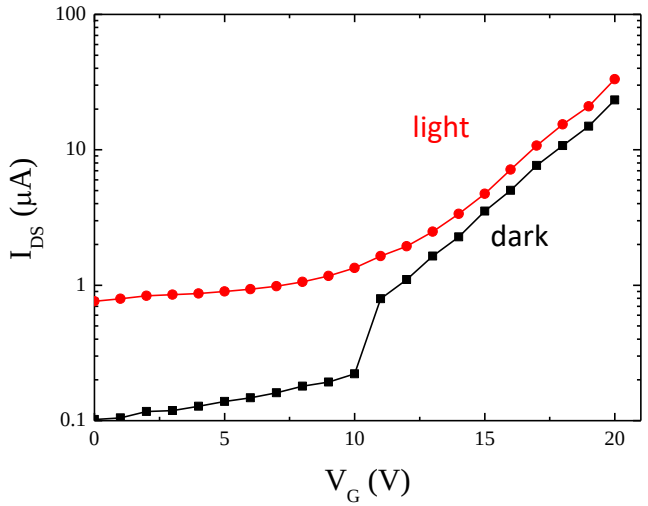


Cerenkov telescopes

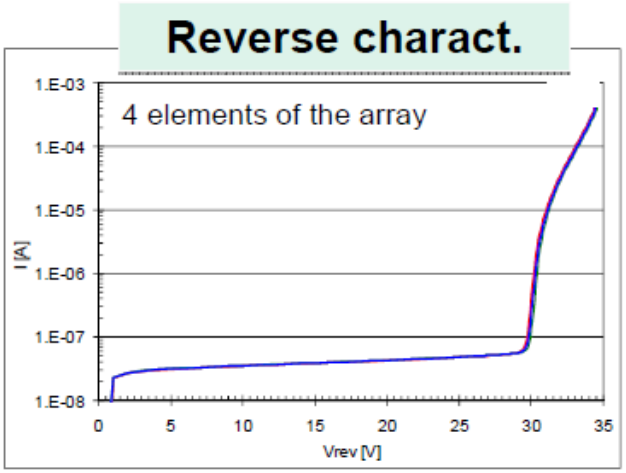
An APD works at a reverse voltage just above the break down.
The photon absorption cause a huge increase of the reverse current

Improvement in the breakdown region is strongly demanded

SWCNT/Si
Reverse characteristics

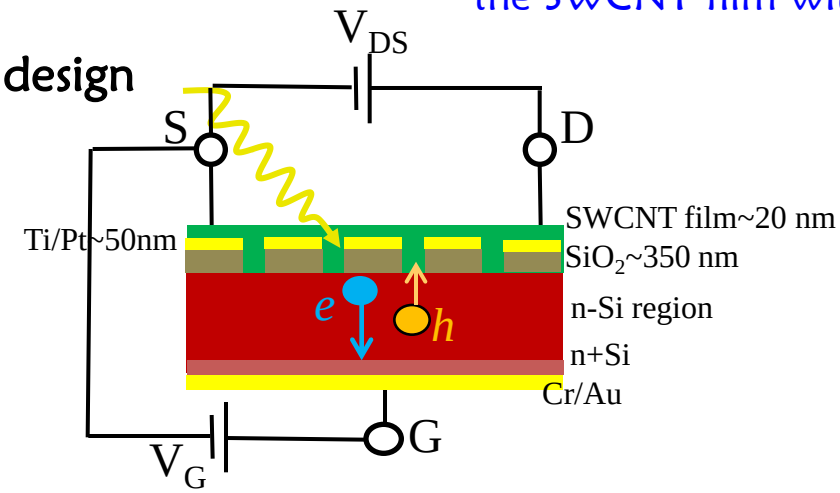


Hamamatsu APD

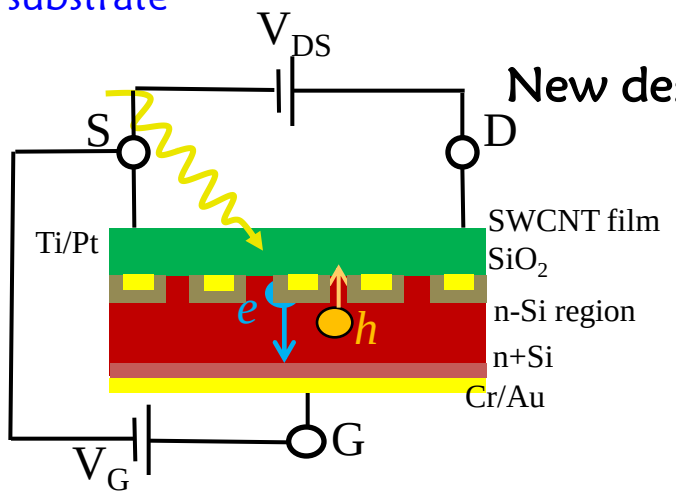


New designed FBK substrates to improve the junction quality through a better contact of the SWCNT film with the Si substrate

Old design



New design



Parameters of interest:

In dark conditions
Voltage breakdown (~30 V),
dark current (<1 nA),
reverse voltage characteristics as a function of temperature and magnetic field.
Schottky or p-n junction

Under light
Quantum efficiency,
responsivity,
detectivity,
response time,
gain
and their dependence on the temperature

SCAPho Silicon Carbon Avalance Photodetector

2 years.

Available facilities

INFN Roma2

-SWCNT film fabrication facilities
-Monocromator
-Lamp
-Current/voltage power supply
-Visible wavelengths Femtosecond laser source

INFN Salerno

-Low temperature transport measurement facilities
-Cryostat with 9 T superconducting magnet

Workplan and financial support required

Description	Final date of the action	Equipment	Costs (euro)
New FBK substrates. Electrical and magnetic characterization of the SWCNT thin films.	**30-06-2019**	**Picoammeter; FBK substrates; chemicals**	**30000**
SWCNT film deposition on FBK substrates; junction characterization vs. temperature. Arrangement of existent facility for electrooptical measurements at different temperature.	**31-12-2019**	**Optical fibers, connectors, adaptors, cryogenic supplies**	
Electro-optical measurements under light. Quantum efficiency, responsivity, detectivity vs. Temperature. Time response measurements. Optimization of the fabrication parameters.	**30-06-2020**	**Refrigeration liquids, cryogenic feedthrought, mirrors, filters, optical spares**	**15000**
APD electrical circuit; avalance photodetector response; gain measurement vs. light power, temperature, wavelength.	**31-12-2020**	**Electronics, refrigeration liquids.**	