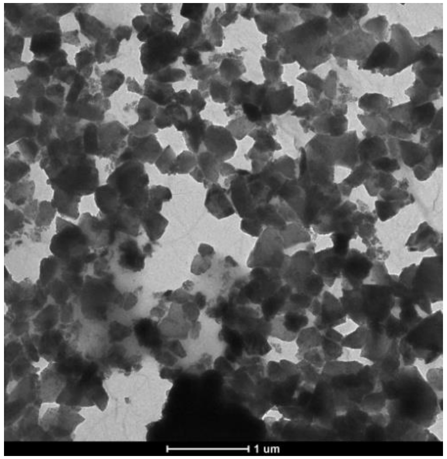
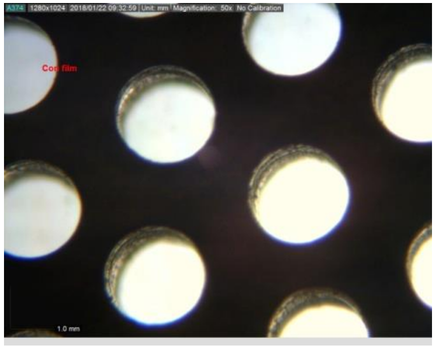
Istituto Nazionale di Fisica Nucleare
SEZIONE DI BARI

Dipartimento Interateneo di Fisica "M. Merlin"

DIAMOND FILM
(RD in Bari)



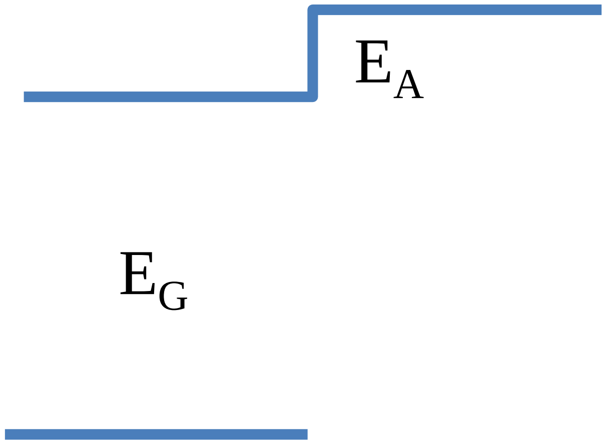


RD51 Mini-Week
10 -13 Feb. 2020 at CERN

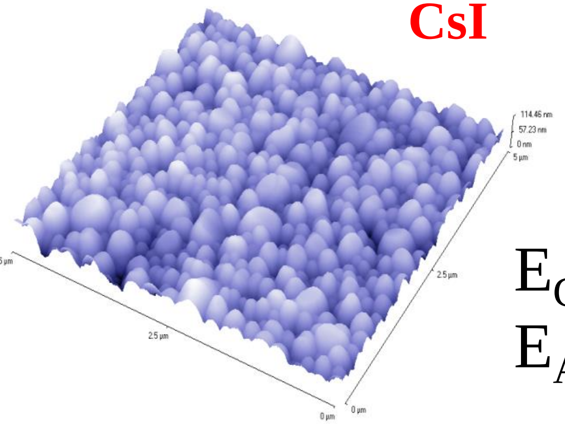
Antonio Valentini et al.
INFN – Sezione di Bari

PCs
Quantum Efficiency (QE)

- Increase with E_G / E_A ratio
  - **$E_G > E_A$**
    - **Scattering electrons-phonons;**
  - **$E_G < E_A$**
    - Scattering electrons-phonons;
    - Secondary electrn generation.

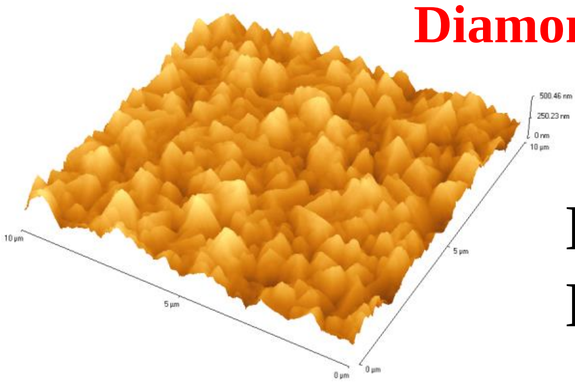


CsI



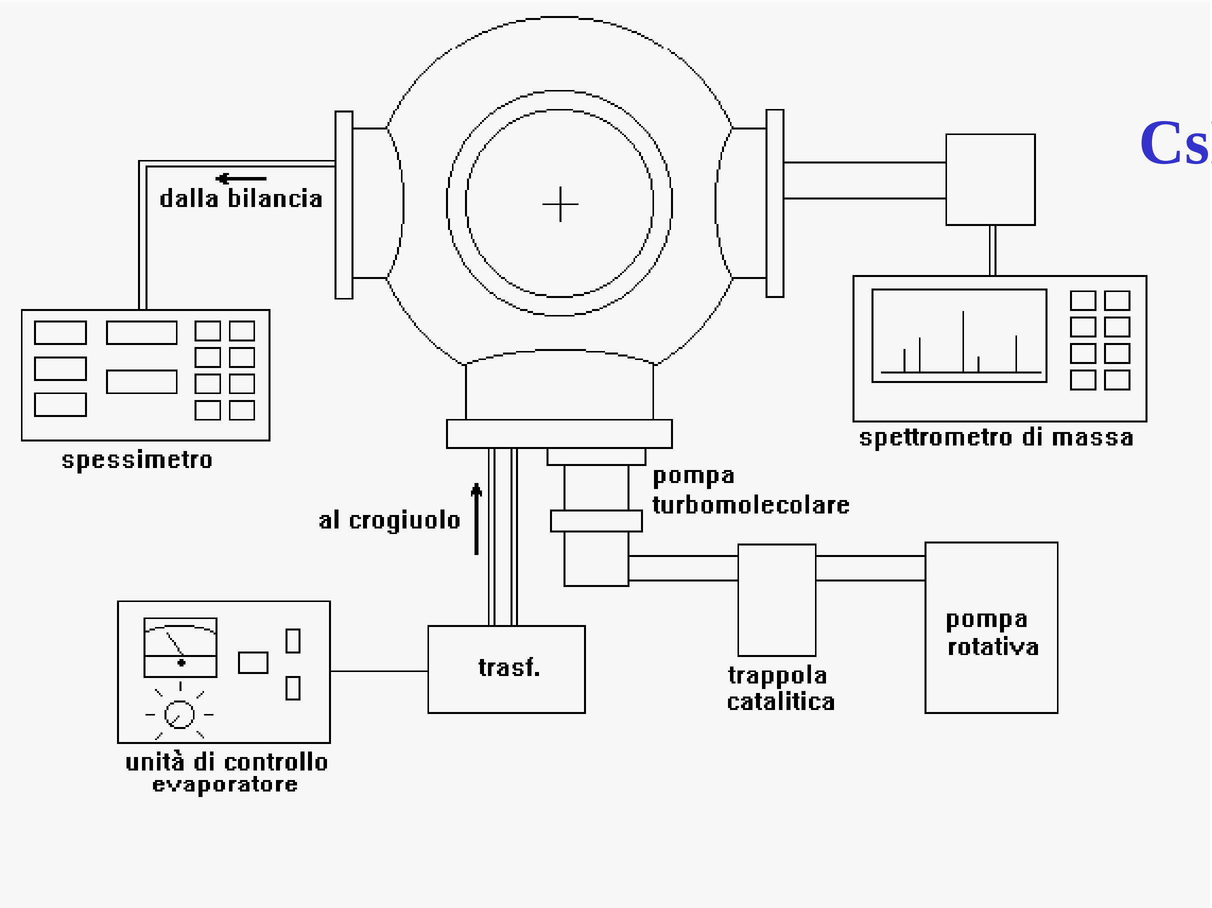
E_G=6.2 eV
E_A=0.1 eV

Diamond



E_G=5.5 eV
E_A<1 eV

Start research on CsI PCs

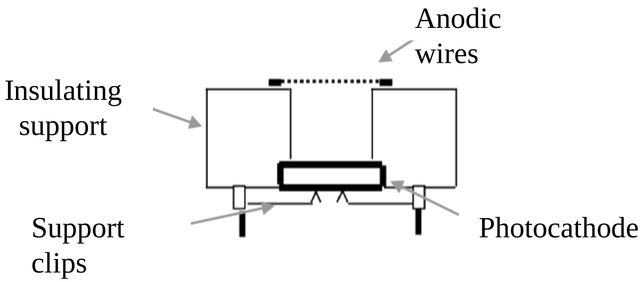


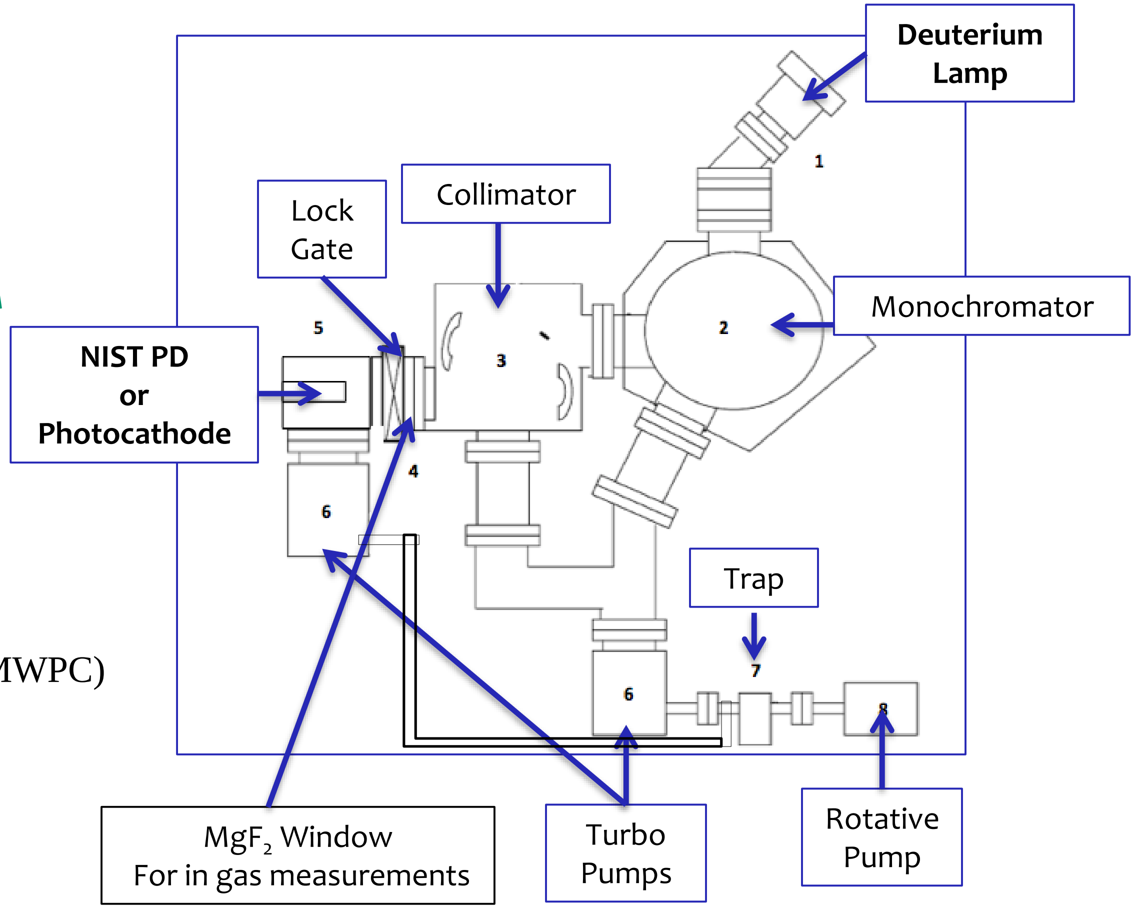
CsI Thermal Evaporator

QE MEASUREMENT SETUP

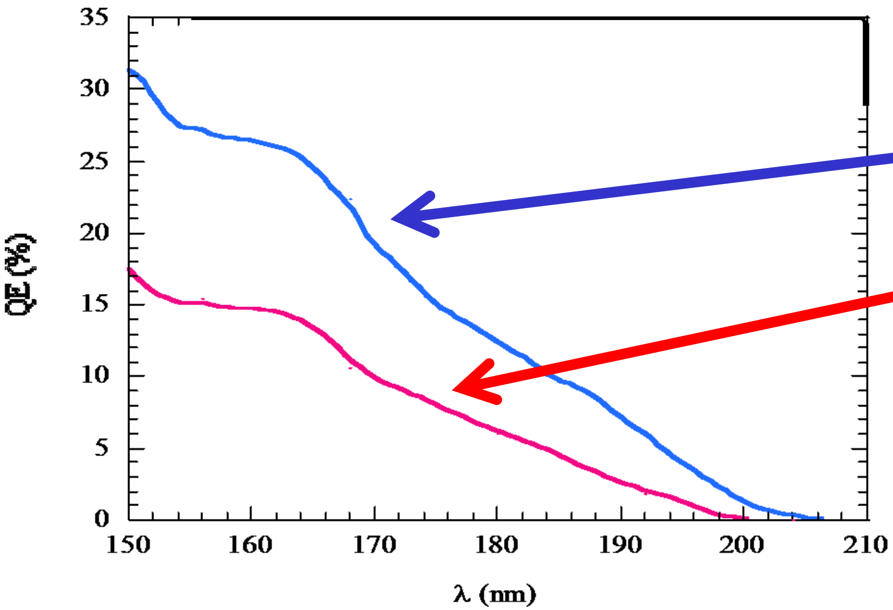
NIST Photodiode

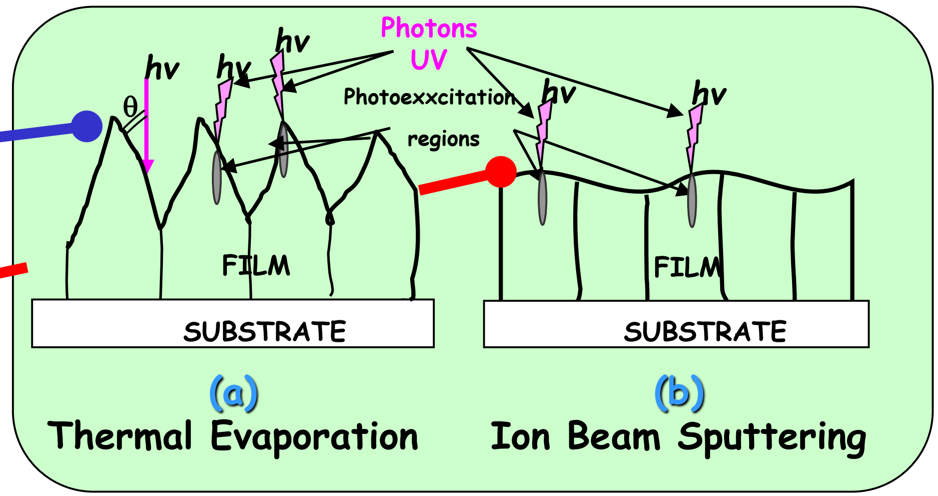
Multiwire Proportional Chamber(MWPC)

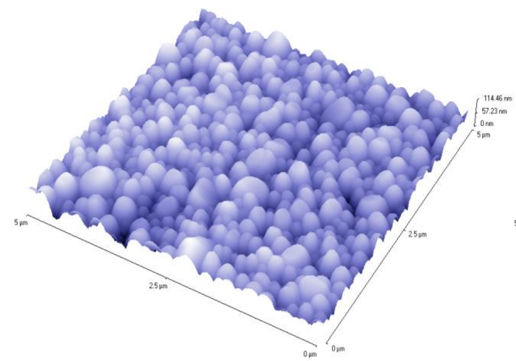


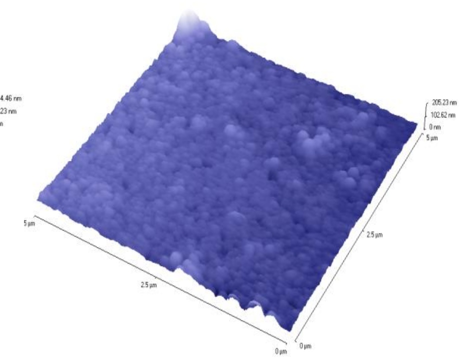


QE – *Surface Roughness Effects*









M.A. Nitti, et al.
Appl. Phys. A 80, 1789–1791 (2005)

QE CsI

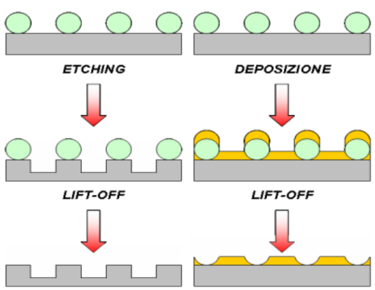
Aging Processes - Effects and Grain Sizes

Nanostructured CsI

Colloidal lithography

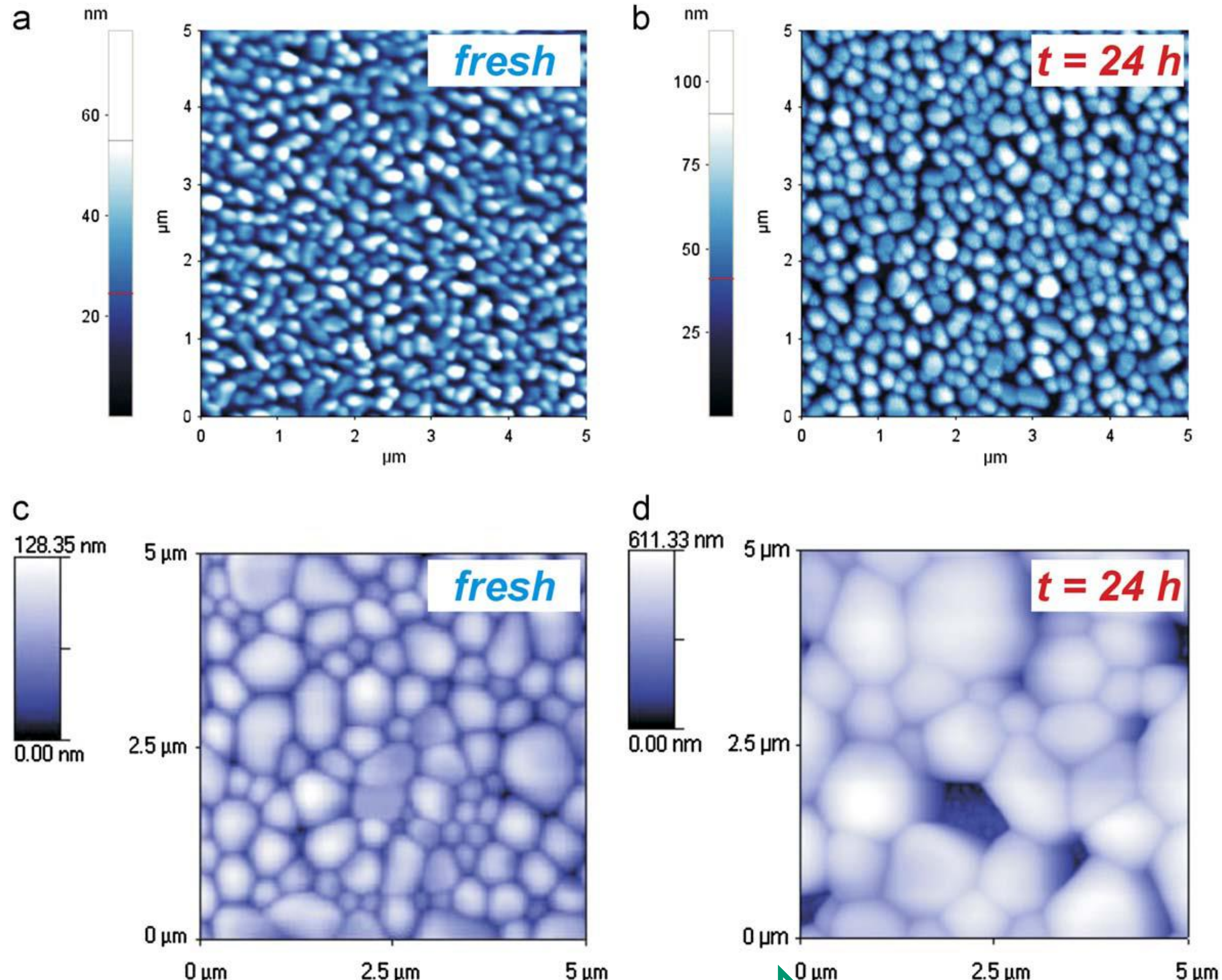
with

Polystyrene balls



LPLT -Low Power Low Temperature Plasma Etching

Microstructured CsI



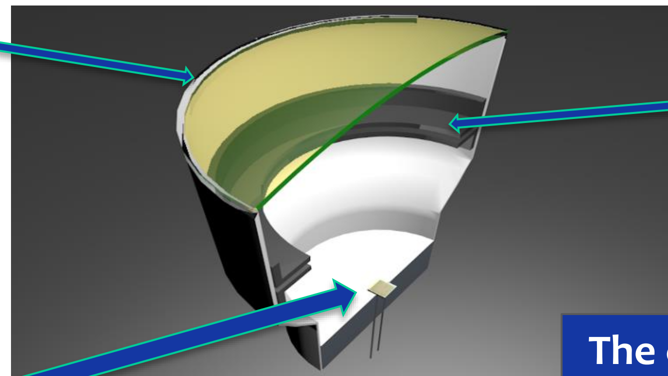
Air exposure

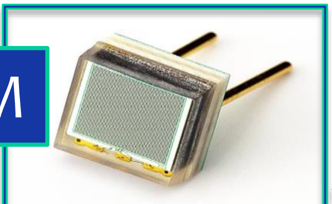
M.A. Nitti et al.
Nuclear Instr. and Met. in Phys. Res. A
610 (2009) 234–237

CsI

Head-On

An innovative design for a modern hybrid photodetector based on the combination of a Silicon PhotoMultiplier (SiPM) with a hemispherical vacuum glass PMT standard envelope





The classical dynode chain of a PMT is replaced with a special windowless SiPM, acting as an electron multiplying detector (e-SiPM).

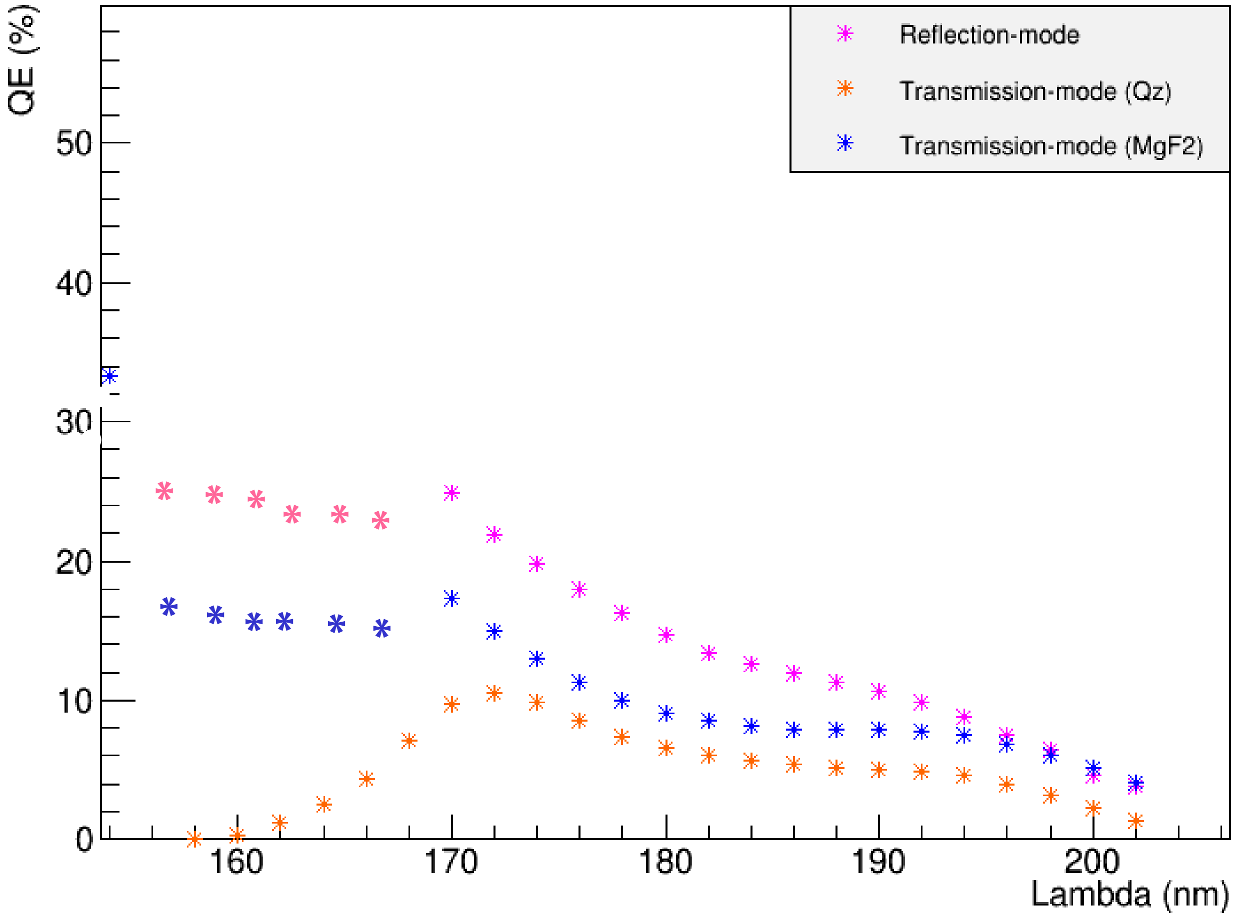
Photocathode realization

Optical Window → Conductive Layer → Photo-cathode

F.C.T. Barbato *et al 2017 JINST* ***12 T07005***.
F.C.T. Barbato *et al* EPJ Web of Conf **136** 02016 (2017)

CsI

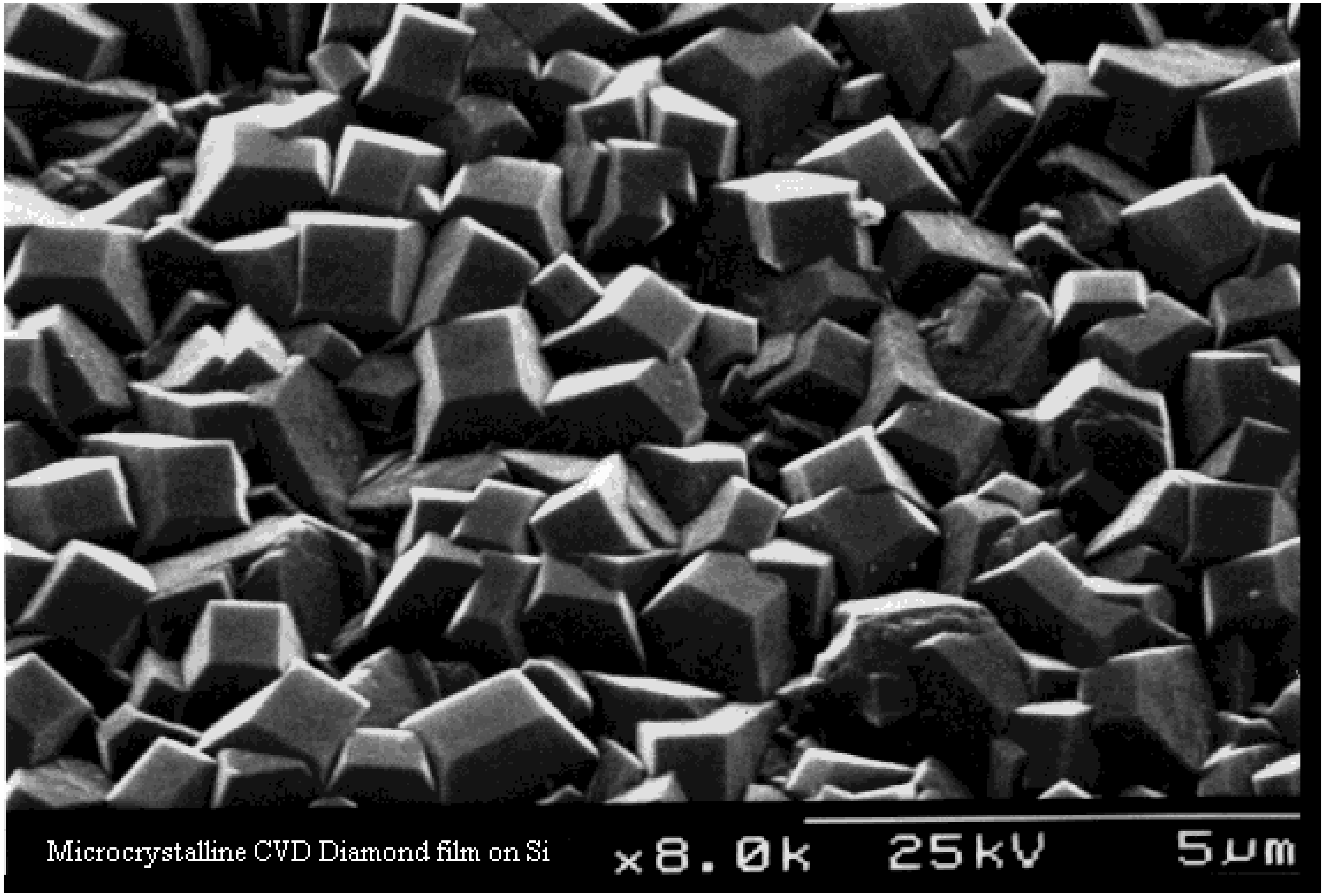
QE



(C 2.5 nm + Ni 0.5 nm) + CsI (20 nm)

F.C.T. Barbato et al.
EPJ Web of Conferences 136 , 0216 (2017)

Diamond Applications in *VUV Photocathodes*



Diamond Applications in *VUV Photocathodes*

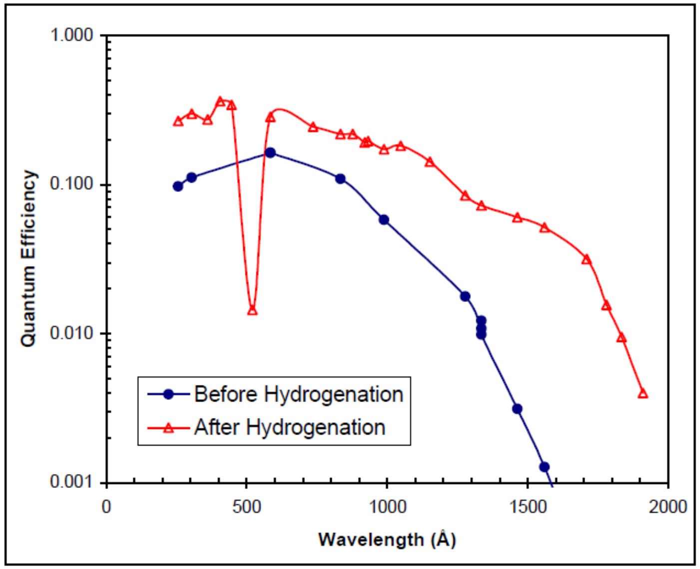
Istituto Nazionale di Fisica Nucleare
SEZIONE DI BARI

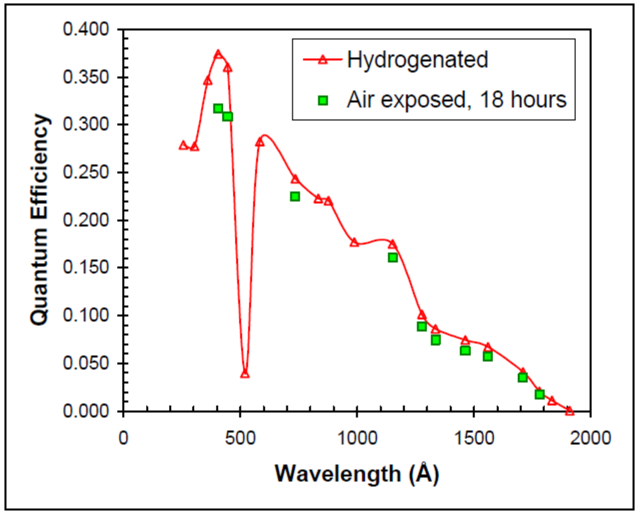
Proceedings SPIE, vol. **4139**, San Diego, California (2000)

Polycrystalline diamond films as prospective UV photocathodes

A.S. Tremsin* and O.H.W. Siegmund

Experimental Astrophysics Group
Space Sciences Laboratory
UC Berkeley
Berkeley, CA 94720





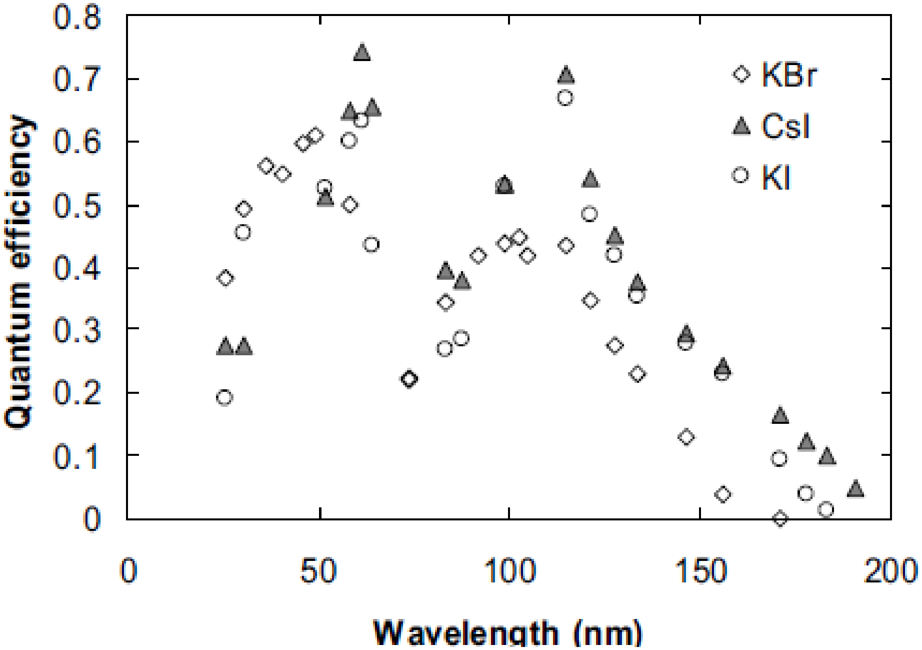
Istituto Nazionale di Fisica Nucleare
SEZIONE DI BARI

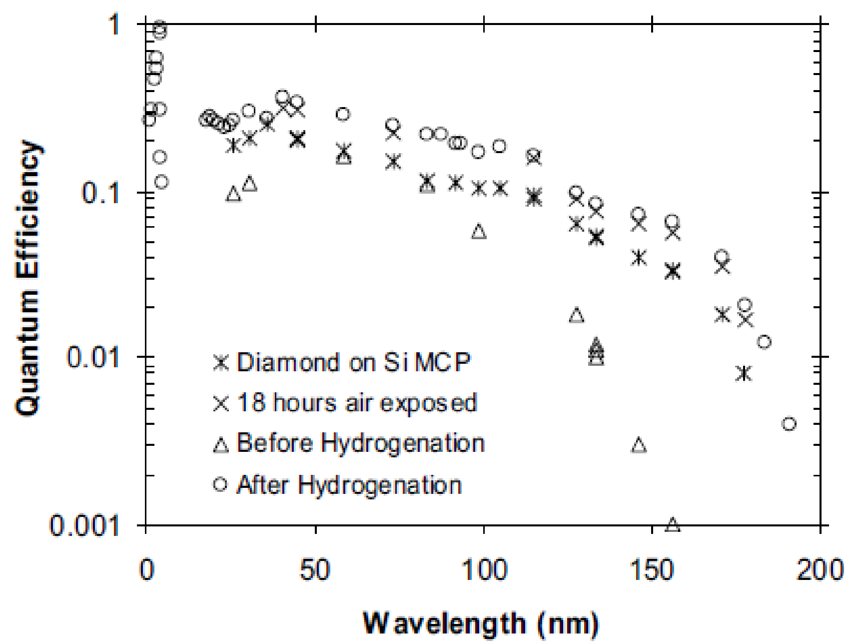
Diamond Applications in *VUV Photocathodes*

The quantum efficiency and stability of UV and soft X-ray photocathodes

Anton S. Tremsin*, Oswald H. W. Siegmund

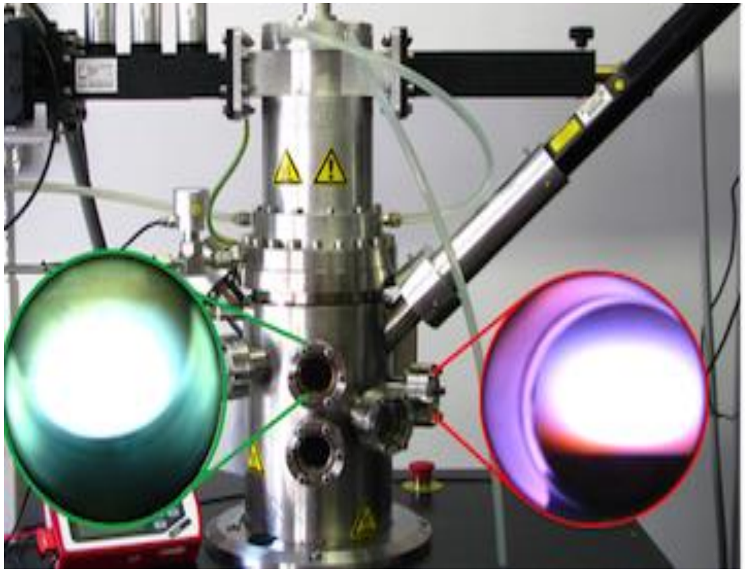
Proceedings of SPIE - The International Society for Optical Engineering - August 2005





MicroWave Plasma Enhanced Chemica Vapor Deposition

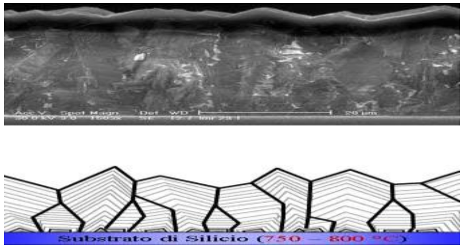
Diamond film growth in Bari



G. Cicala
CNR-ISTP *Sezione di Bari*

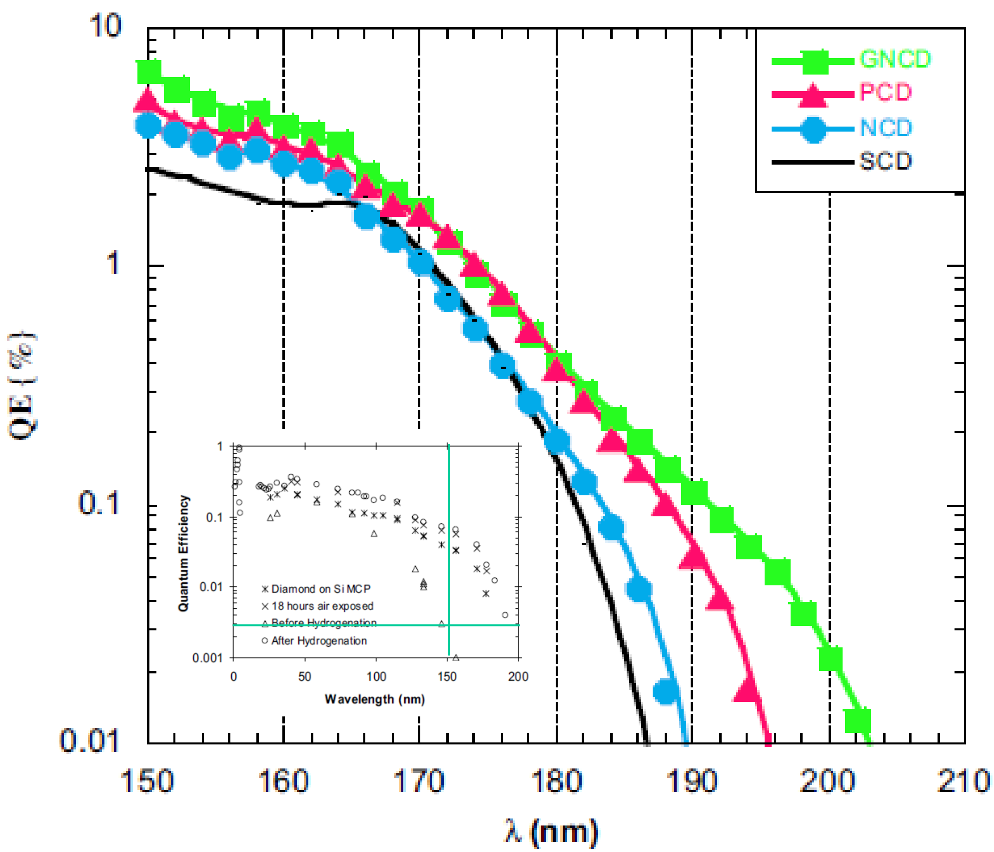
1. UHV reactor coupled to a Microwave generator (2.45 GHz)
2. Highly diluted CH_4 in H_2 (CH_4 < 4%)
3. High deposition temperatures (**750-900 ° C**)
4. High power inputs of the Microwaves (0.45-2.5 kW)
5. High pressures (10-200 mbar)

Polycrystalline film



DIAMOND PHOTOCATHODES (MWPECVD)

QE - Grain Properties Effects

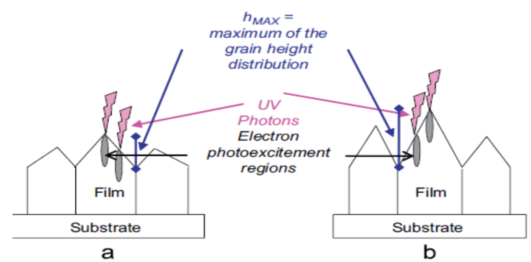


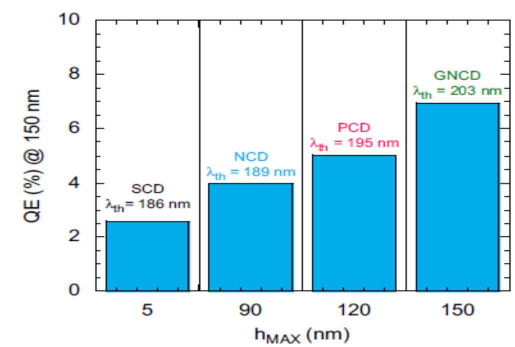
GNCD-Graphite NanoCrystalline

PCD-PolyCrystalline Dia

NCD-NanoCrystalline Dia

SCD-SingleCrystal Dia



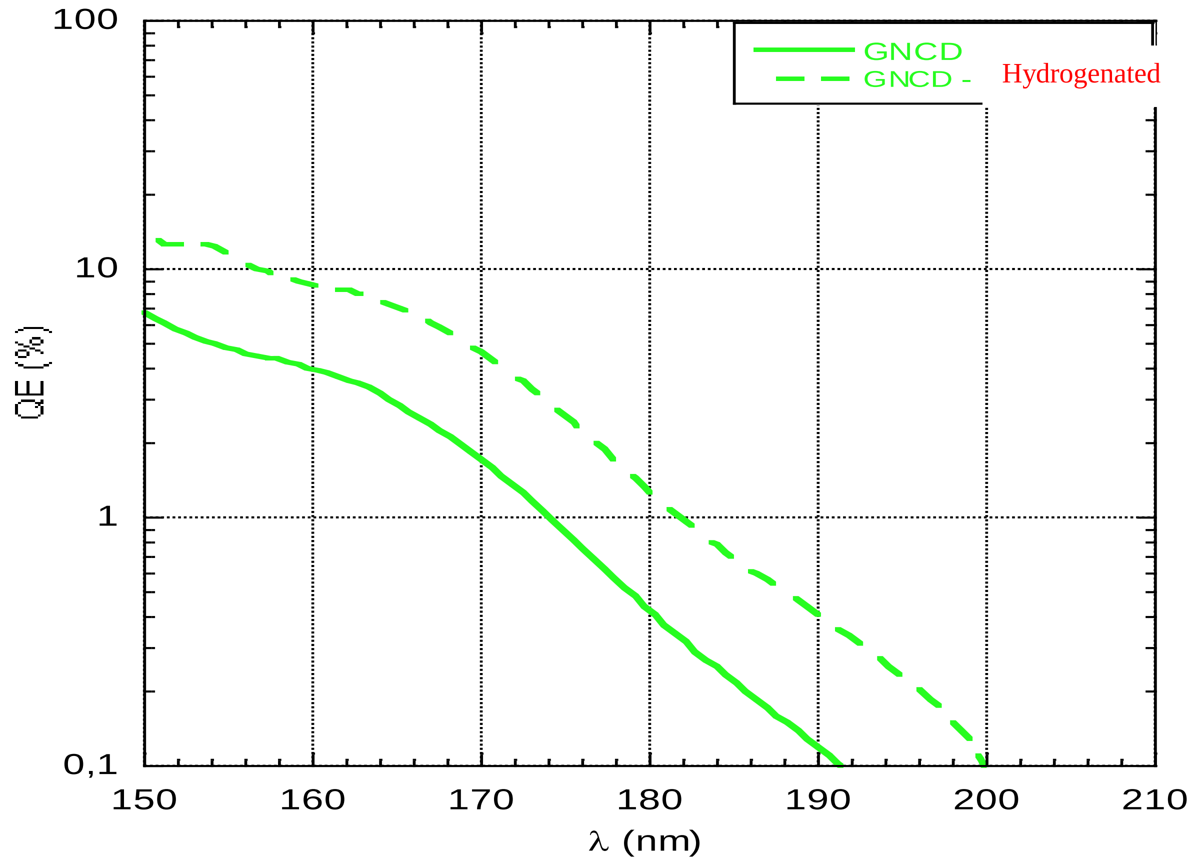


h_{max} from AFM

M.A. Nitti, et al.
Nuclear Instr. and Met. in Phys. Res. A
595 (2008) 131–135

DIAMOND PHOTOCATHODES (MWPECVD)

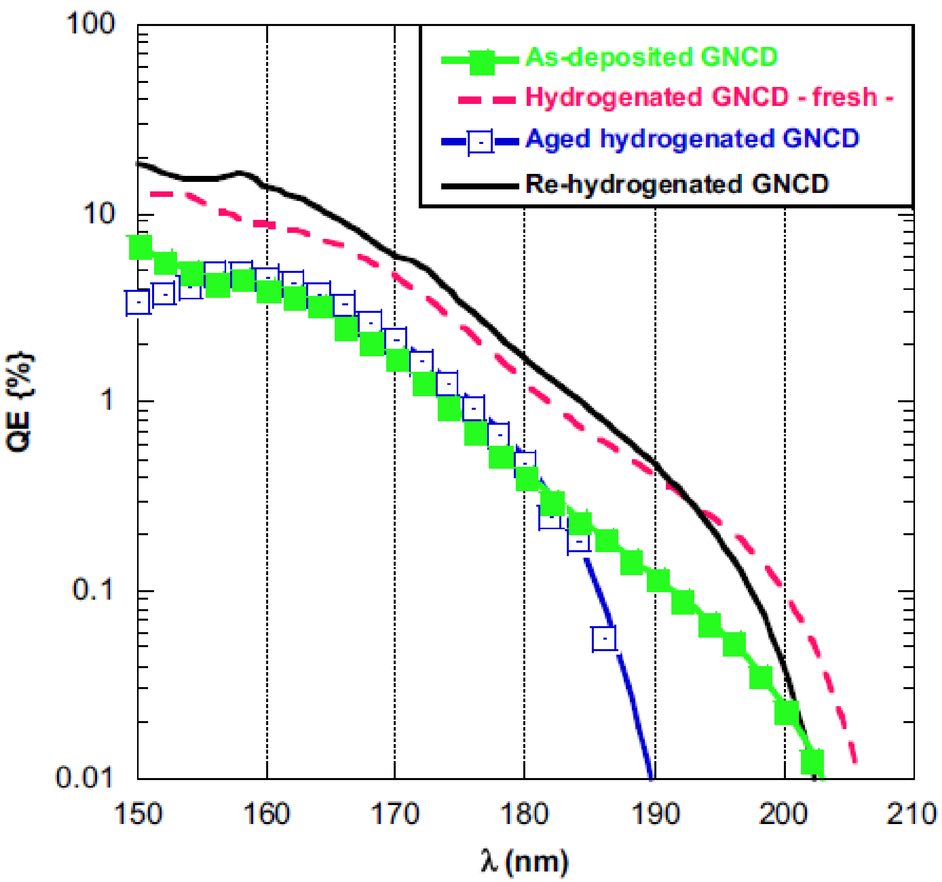
QE – Hydrogenated Diamond

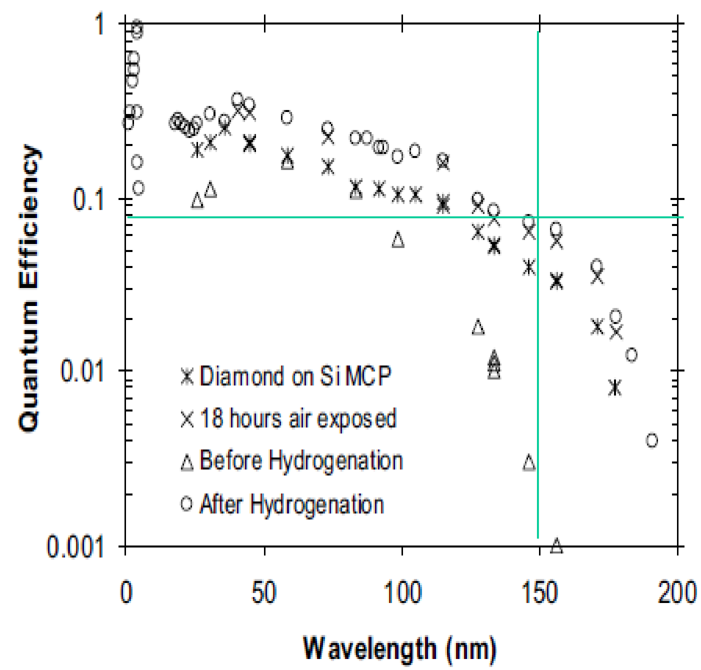


M.A. Nitti, et al.
Nuclear Instr. and Met. in Phys. Res. A
595 (2008) 131–135

DIAMOND PHOTOCATHODES (MWPECVD)

QE – Ageing Effects on Hydrogenated Diamond

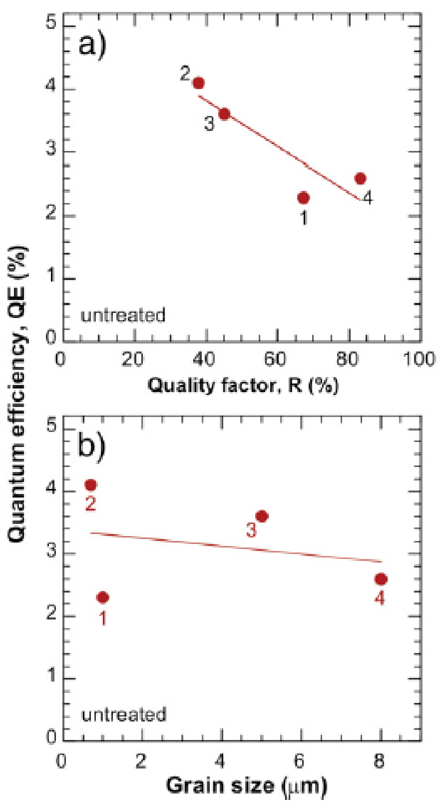


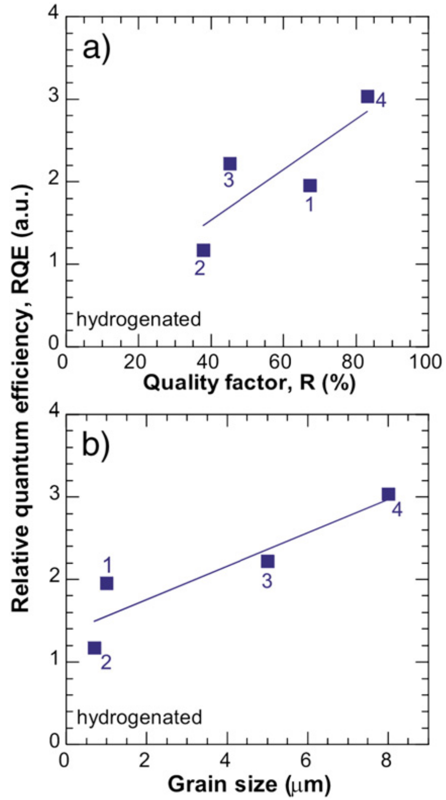


M.A. Nitti, et al.
Nuclear Instr. and Met. in Phys. Res. A
595 (2008) 131–135

DIAMOND PHOTOCATHODES (MWPECVD)

QE –Hydrogenated Diamond





RQE= QEhyd. / QEuntr.

Before hydrogen plasma treatment

The higher sp^2 content (lower R%) seems to improve the photocathode performance, independent of the grain size.

After hydrogen Plasma treatment

Hydrogenation affects only the diamond component of the film

↓

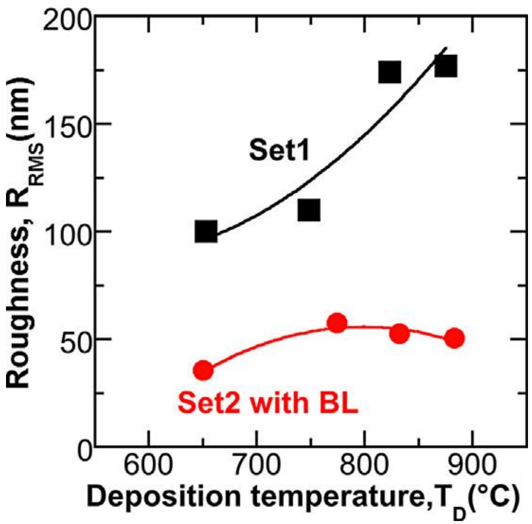
Larger grain size and **Lower sp^2**

↓

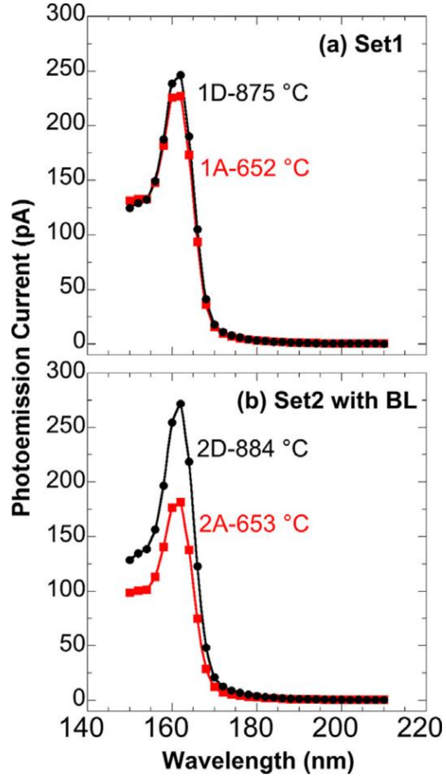
Higher QE

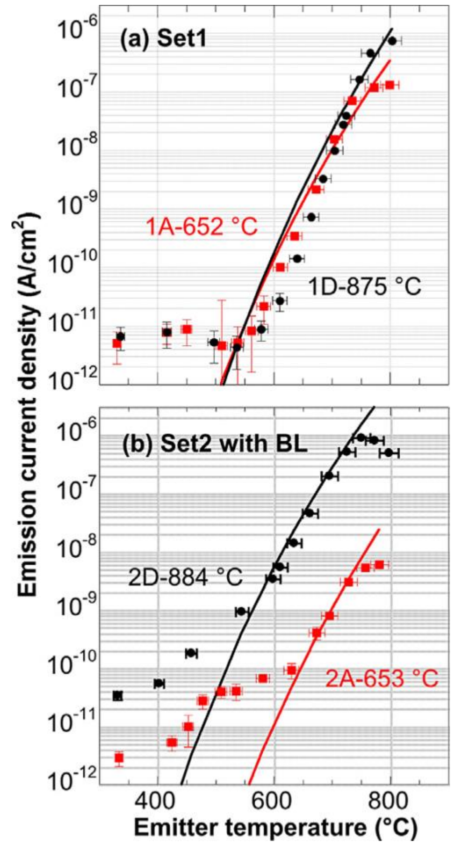
G. Cicala et al.
Diamond & Related Materials 20 (2011) 1199–1203 1–8

Photo- and Thermionic Emission of MWPECVD Nanocrystalline Diamond Films.



The Buffer Layer (BL) of Set2 is microcrystalline diamond





The solid lines are the Richardson–Dushman curve fits.

The NCD films with BL grown at the highest deposition temperature have shown the highest photo- and thermionic emission currents.

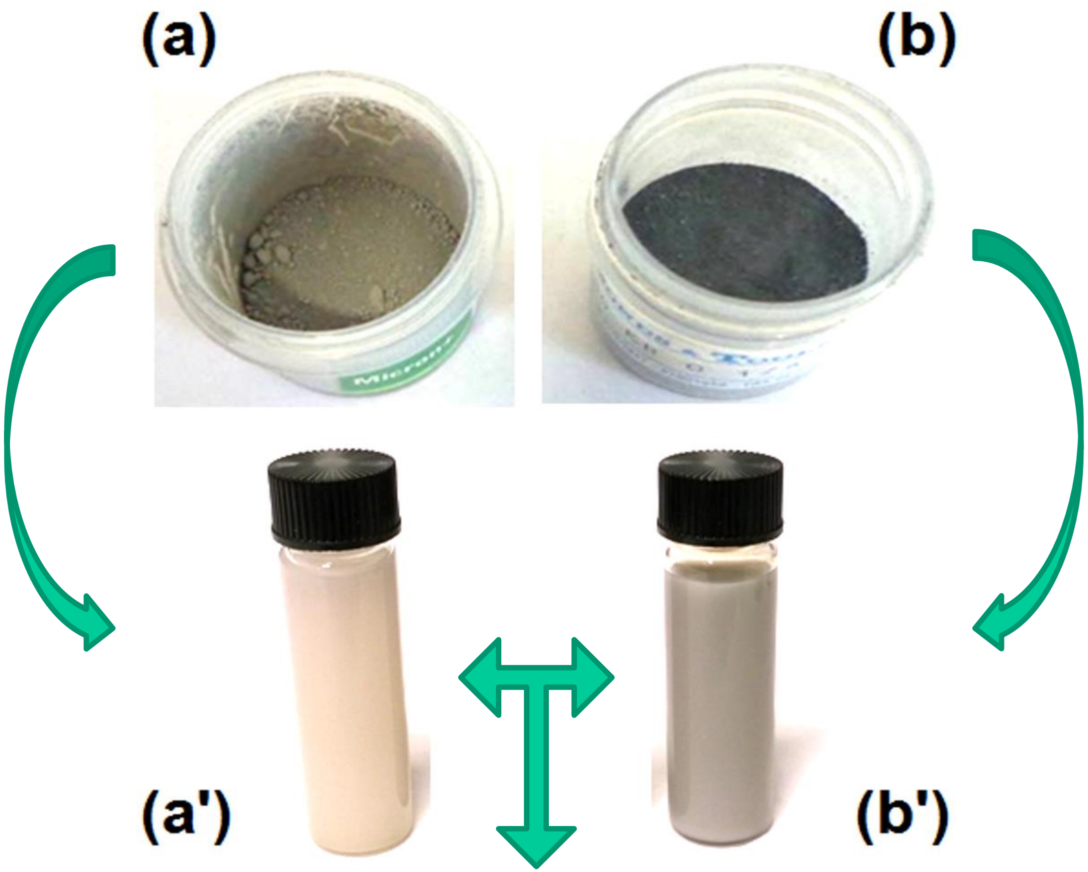
G. Cicala et al.
Applied Surface Science 320 (2014) 798–803

DIAMOND POWDERS

Nanodiamond (≤ 250 nm)

Rich-Diamond

Rich-Graphite

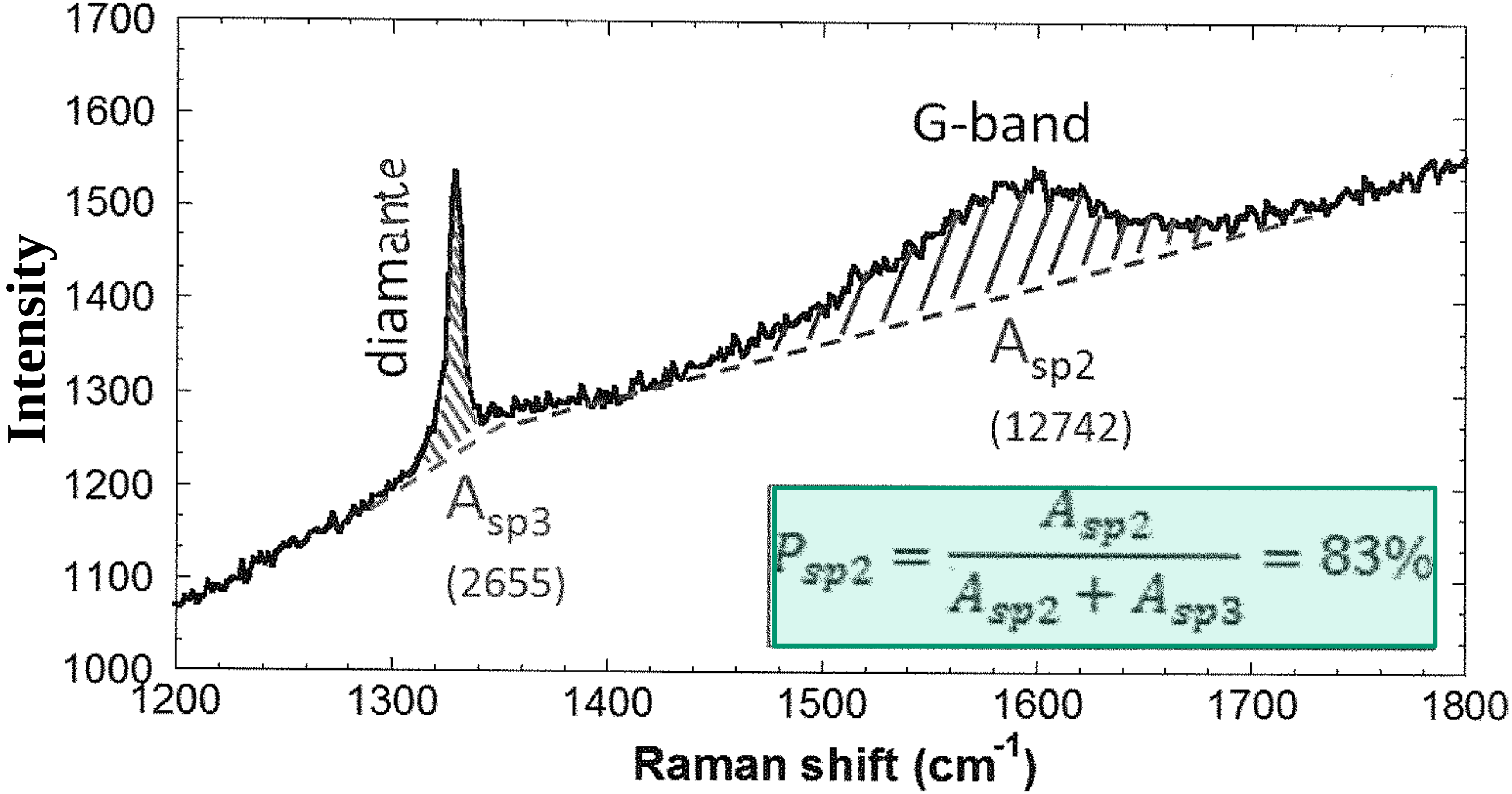


Solutions in (DCE)⇨H_2O

POWDER CHEMICAL PROPERTIES

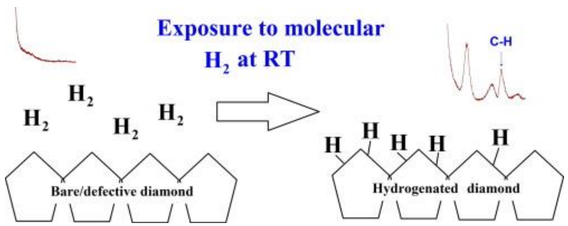
RAMAN

Rich-Graphyte



MATERIAL TREATMENTS IN HYDROGEN *PLASMA*

Annealing in Hydrogen (T around 500°C)**:** is a process that involves the treatment of material in the flow of a molecular hydrogen gas H_2, which remains so, or affects defective diamond.



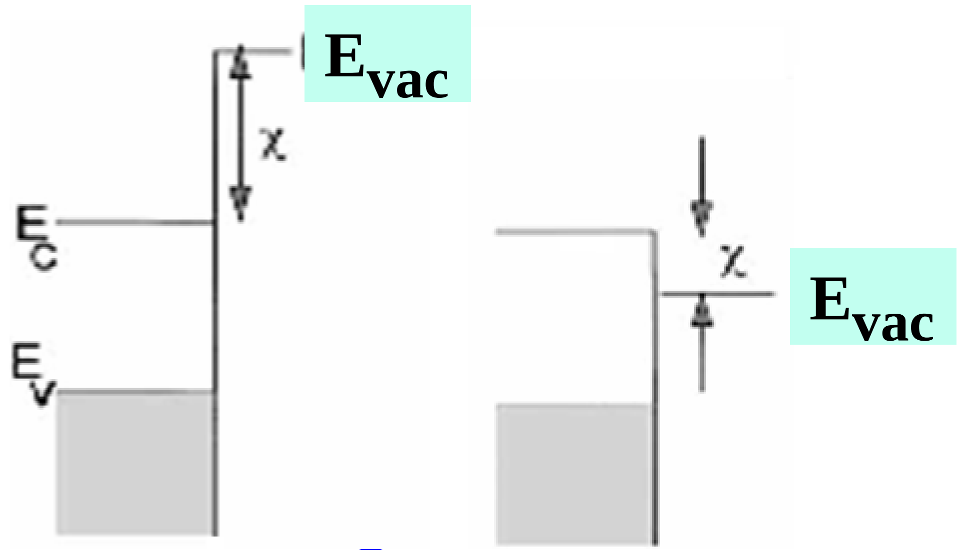
Plasma Hydrogen Treatment (T in the range 850-1200 °C): the molecule H_2 is ionized by producing ions of the type H+, H_2+ ecc., and gets excited by forming species of the kind H_2^*, H^* (Hα, Hβ, Hγ, ecc.) that, decaying in their fundamental state($H^* \rightarrow H + h\nu$), produce the typical Plasma glow.

Under such conditions, the production of ***active species*** is more efficient.

These highly reactive species lead to the formation of
C-H bonds
with much higher probability
compared to an H2 flow annealing process.

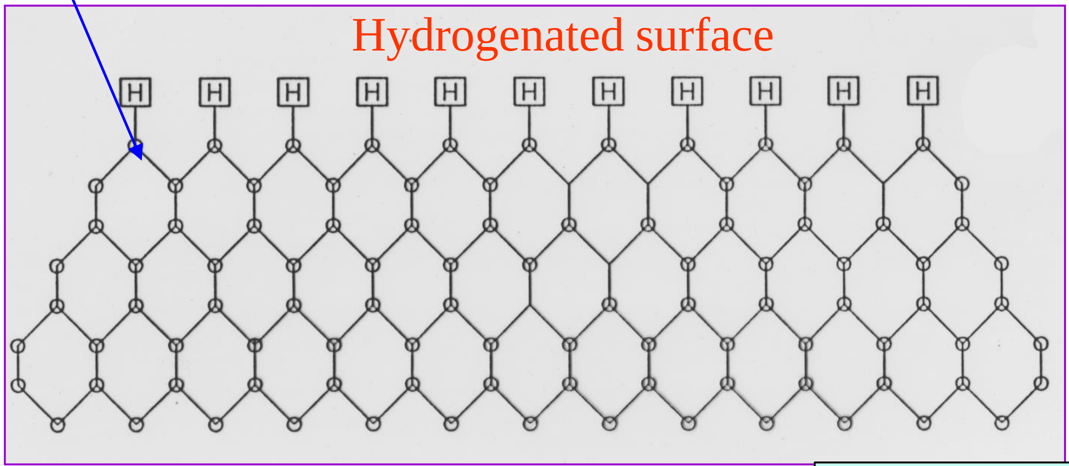
Hydrogen Plasma Effects

The surface of the diamond treated with hydrogen leads to a **Negative Electronic Affinity** (**NEA**)



a) **PEA** b) **NEA**

○ C atoms



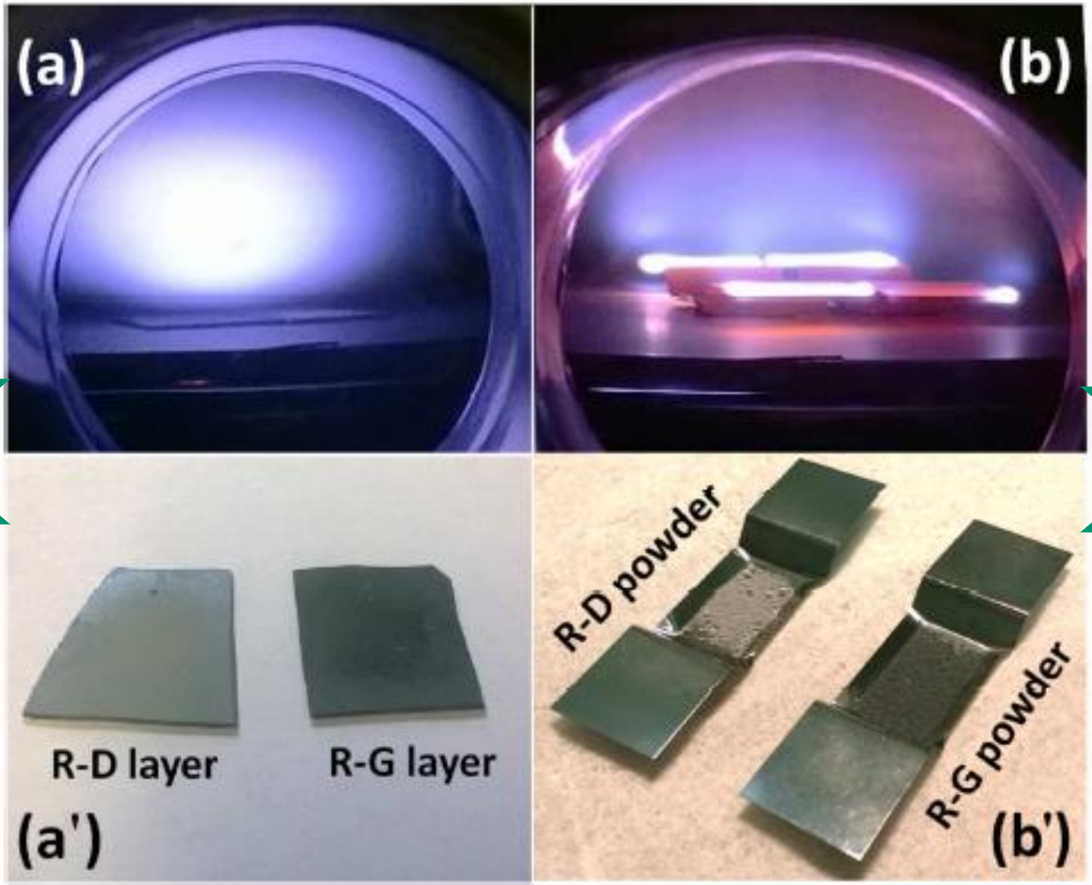
The hydrogenated surface leads to the formation of

C-H polar bonds

that allow the lowering of the Electronic Affinity

Hydrogen Plasma

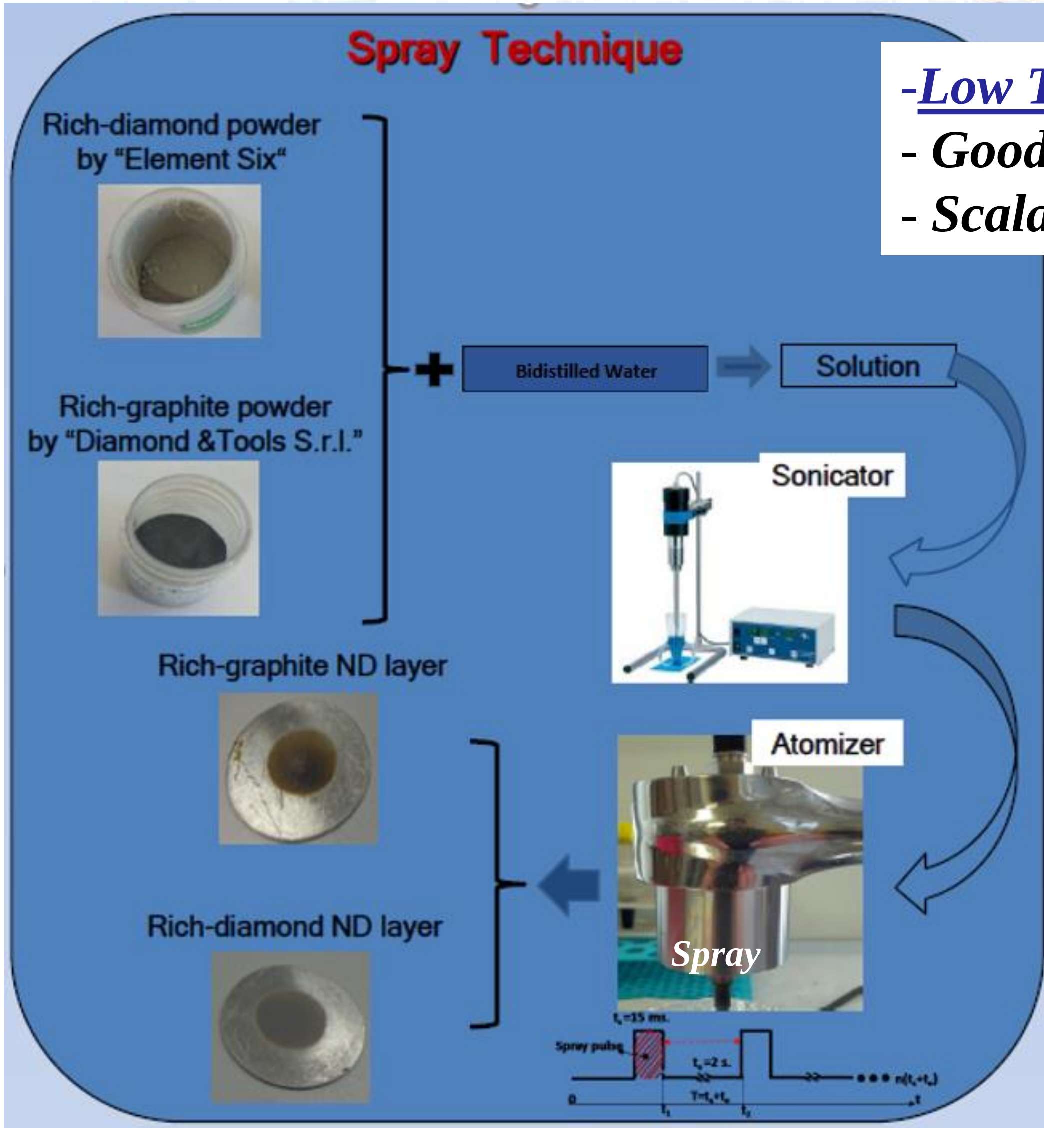
Film/Si



Powder

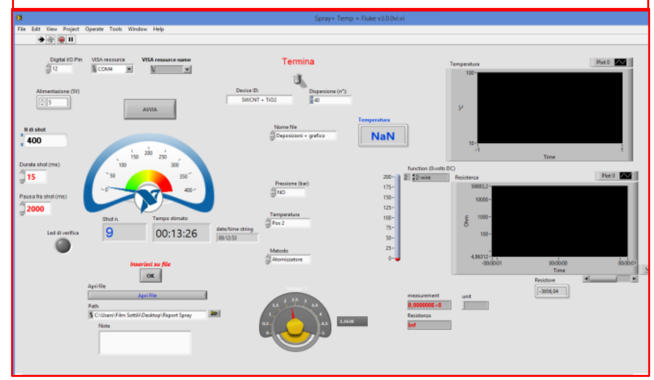
L. Velardi, et al
Diamond & Related Materials 76 (2017) 1–8

Diamond Layer Growth



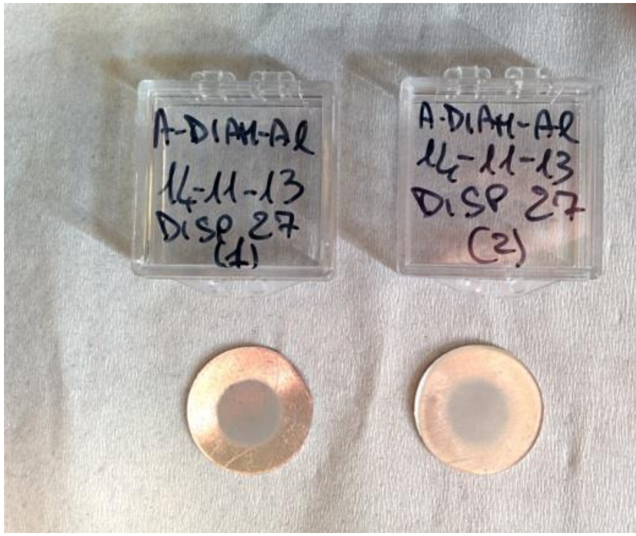
- ***Low Temperature Deposition (≤120 °C)***
- ***Good reproducibility technique***
- ***Scalable to cover large areas***

Spray Control Interface



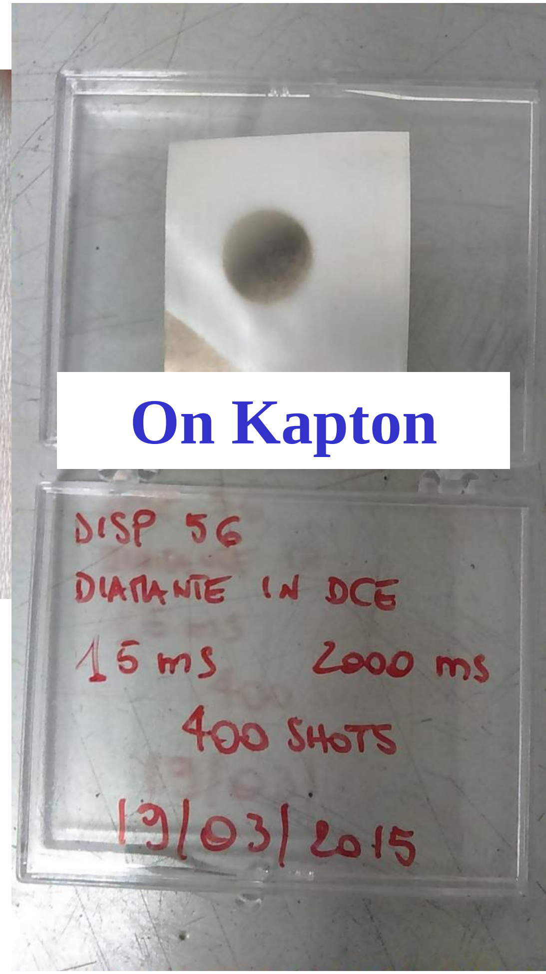
DIAMOND PHOTOCATHODES

SPRAY METHOD

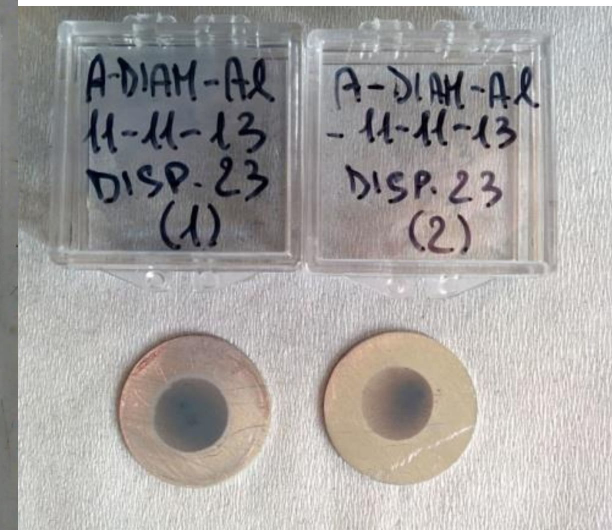


R-D

On PCB



On Kapton



R-G

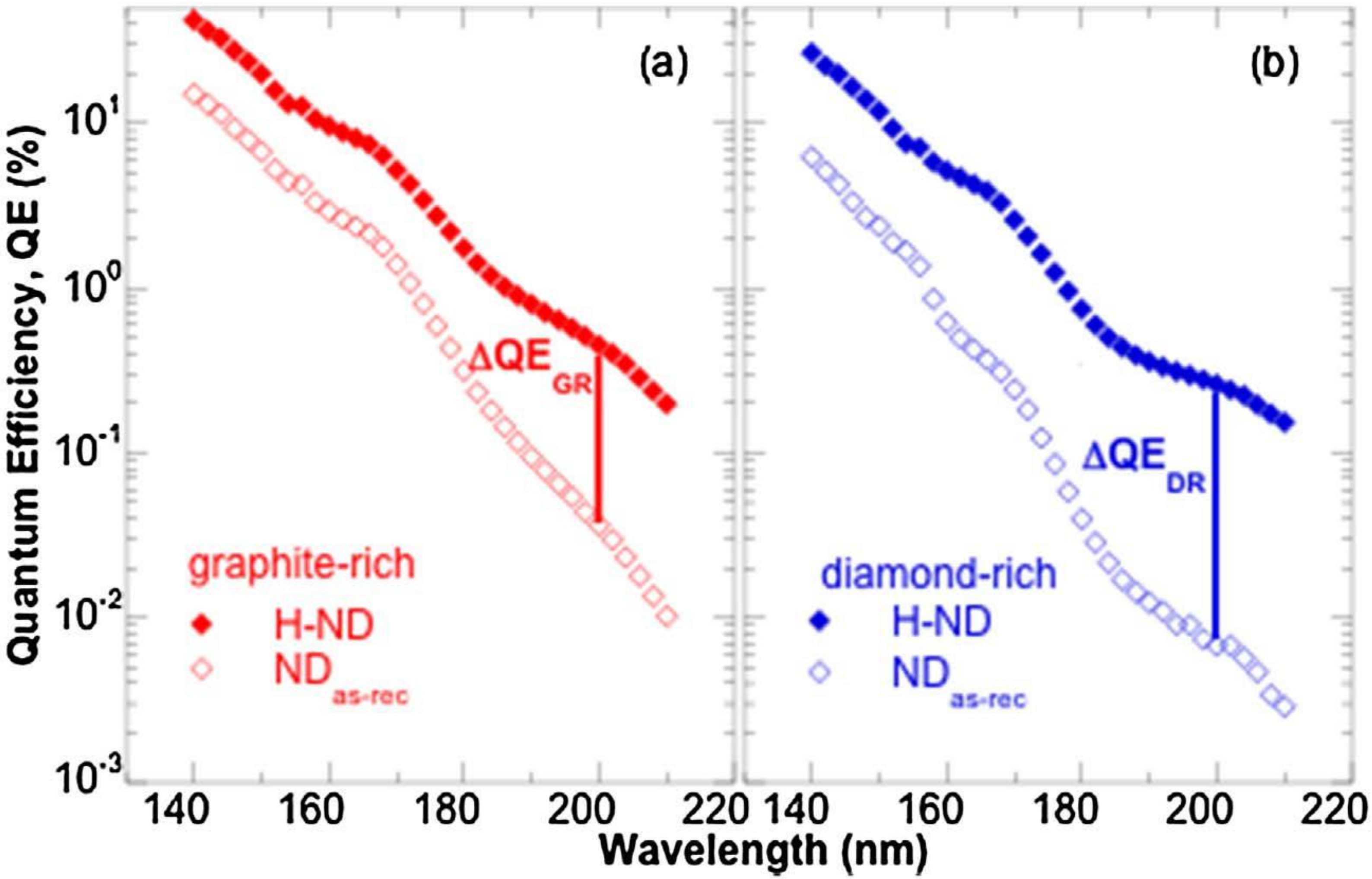
On PCB

International Patent Application

PCT/IB2016/055616

DIAMOND PHOTOCATHODES

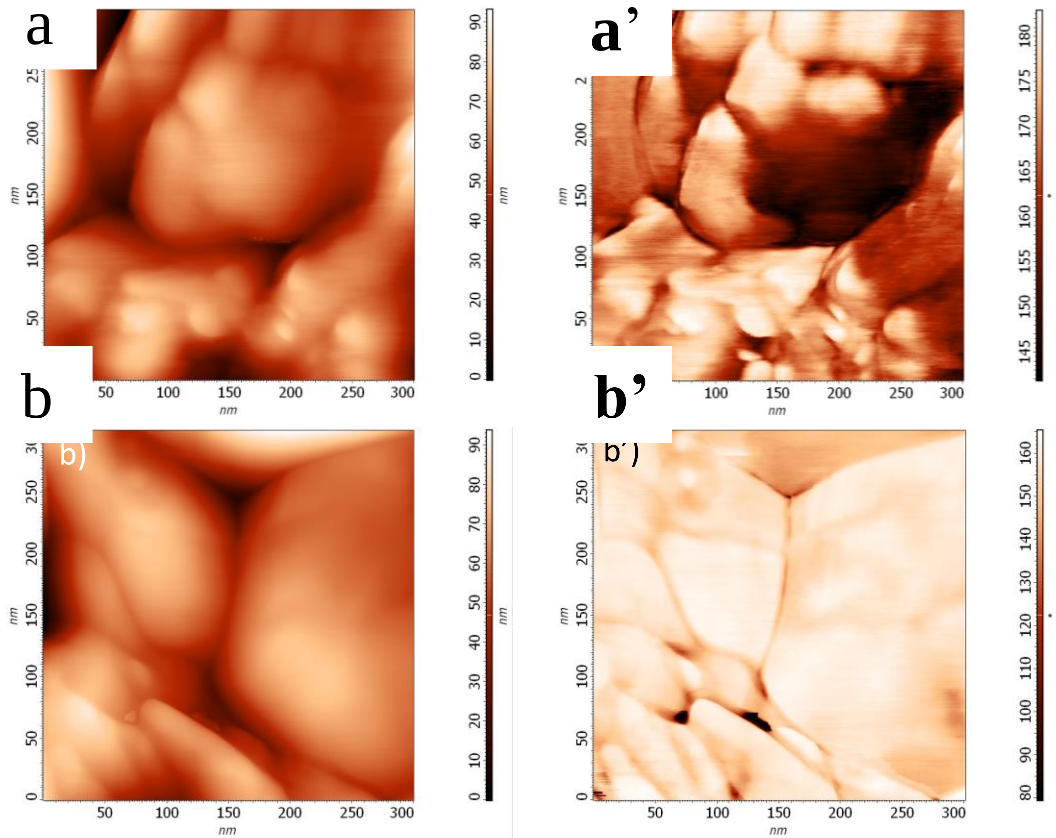
SPRAY METHOD



G. Cicala et al.
Colloids and Surfaces A – April 2017

SPRAY DIAMOND FILMS

AFM *IN PHASE CONTRAST*



R-G

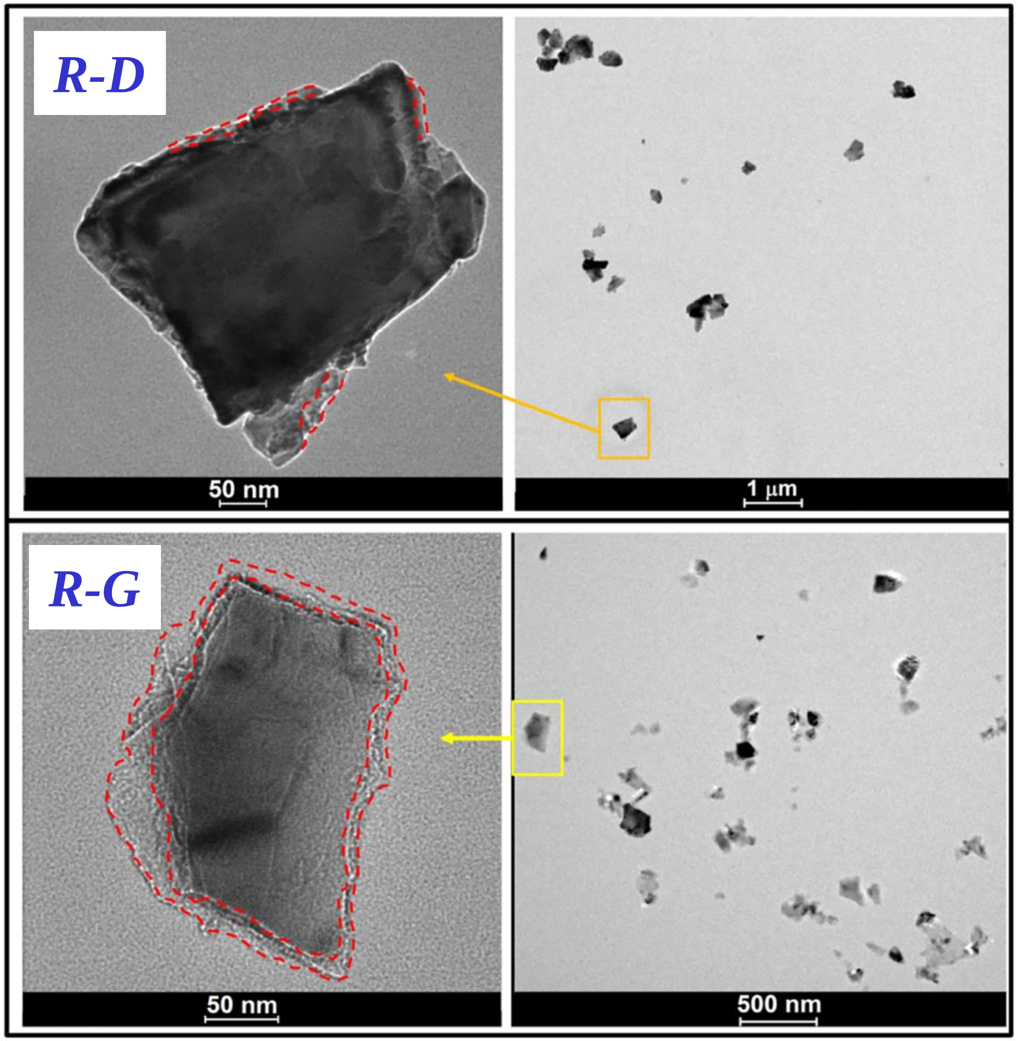
R-D

The **dark regions (Fig. a’)** represent the contribution of graphite ***sp^2*** on diamond ***sp^3***

The **bright regions (Fig. b’)** represent the contribution ***sp^3*** on graphite ***sp^2***

TEM IMAGES

DIAMOND GRAINS

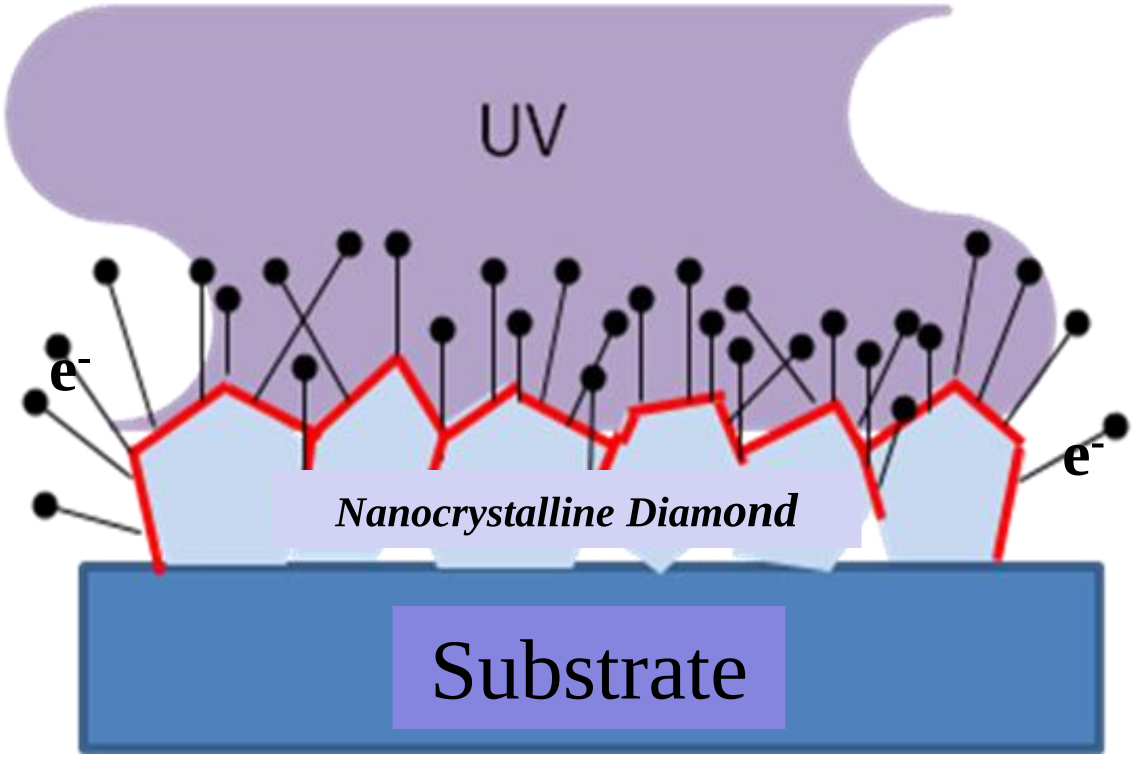


In **hatred** highlighted the ***sp²*** component present at ***the Grain Boundaries***

L. Velardi et al
Diamond & Related Materials 76 (2017) 1–8

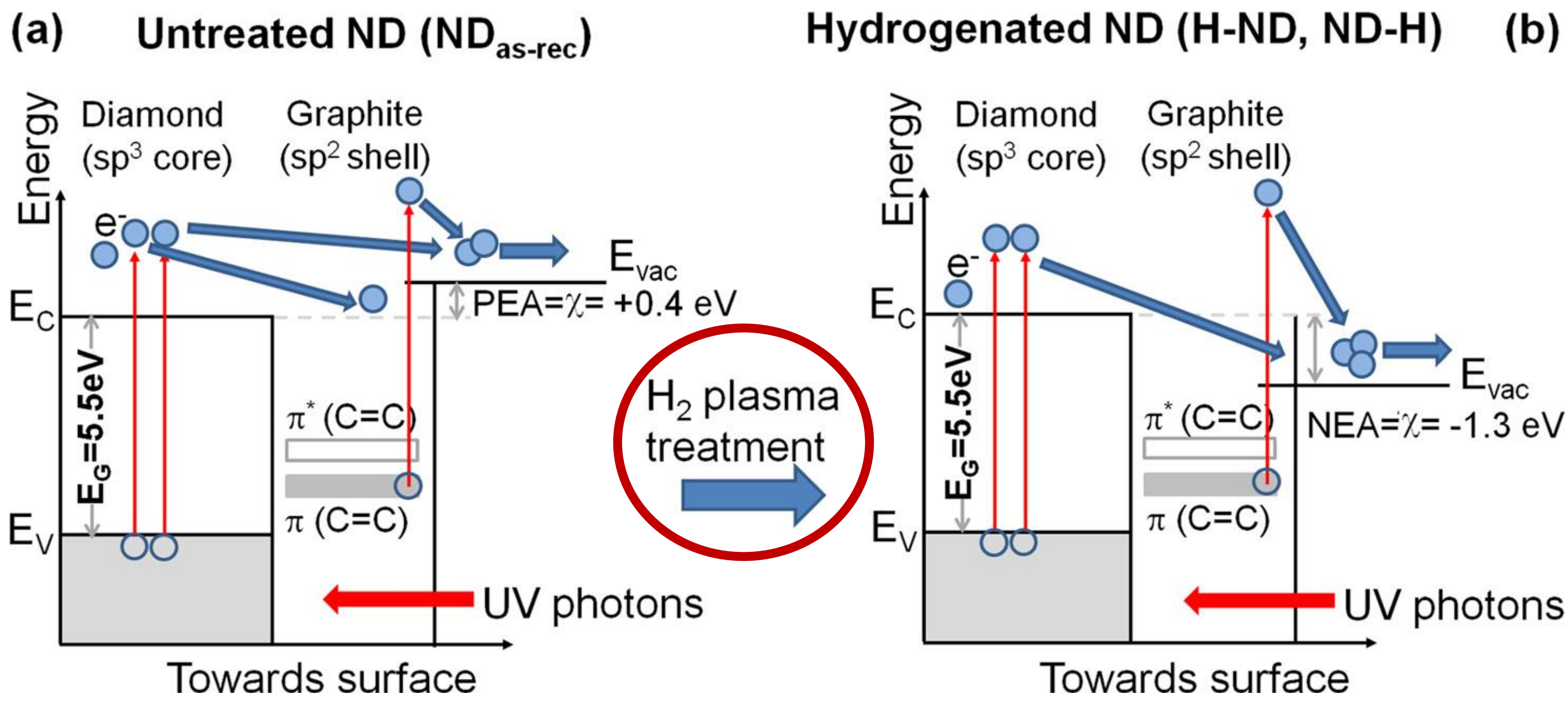
PHOTOELECTRON EMISSION in *NANOCRYSTALLINE STRUCTURE*

Emission favored at the grain boundaries



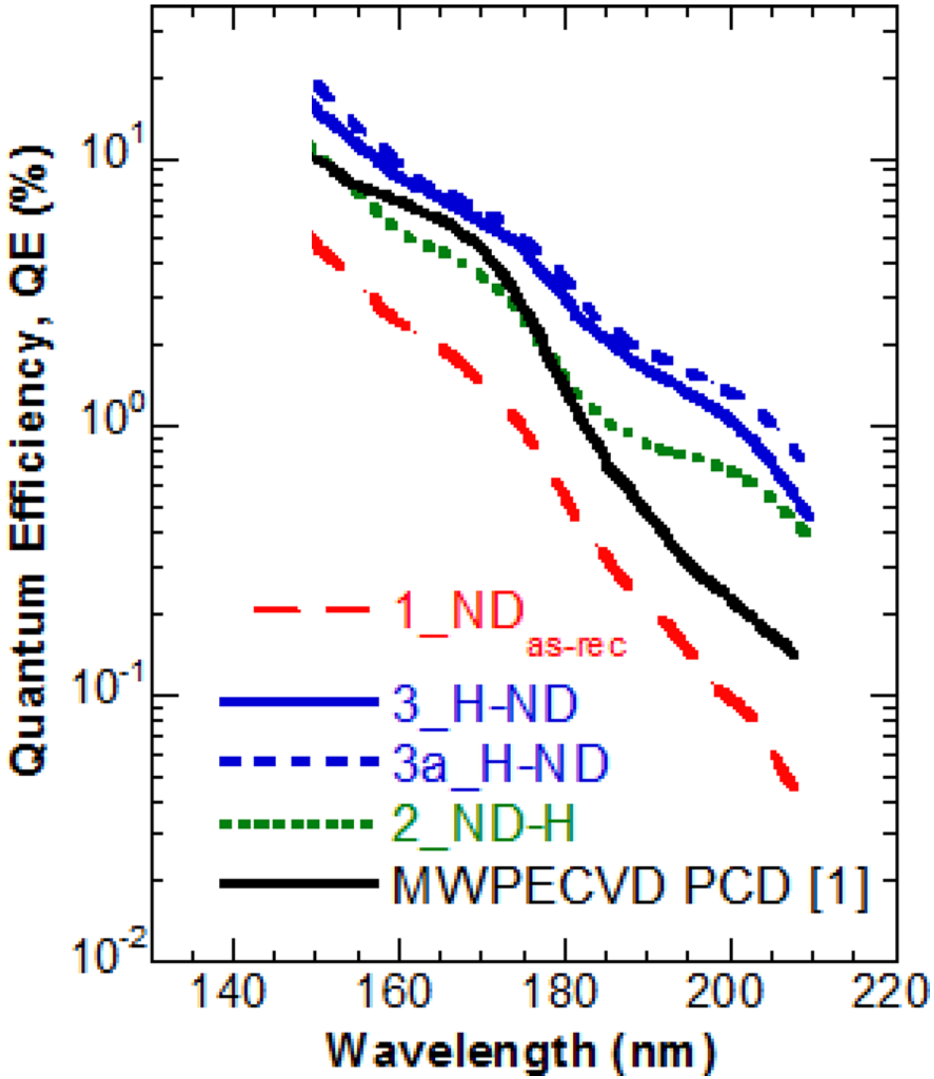
Graphite at the grain bounderies can help the charge neutralization !!

PHOTOEMISSION MODEL



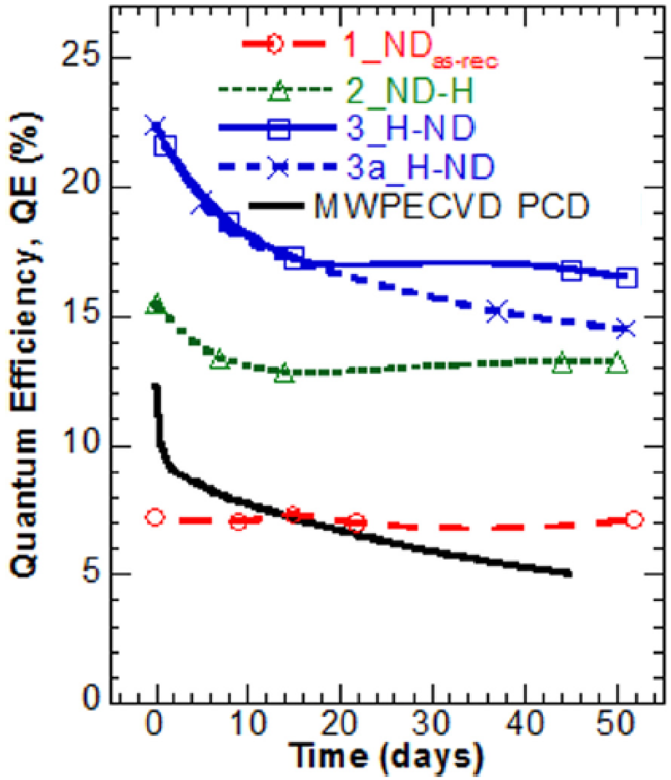
Schematic representation of the process of photoemission components **sp^3** e **sp^2** for **PEA** (a) and for **NEA** (b)

Quantum Efficiency



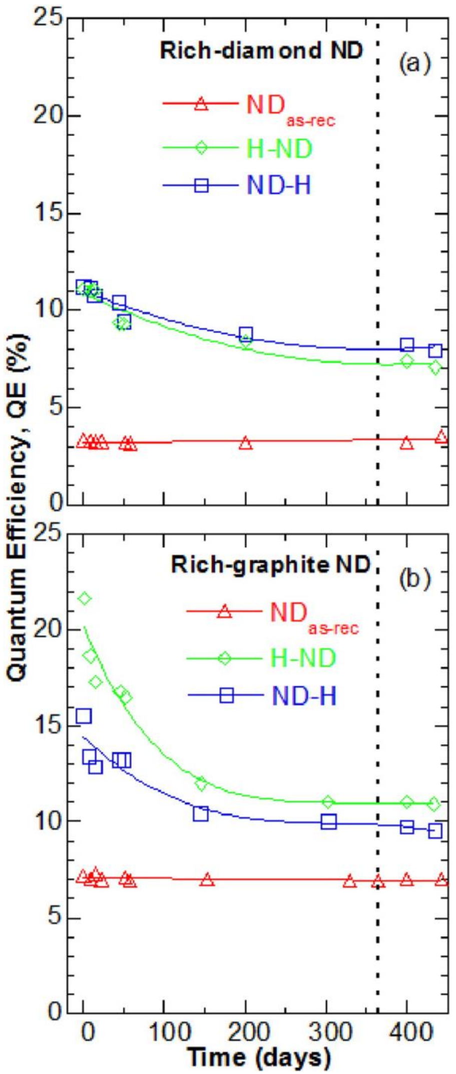
Diamond

QE Decay for Hair Exposure



ND-H
Hydrogenated film
After Spray

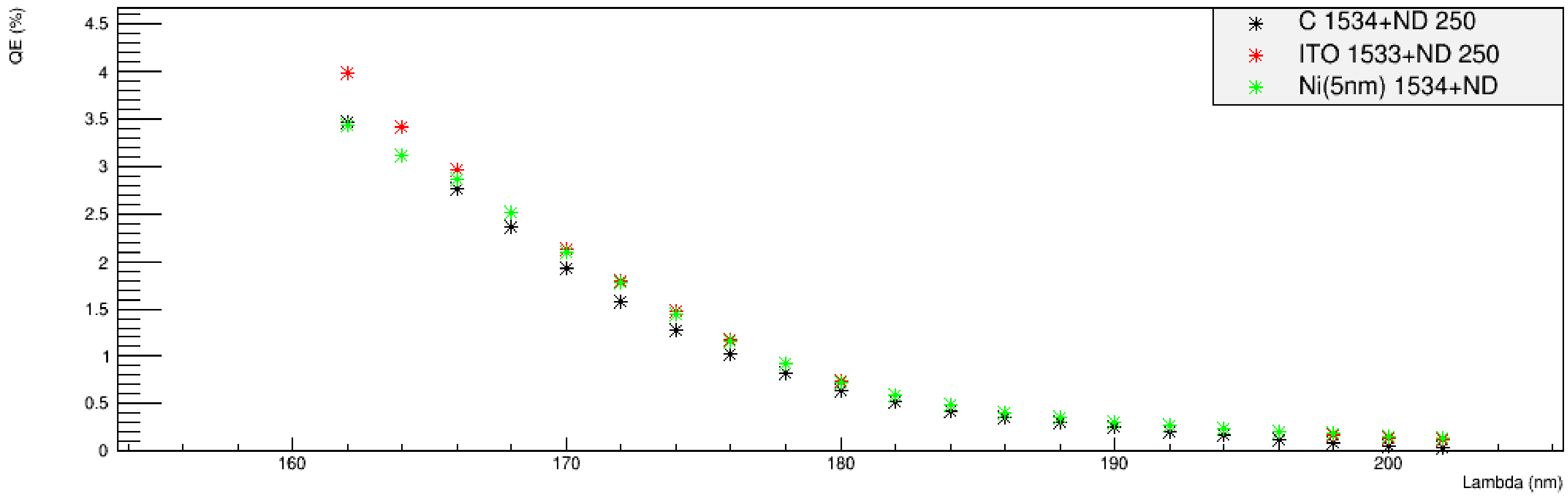
H-ND
Hydrogenated powder
Before Spray



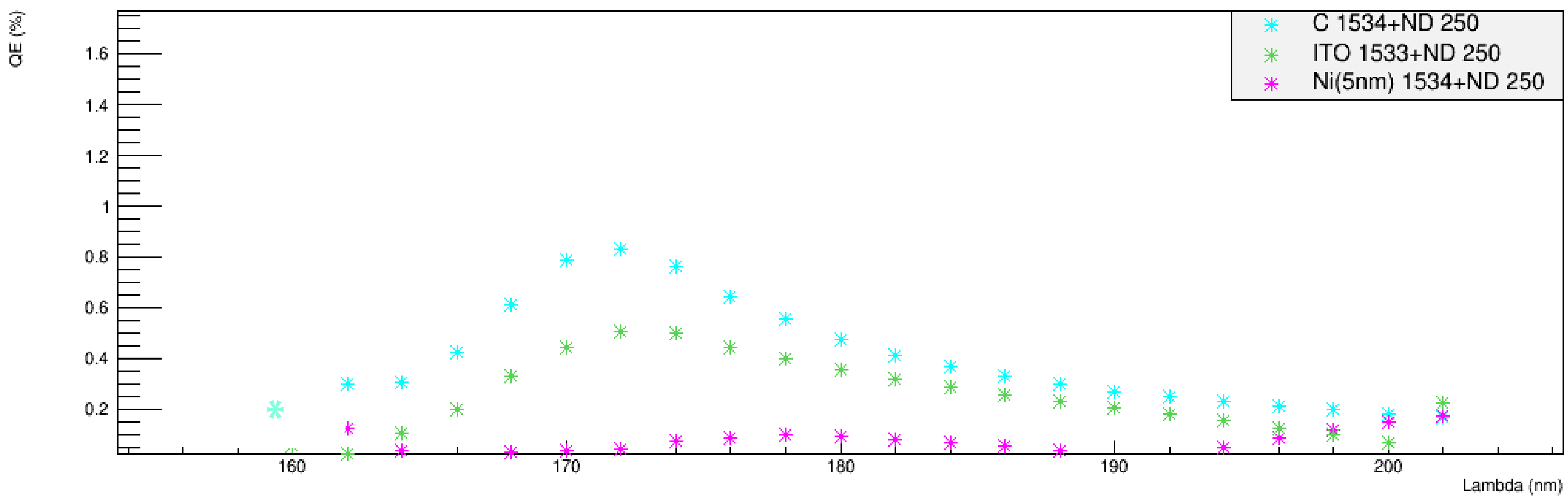
L. Velardi et al.
Appl. Phys. Lett. 108, 083503 (2016)
Diamond & Related Materials 76 (2017) 1–8

Head-On Photocathodes

QE Diamond – *Reflection mode*



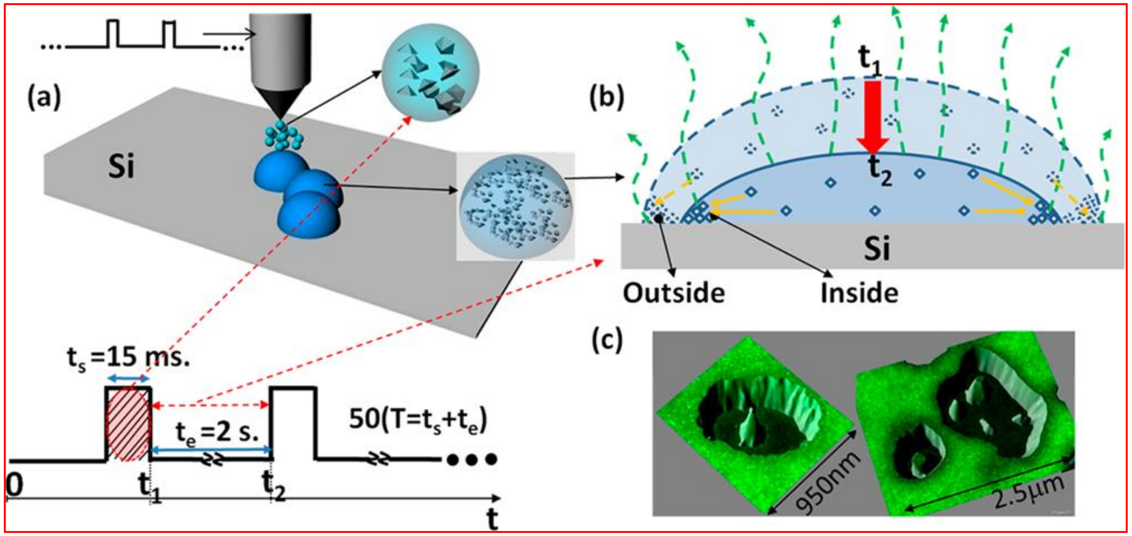
QE Diamond – *Transmission mode mode*



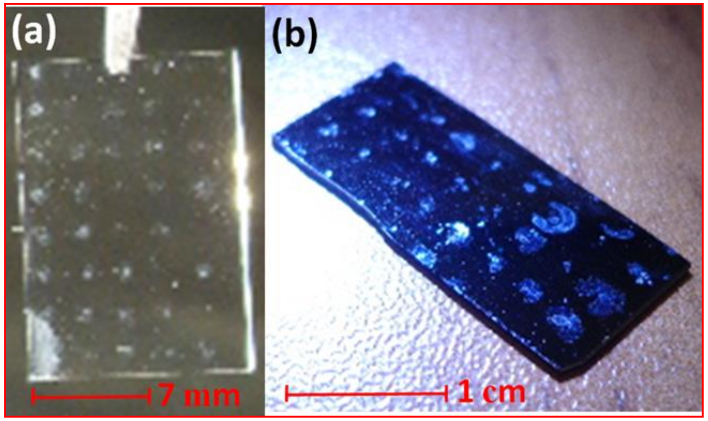
Nanodiamond Application

Self-Assembled Pillar-like Structures in Nanodiamond Layers by Pulsed Spray Technique

Pillar-like structures of nanodiamonds on a silicon substrate are self-assembled for the first time by a pulsed spray technique.



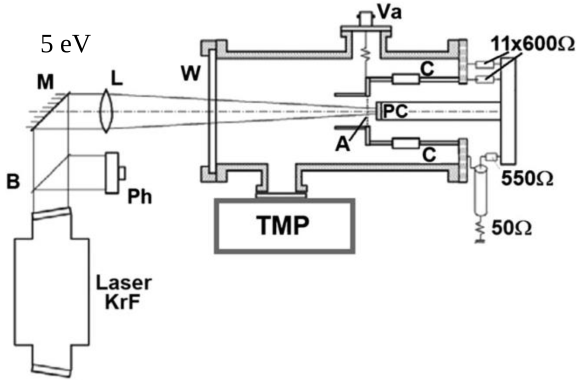
Suggested layout of a biochip on
(a) glass and
(b) silicon substrates,
based on arrays of sprayed ND spots obtained by a mask

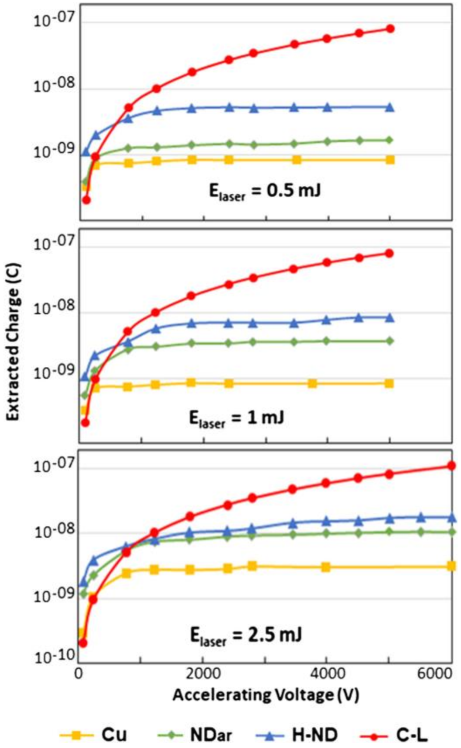


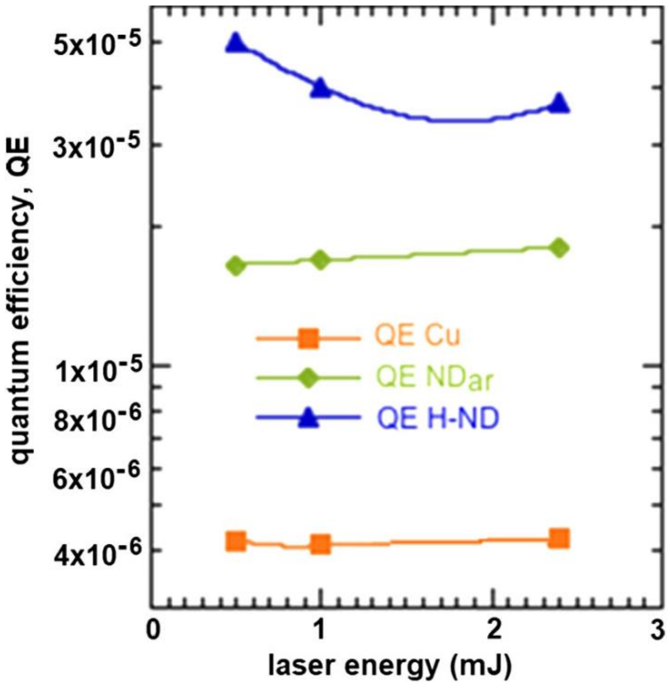
G. Cicala, et al.
Appl. Mater. Interfaces 2014, 6, 21101−21109

Nanodiamond Application

Electron Beams Produced by Innovative Photocathodes Based on Nanodiamond Layers





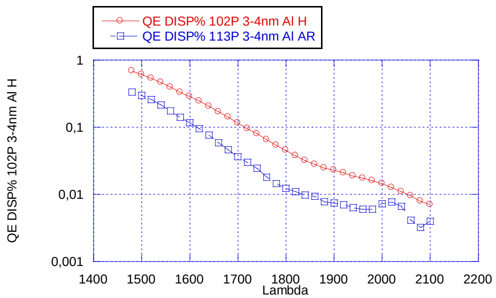


Photoemitted extracted charge of the Cu, NDar and H-ND-based cathodes and the Child-Langmuir (C-L) red curve as function of the accelerating voltage.

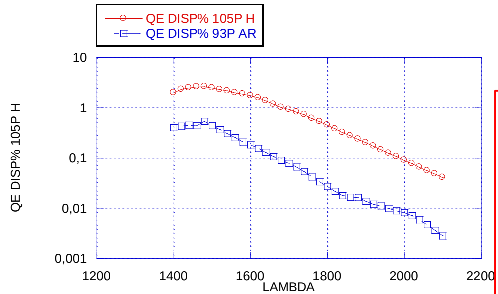
L. Velardi, et al.
PHYS. REV. ACCEL. BEAMS 22, 093402 (2019)

QE Nanodiamond

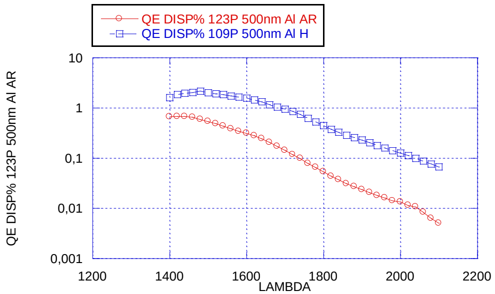
New Powders



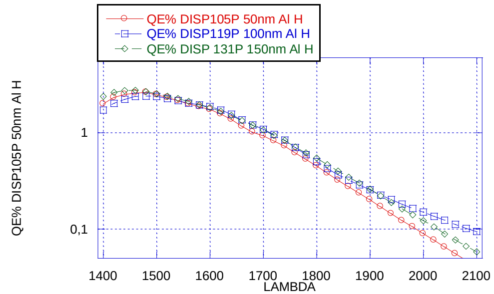
ND-B Doped 95% - 3-4nm



Vammoppes 50nm



ND-Diamonds & Tools – 500 nm

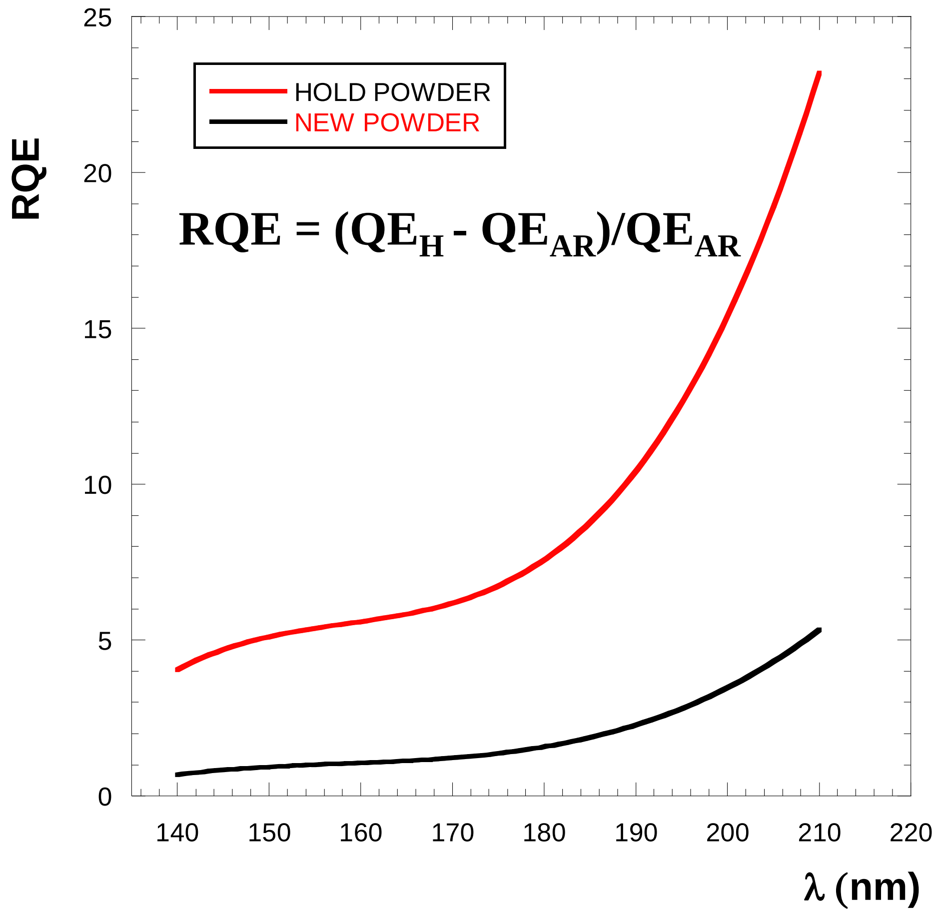


Vammoppes H
50nm 100 nm 150 nm

- Very small grains give low QE:
  - **Only a single grain partecipates to photoemission!**
- Grain size greater than 50 nm does not change QE:
  - **The mean free path of electrons is about 50 nm!**
- ……………………………

QE Nanodiamond

New Powders *



- **QE dependence on the properties of the individual grains:**

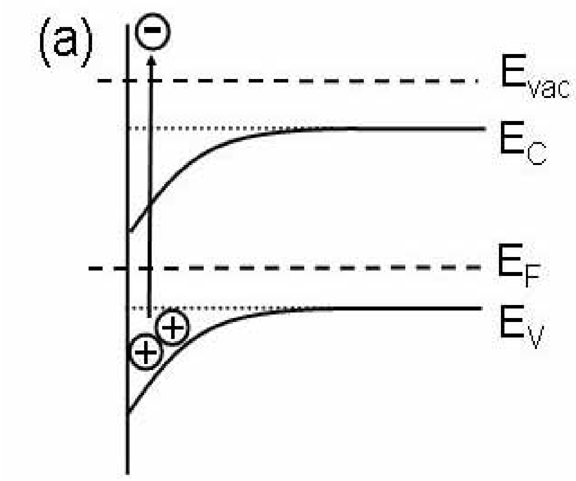
  - Surface chemical properties are very important

*** Same powder !!?? From same supplier**

WORK in PROGRESS

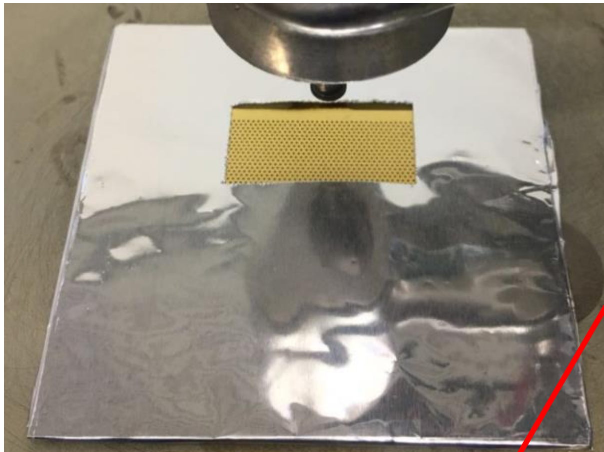
The research on diamond powders continues with particular attention to:

- ✓ Powder reproducible chemical and morphological properties
- ✓ Boron doped diamond (p-type) powders



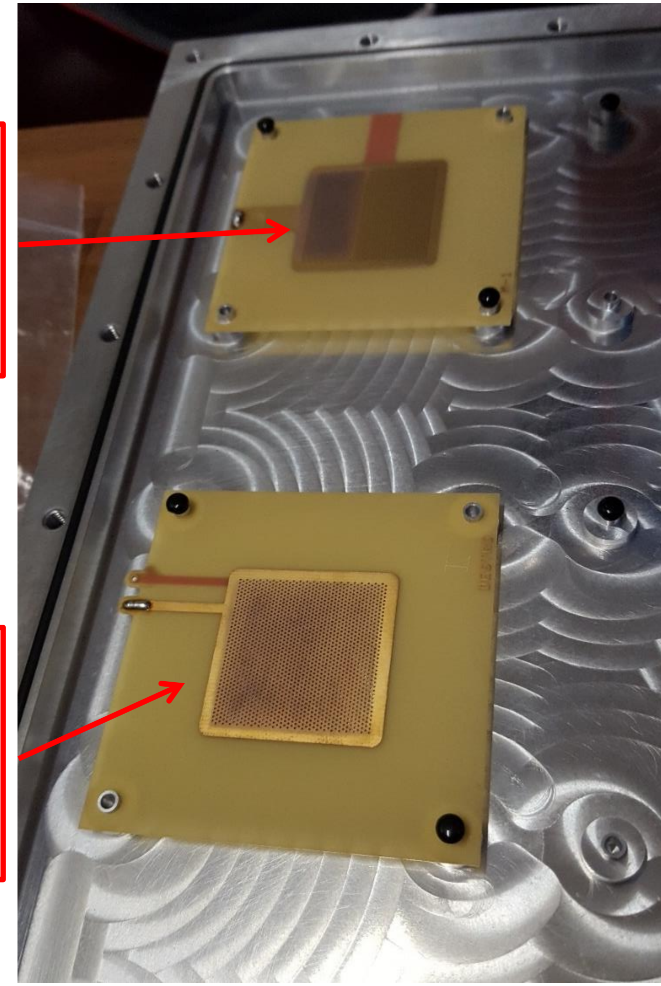
- ✓ ***Applications in MicroPattern Gaseous Detectors***

Nanodiamond PCs on MPGD



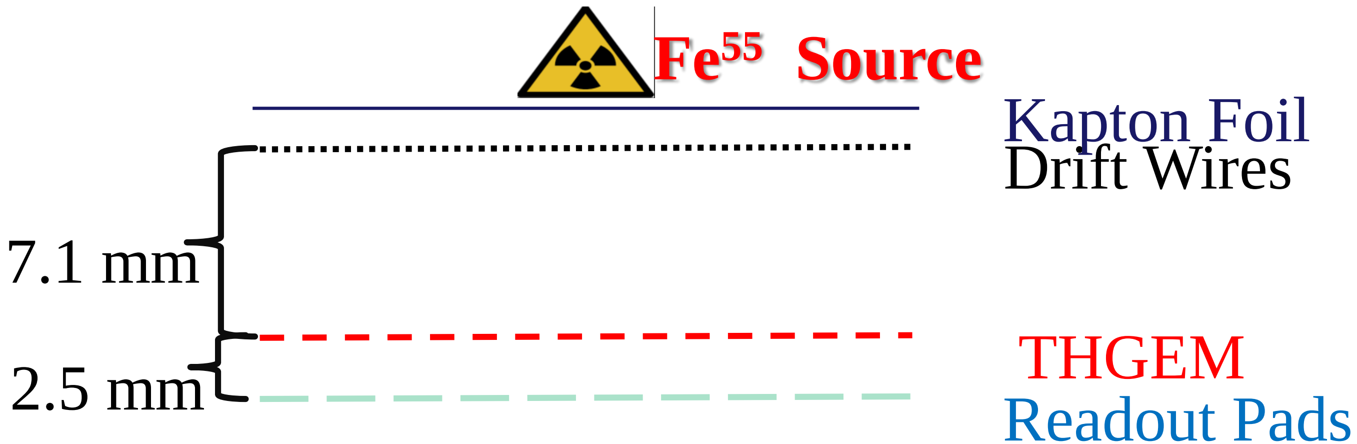
Half Covered THGEM

Full Covered THGEM

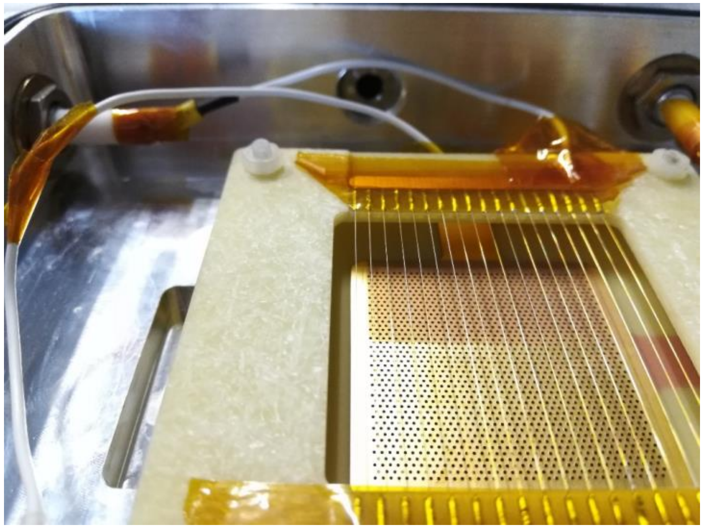


Nanodiamond PCs on MPGD

Test - Trieste Group



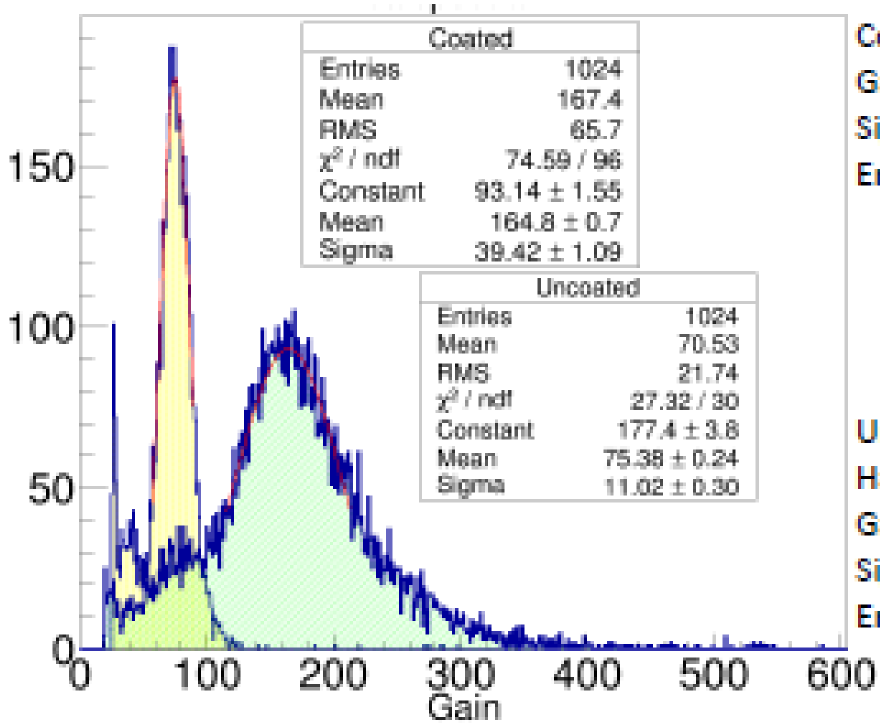
Schematic Diagram of the Chamber



Half coated with non-Hydrogenated ND

Nanodiamond PCs on MPGD

First Test Results



Coated Half:
Gain164.8
Sigma 39.42
En. Res. 0.24

Uncoated
Half:
Gain 75.48
Sigma 11.12
En. Res. 0.15

Figure 4: Gain behavior of THGEM with 20 μm rim, half-coated with nanodiamond. It is clearly shown that the gain in the coated part is almost two times higher than that in the the uncoated part.

J. Agarwala, et al.
Nuclear Inst. and Methods in Physics Research, A 952 (2020) 161967

WORK in PROGRESS

Preliminary results of ND Photocathode coupled to THGEMs

S. Dasgupta and Triloki

On Behalf of a INFN, Trieste & INFN, Bari collaboration

Outline

- Motivation
- QE Setup in Bari
- QE measurement in Bari
- ASSET @ CERN
- Preliminary measurement with ASSET
- Conclusion

Thanks for the attention