Characterization by KrF laser of highly efficient photocathodes based on Nanodiamond layers

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Outline of talk:

- *UV photocathode*
- *Diamond as electron emitter*
- *Production of nanodiamond layers by pulse spray technique for UV photocathode*
- *Measurement of the photocathode quantum efficiency by pulsed laser-induced photoelectric charge measurements at LEAS Laboratory*

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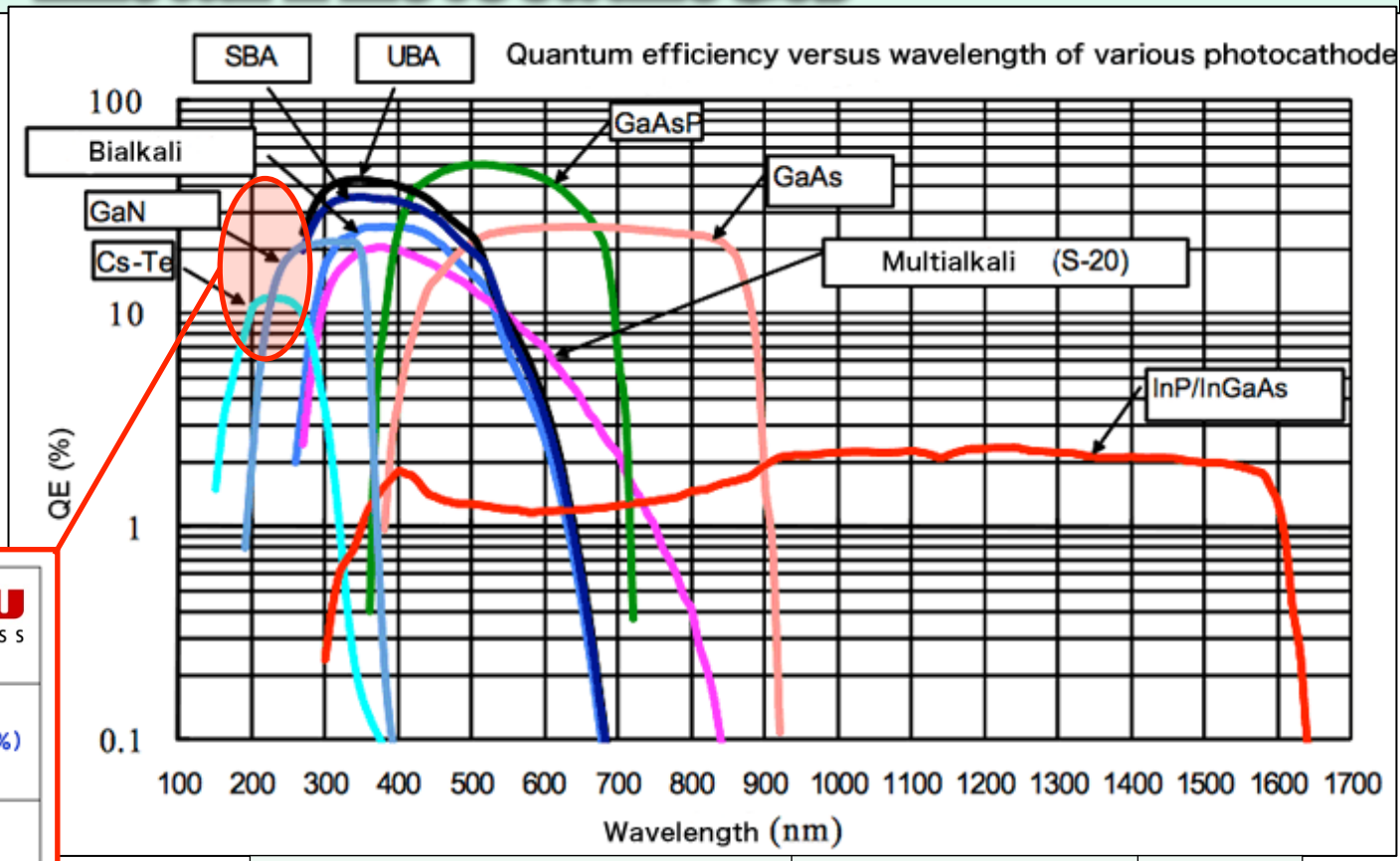
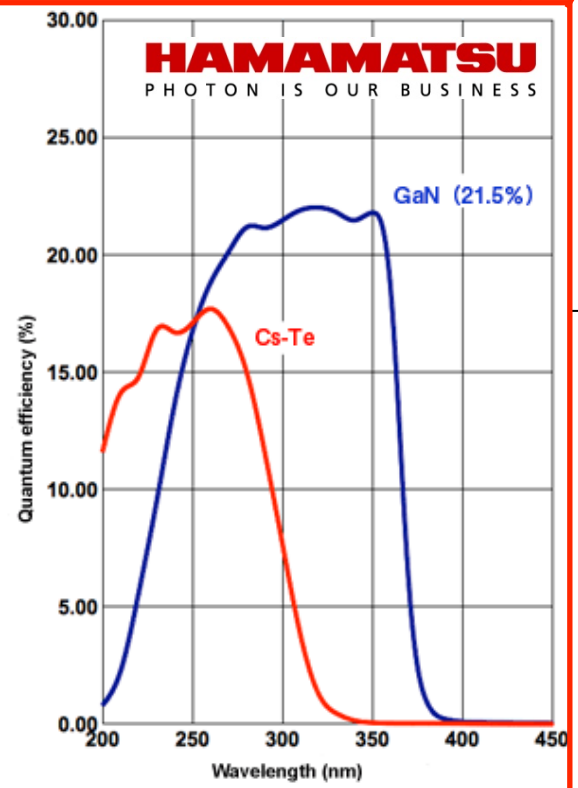
Metal Photocathodes

A photocathode usually consists of alkali metals with very low work functions.



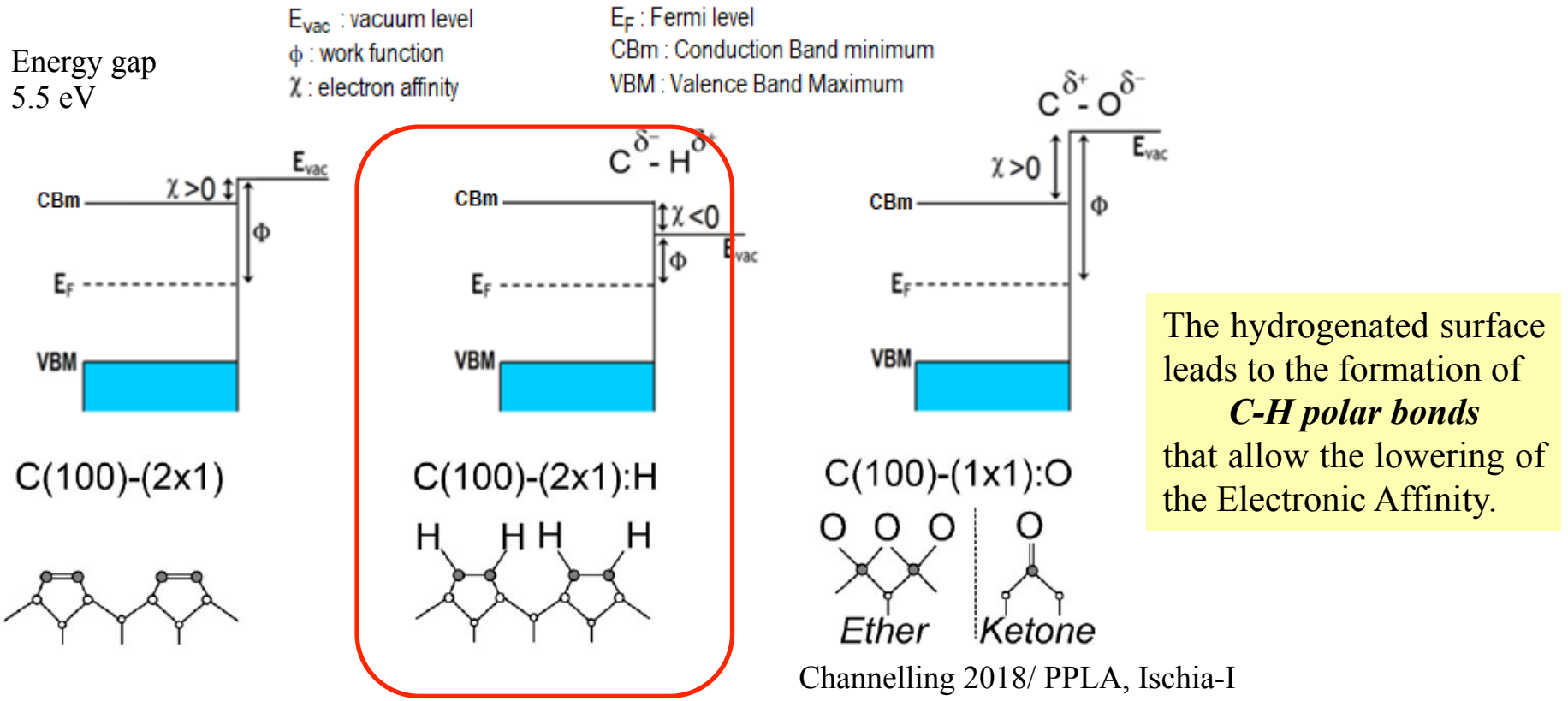


	range	QE_{MAX} %
Ultra Bialkali (UBA)	280-680 nm	43
Super Bialkali (SBA)	280-680 nm	35
Bialkali (Sb-Rb-Cs, Sb-K-Cs)	250-680 nm	25
Multialkali (Na-K-Sb-Cs)	250-840 nm	20
GaAs	400-930 nm	28
InP/InGaAs	350-1600 nm	2
Cs-Te	320-350 nm	18
Cs-I	200-400 nm	30
GaN	200-400 nm	21

Diamond films ideal for thermo- and photo-emission

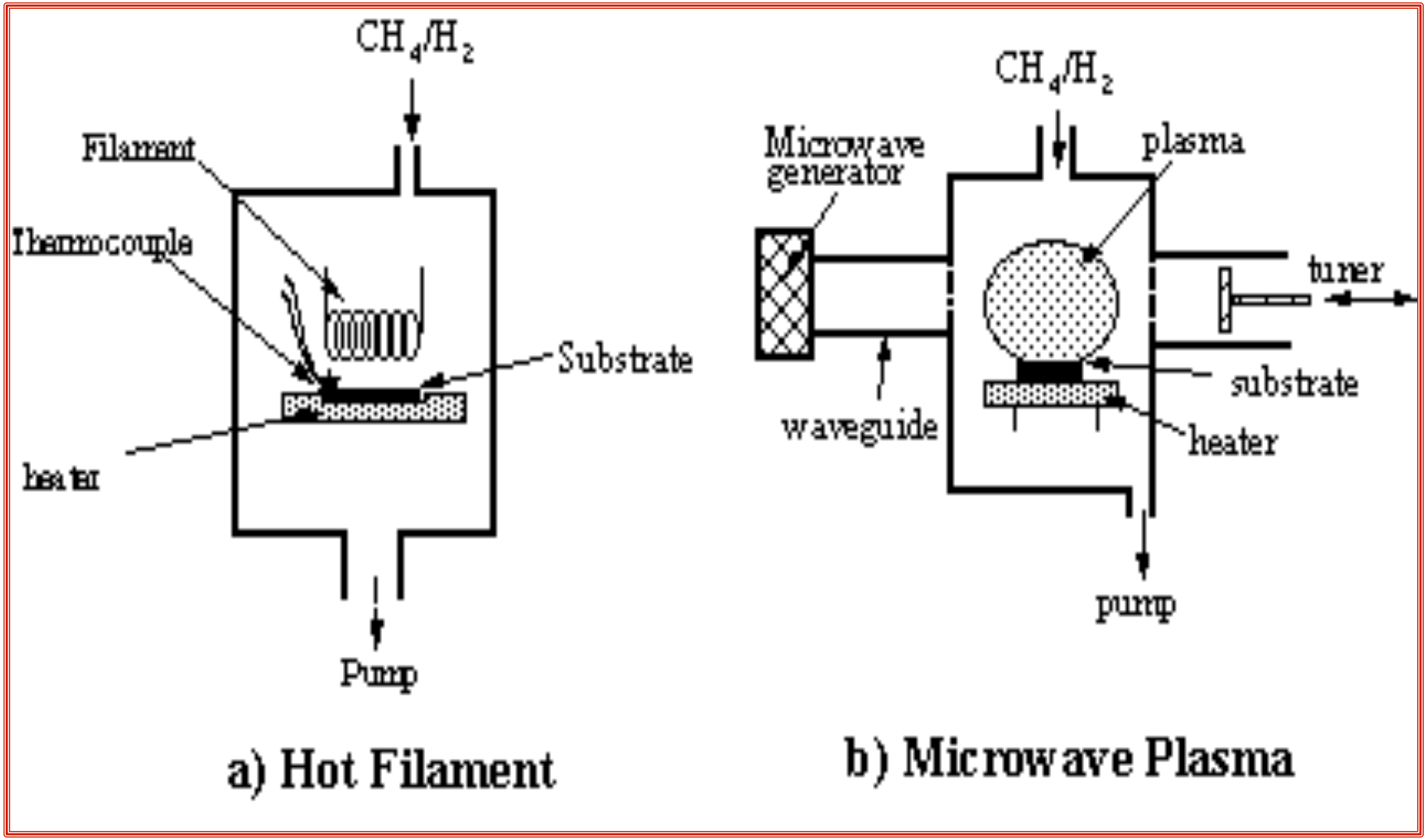
Negative electron affinity (**NEA**) of materials allows an efficient escape of electrons generated by irradiation or heating or field effect into vacuum without an energy barrier at the surface.

The surface of the diamond treated with hydrogen leads to a *Negative Electronic Affinity* (**NEA**) ----> reduction of the work function **f**



The hydrogenated surface leads to the formation of ***C-H polar bonds*** that allow the lowering of the Electronic Affinity.

Typical deposition techniques for diamond films



High deposition temperature (~ 800 °C)

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Production of nanodiamond layers by pulse spray technique for UV photocathode

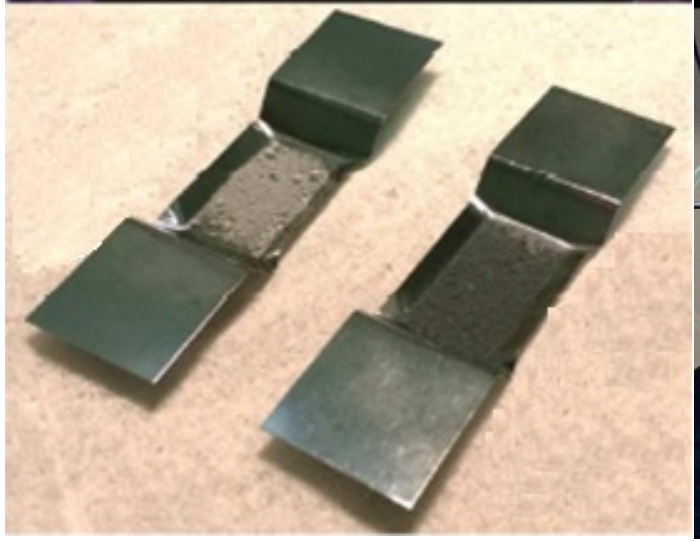
International patent n. WO/2017/051318A1

A. Valentini, D. Melisi, G. De Pascali, G. Cicala, L. Velardi, A. Massaro,

High-efficiency nanodiamond-based ultraviolet photocathodes

Channelling 2018/ PPLA, Ischia-I

Hydrogen treatment by H2 plasma to obtain NEA surface



ND powder treated in a MWPECVD reactor

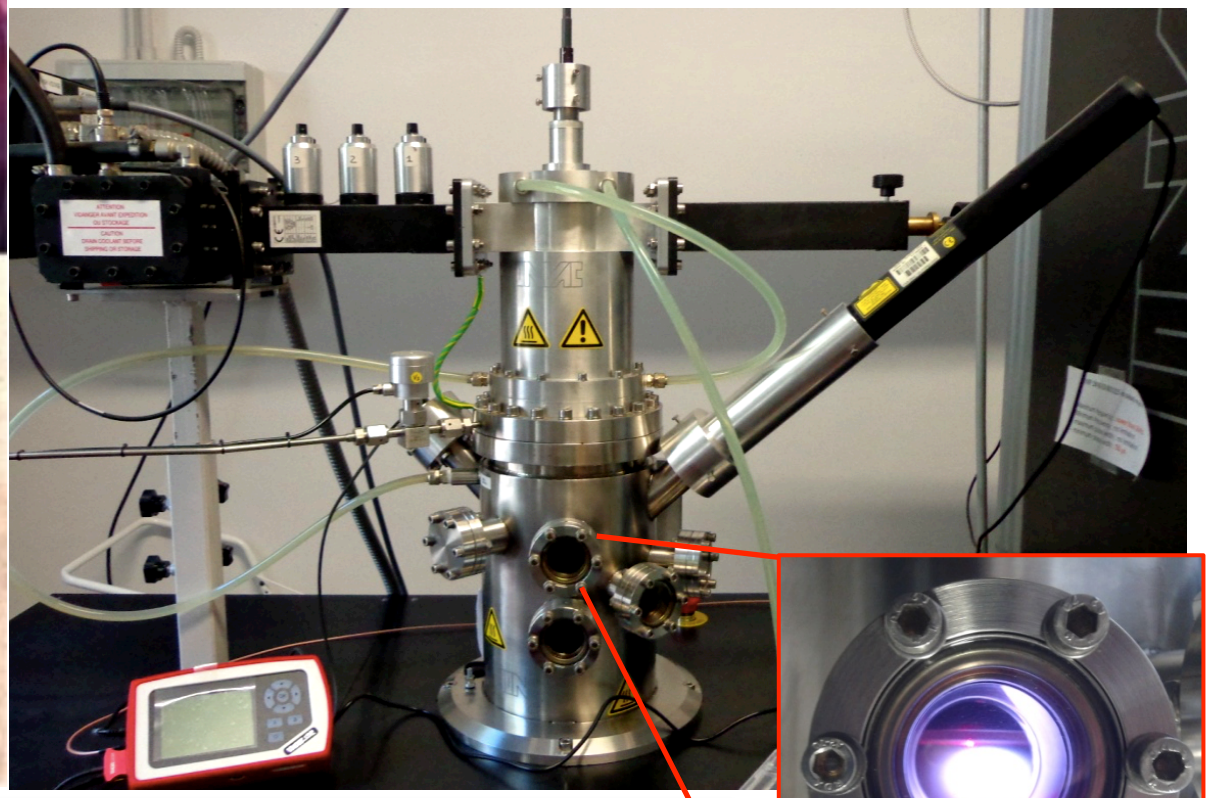


Photo of the MWPECVD reactor used

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Elettronica
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Strumentazione

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Measurement of the photocathode quantum efficiency by pulsed laser-induced photoelectric charge measurements at LEAS Laboratory

Richardson theory of the electron emission by solid cathodes

$$J = J_0 + J_{n-photon(>1)}$$

J_o is the term due to the thermionic mechanism and $J_{\text{n-photon}}$ is the term related to the photonic processes.

$$J_0 = AT^2 \exp(-\varphi / kT),$$

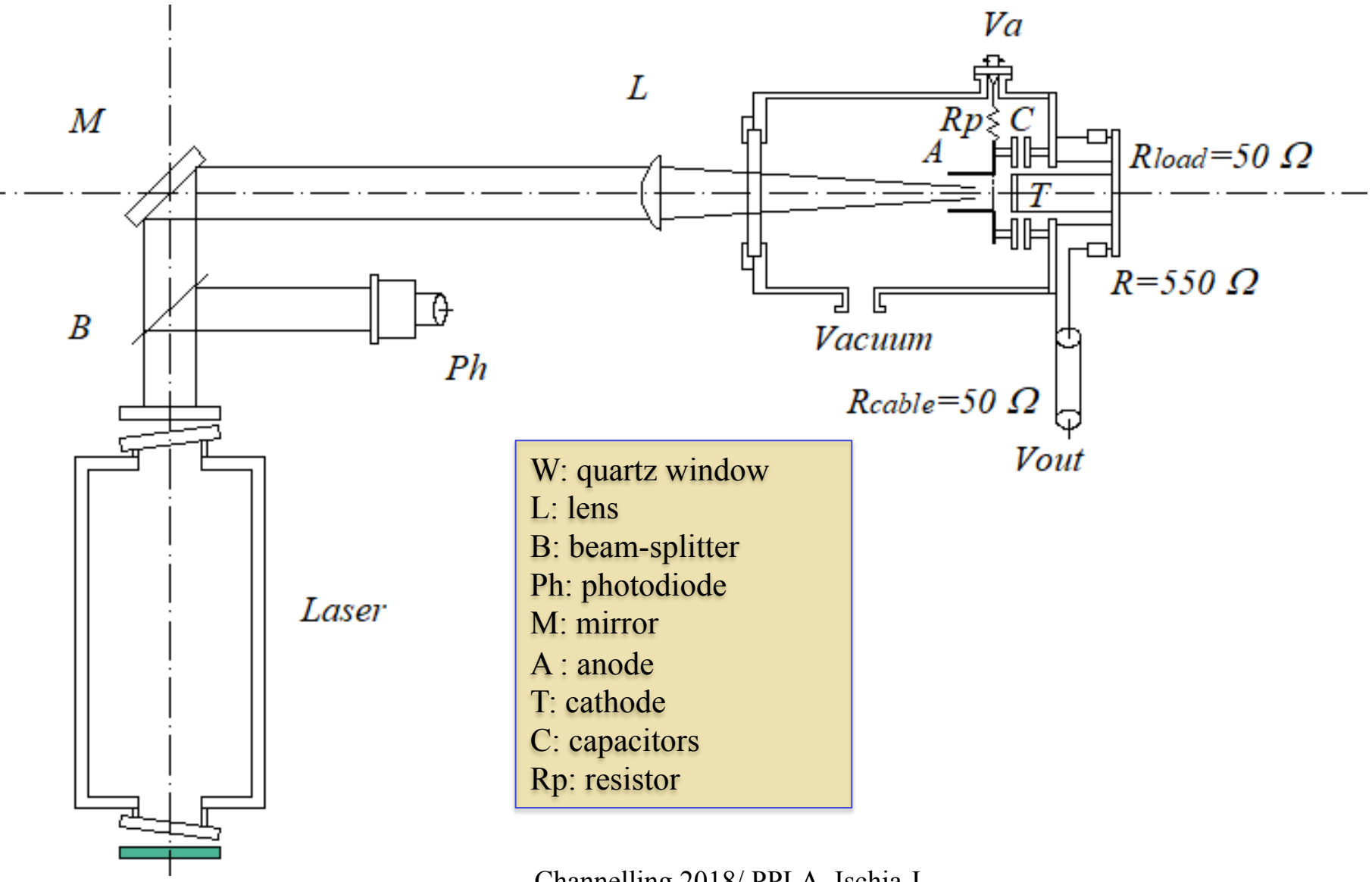
Cu 4.5 eV
ND 5.5-6.5 eV
H-ND 4.5-5 eV.

$$J_{n-photon} = \sum_{n=1}^{N+1} a_n I^n(t) A(1-R)^n T^2(t) f\left(\frac{nh\nu - \varphi}{kT}\right)$$

A=120 A/(K^2 cm^2) is the Richardson constant, **T** is the temperature of the metal, **f** is the work function, **k** is the Boltzmann constant, **I** is the incident laser power, **R** is the target optical reflection, **f** is the Fowler function.

a_n is a coefficient related to the quantum n-photon process.

Experimental apparatus for photoemission measurements



W: quartz window
L: lens
B: beam-splitter
Ph: photodiode
M: mirror
A : anode
T: cathode
C: capacitors
Rp: resistor

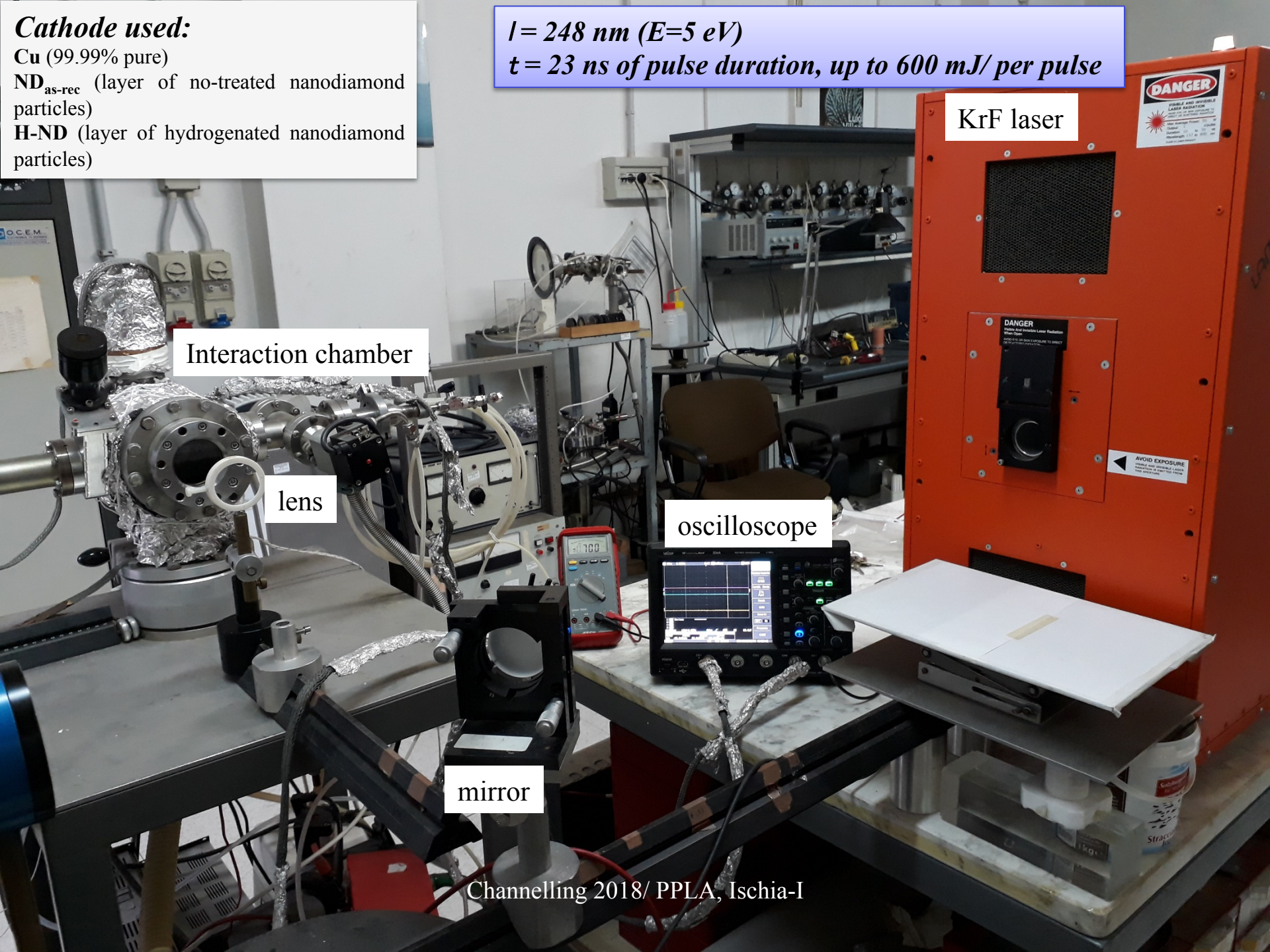
Cathode used:

Cu (99.99% pure)

$ND_{as\text{-}rec}$ (layer of no-treated nanodiamond particles)

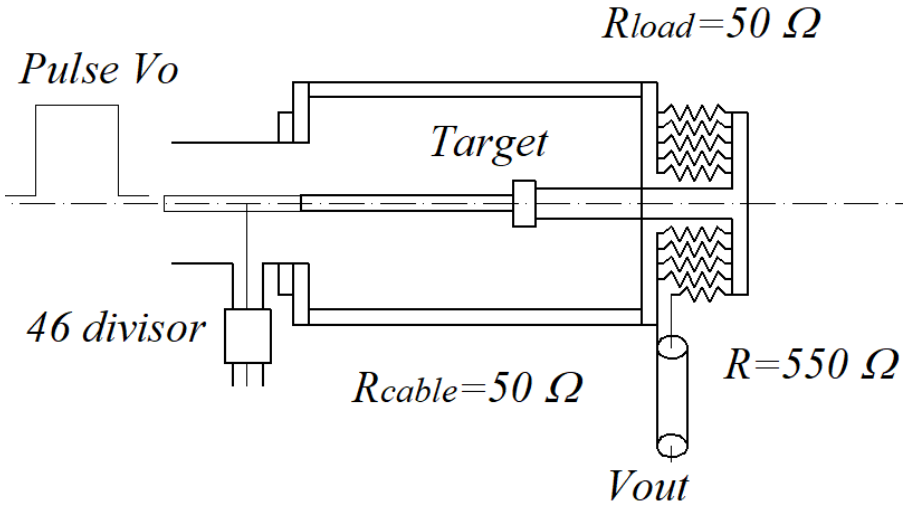
H-ND (layer of hydrogenated nanodiamond particles)

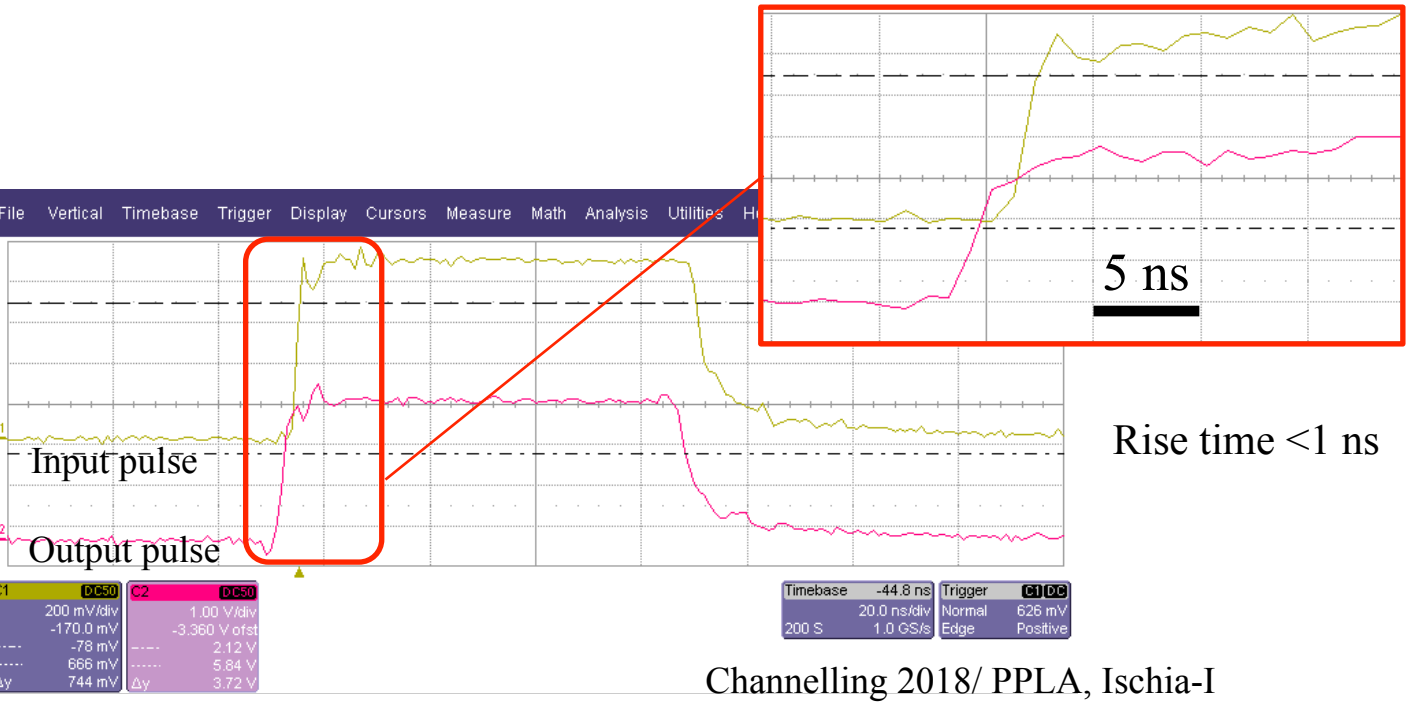
l = 248 nm (E=5 eV)
t = 23 ns of pulse duration, up to 600 mJ/ per pulse



Shunt Calibration

The target support and camera diameters form a characteristic impedance of about 50 W. In order to avoid signal reflections and to record the real current pulses, the cathode was connected to the ground by 12 resistors of approximately 600 W, used as shunt. But, one of these resistors was composed by a 550 W resistor, connected in series to a 50 W coaxial cable.





Rise time <1 ns

A voltage pulse $V\downarrow o$ was applied to the cathode support . The output voltage resulted:

$$V\downarrow out = 50/550+50\ V\downarrow o$$

The experimental value of the current was:

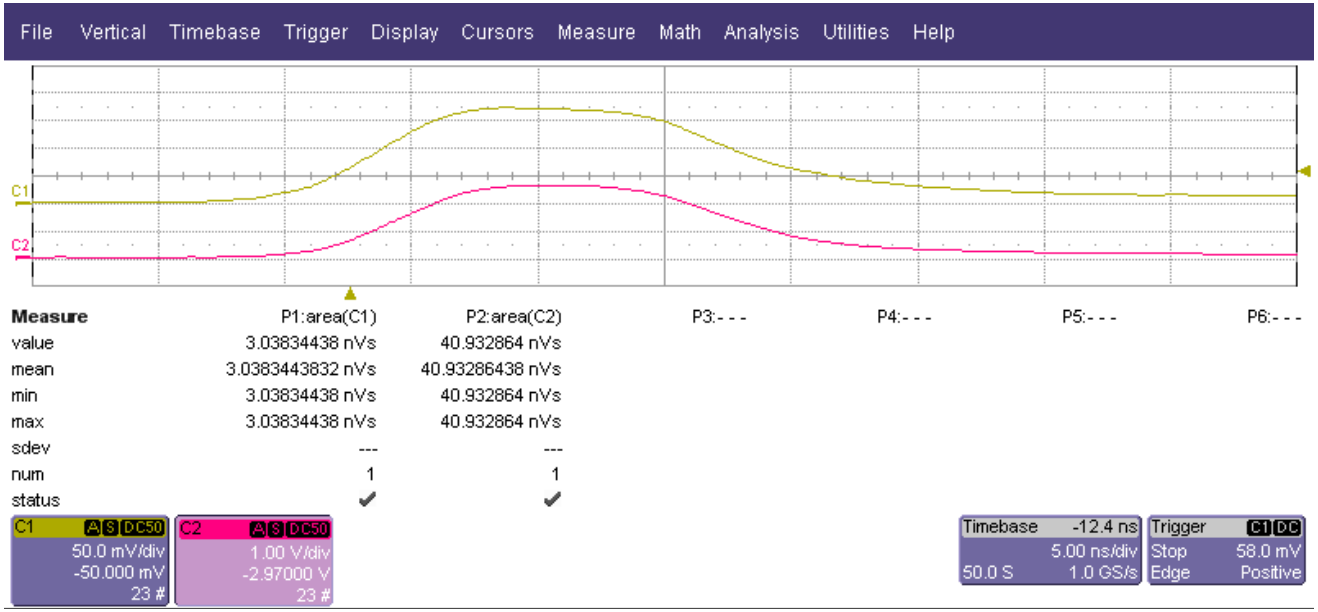
$$I\downarrow o = 550+50/50\ V\downarrow out/R\downarrow load$$

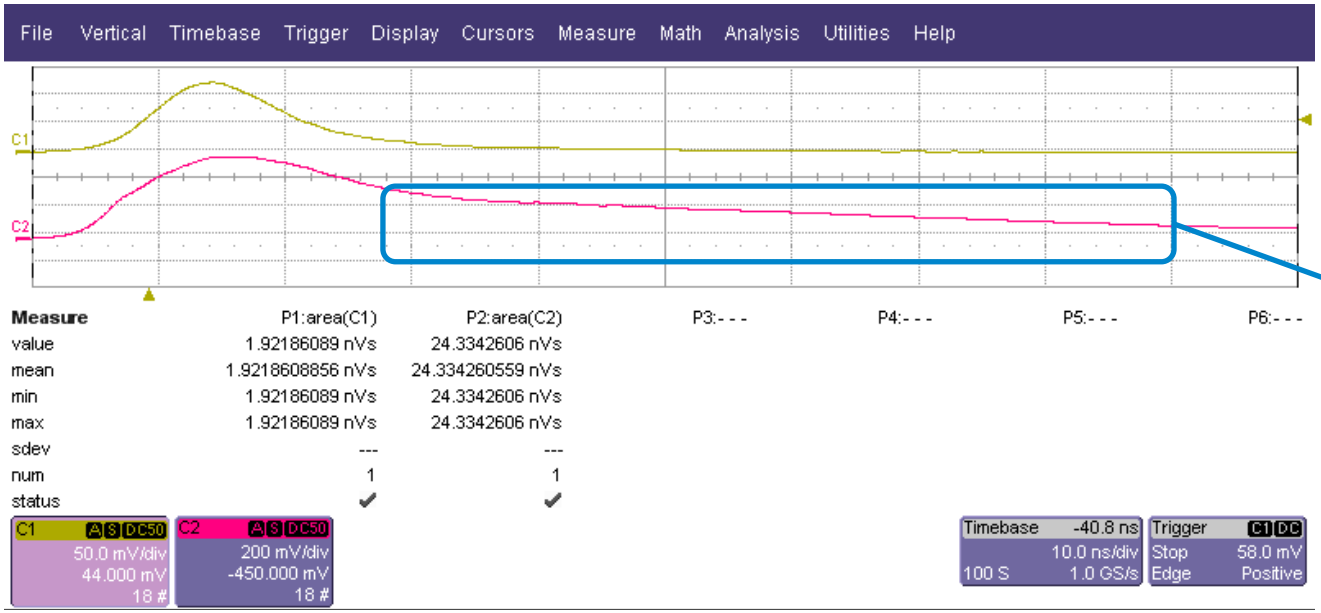
$$I\downarrow o = 0,247 * V\downarrow out$$

The upper trace (yellow) represents the temporal evolution of the input pulse, whereas the bottom trace (pink) represents $V\downarrow out$.

Typical acquired Signals

The upper trace (yellow) represents the temporal evolution of the laser current, whereas the bottom trace (pink) represents the output signal due to the electron emission.

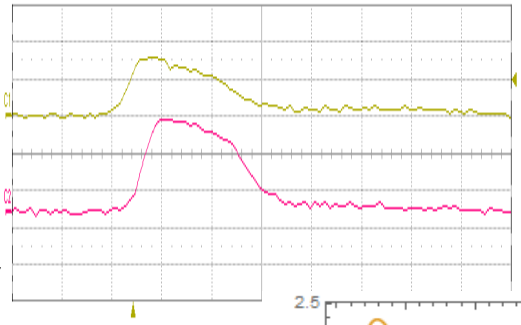




Modification of the output signal due to the presence of **plasma formation** in the anode-cathode gap.

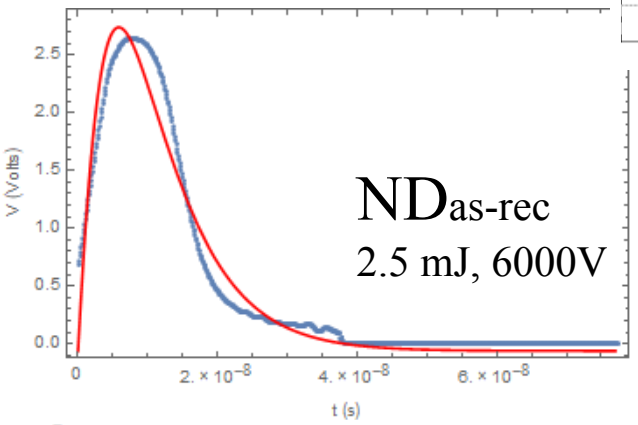
$$J = J_0 + J_{n-photon} \qquad J_{n-photon} = \sum_{n=1}^{N+1} a_n I^n(t) A (1-R)^n T^2(t) f\left(\frac{nh\nu - \varphi}{kT}\right)$$

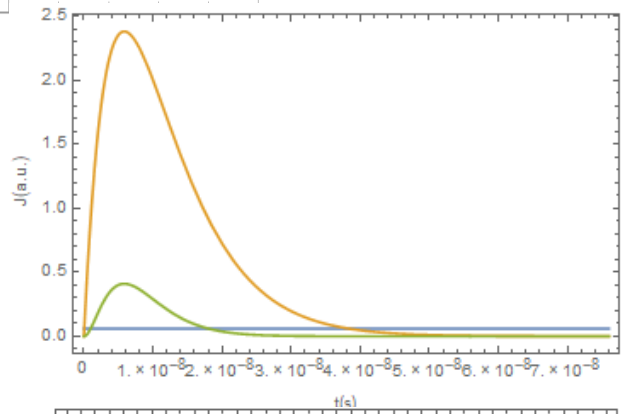
Cu
2,5 mJ, 500V



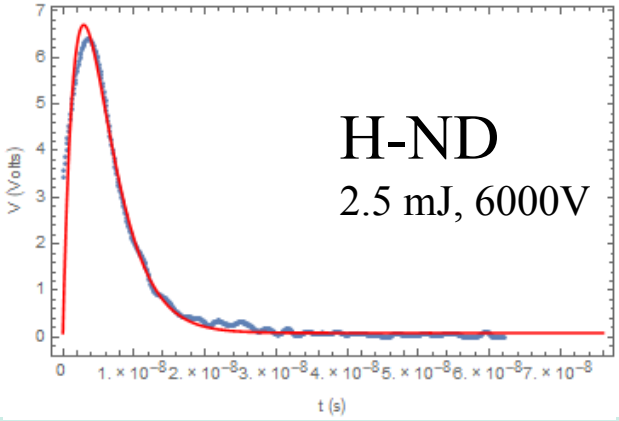
J1 1
J2 0.01

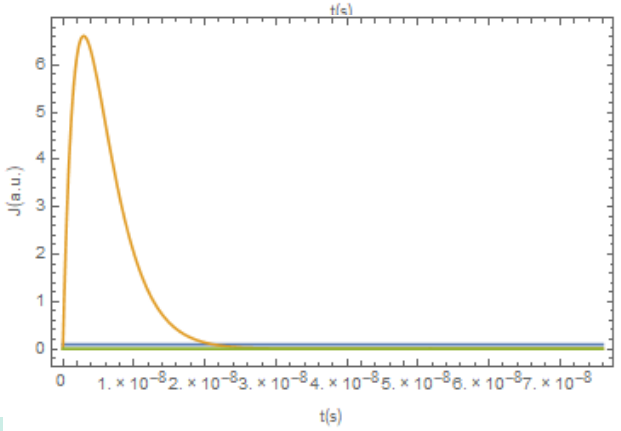
NDas-rec
2.5 mJ, 6000V





H-ND
2.5 mJ, 6000V



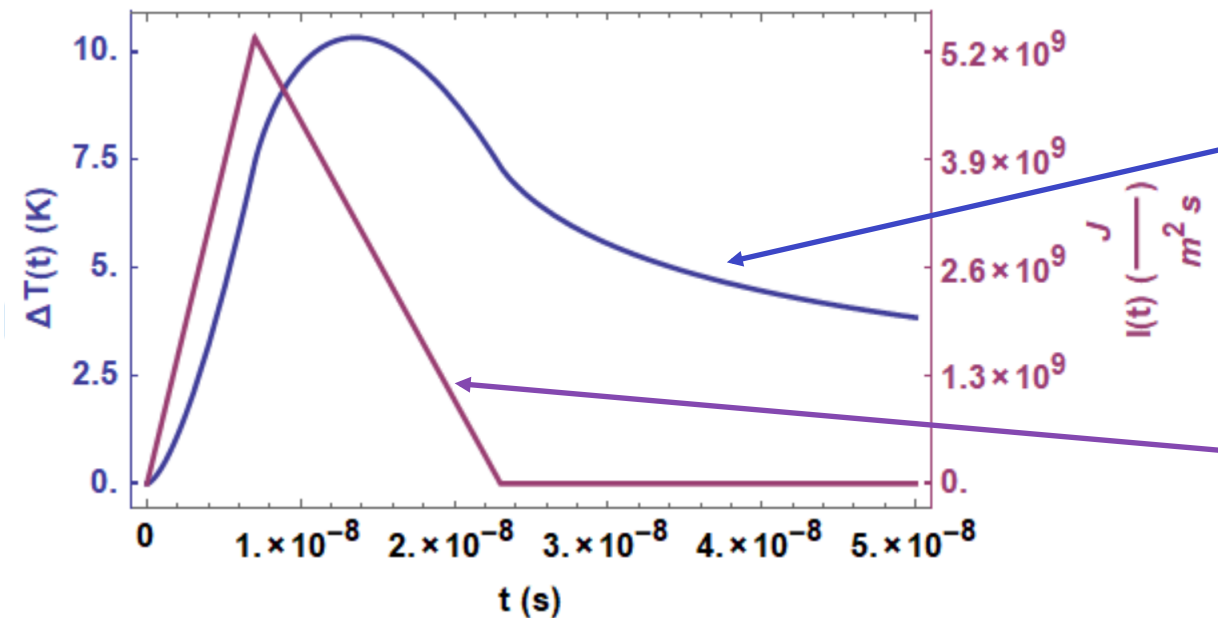


Thermionic emission is negligible for all the cathodes. Two-photon emission contribution is lower in Cu and H-ND cathodes due to their lower work functions (∼4.5eV) whereas dominates in the NDas-rec cathode due to the large energy gap (∼5.5eV) of the untreated diamond.

Cathode surface temperature

$$T(t)=T_0+C\,I_0\int_0^t g(t-t')\,t'-1/2\;dt'$$

Utilising the Fourier equation, the expression **T(t) is the temporal evolution** (during the laser-cathode interaction) of the cathode surface temperature, where T_0 is the initial temperature, C is a constant dependent on cathode material and $I_0 g(t)$ is the laser intensity.

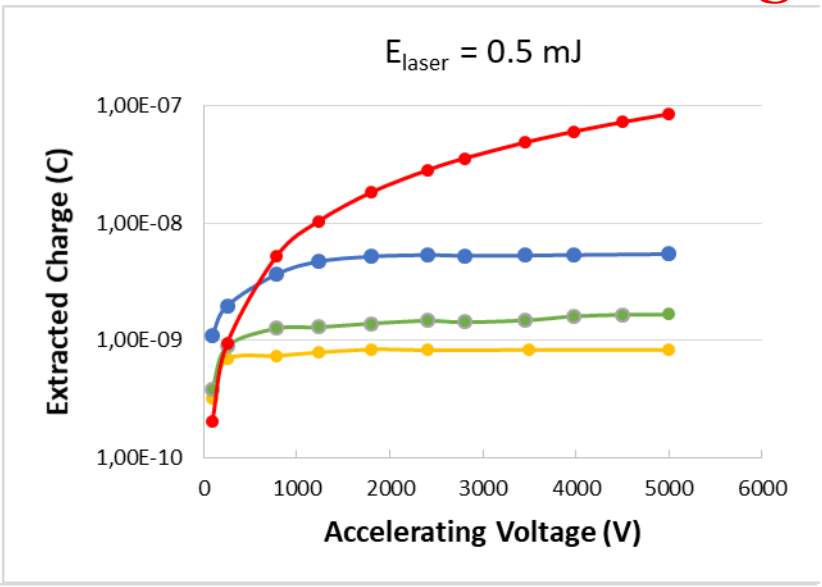


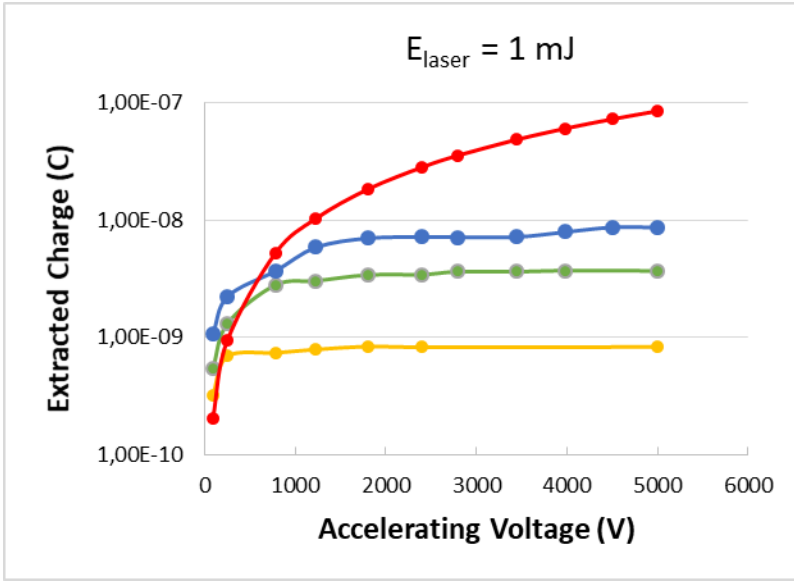
Temporal evolution of the target surface temperature (blue trace).

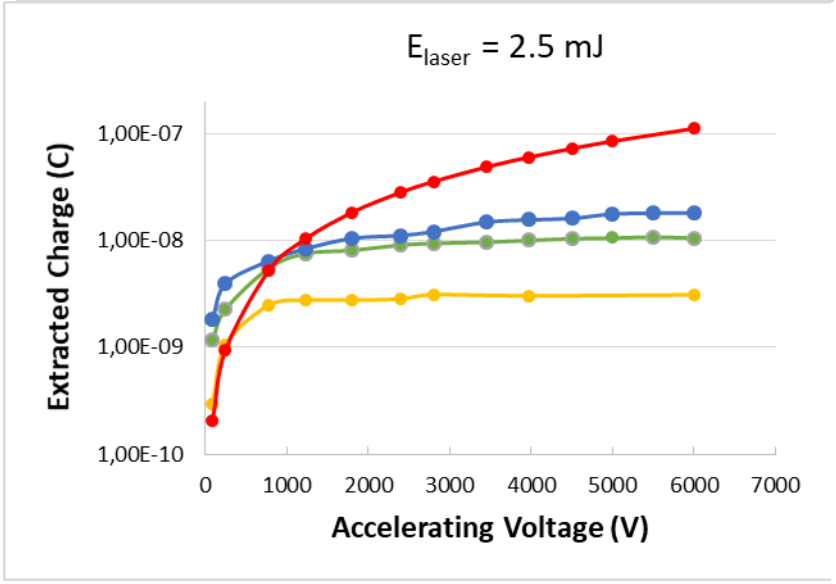
I_0: the laser pulse is approximated by a triangular piecewise function (purple trace).

Considering the maximum laser energy employed in this experiment (20 mJ) and the laser pulse temporal profile, the target surface temperature assumes the values showed in the figure. As we can easily note, **the temperature does not change significantly over the entire duration of the pulse.**

Extracted charge vs Accelerating voltage







- Cu cathode
- $ND_{as\text{-}rec}$ cathode
- H-ND cathode
- Child-Langmuir law

Spot laser 40 mm^2
d = 3 mm

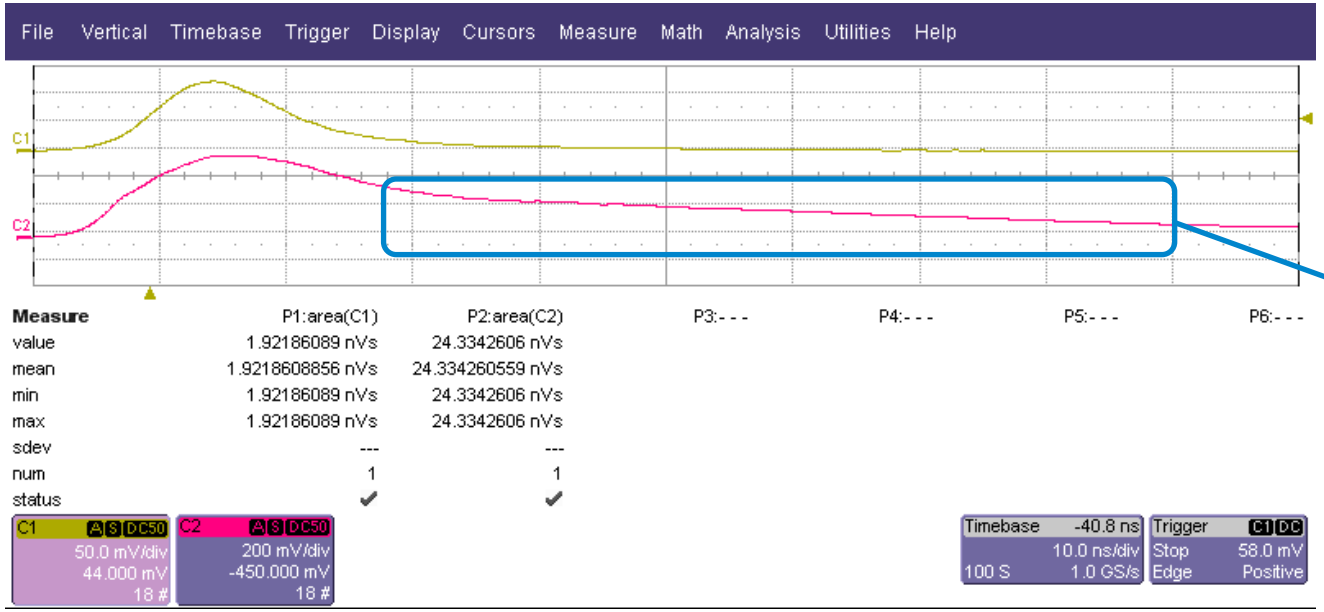
Child-Langmuir law

$$J = 2.43x10^{-6}\frac{V^{3/2}}{d^2}$$

where **V** is the accelerating voltage and **d** is the anode–cathode distance.

The extracted charge is higher in the diamond-based photocathodes

Plasma formation due to the high laser energy



Modification of the output signal due to the presence of **plasma formation** in the anode-cathode gap.

H-ND ➡ 5.4 mJ, 1000 V

ND ➡ 8.5 mJ, 500 V

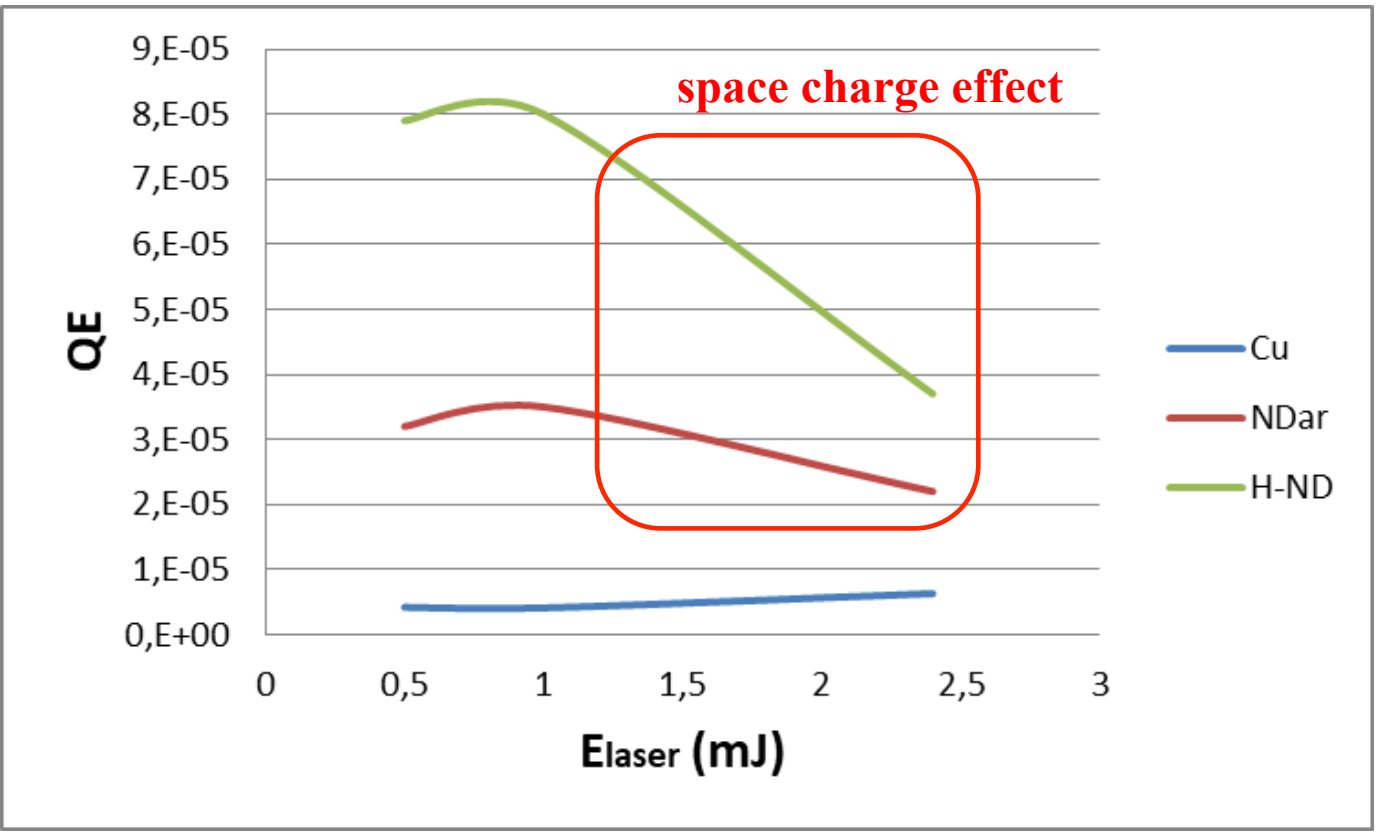
Cu ➡ 22 mJ, 2500 V

Child-Langmuir law

$$I = 2.43 \times 10^{-6} S \frac{(V - ZI)^{3/2}}{(d - vt)^2}$$

where **V** is the accelerating voltage and **d** is the anode–cathode distance, **Z** is the plasma impedance, **S** the laser spot and ***v*** the plasma velocity

Quantum Efficiency (QE)



The diamond-based photocathodes show a better quantum efficiency with respect to the copper one.

The H-ND cathode shows the highest QE due to its NEA surface that lowers the vacuum level -> **improvement of the electron emission in vacuum.**

The QE of Cu cathode doesn't change at the varying of the laser energy (E_{target}), as expected.

The decrease of the QE at the rise of the laser energy for the diamond-based cathodes is due to the **space charge effect (high electron density near the cathode surface)** that limits the extraction current.

Conclusions

good values of QE by H-ND are obtained

Thank You