Electric Current Characteristics of Irradiated Diamond Detectors

Fabio Schirru

GSI Helmholtzzentrum für Schwerionenforschung
Darmstadt - Germany

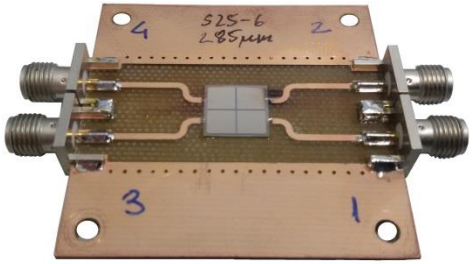
GSI Helmholtzzentrum für Schwerionenforschung GmbH

FAIR
Facility for Antiproton and Ion Research in Europe GmbH

Motivation

- Diamond detectors have been heavily irradiated to explore their timing and radiation hardness properties.
- Measurements aimed in particular at understanding the possibility of employing the diamond material as large-area time-of-flight particle detectors for the Super-FRS.
- X-rays can be employed to perform a preliminary check of the influence of the radiation damages on the electric current response of the irradiated diamond devices.

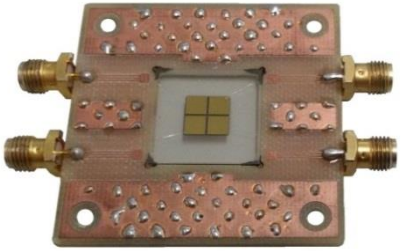
Diamond Devices for X-rays Tests



1 x 4 Quad PC CVD (10x10 mm^2)
Electrodes Area: 5x5 mm^2
Bias: +300 V
Electrodes Type: Cr/Au, 50/150 nm

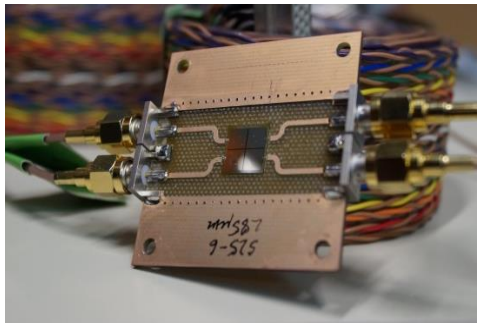
F. Schirru et al., Diamond & Related Materials 49 (2014) 96–102

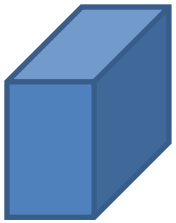
2 x SC CVD (2x2 mm^2)
Electrodes Area: 2x2 mm^2
Bias: +100 V
Electrodes Type: Au 100 nm



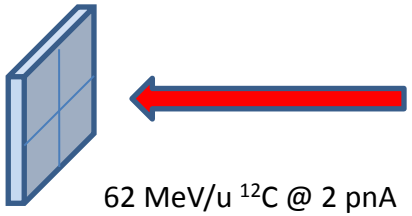
1 x 4 Quad PC CVD (20x20 mm^2)
Electrodes Area: 5x5 mm^2
Bias: +300 V
Electrodes Type: Ti/Pt/Au 50/50/200nm

Radiation Hardness Tests (LNS, 2015)

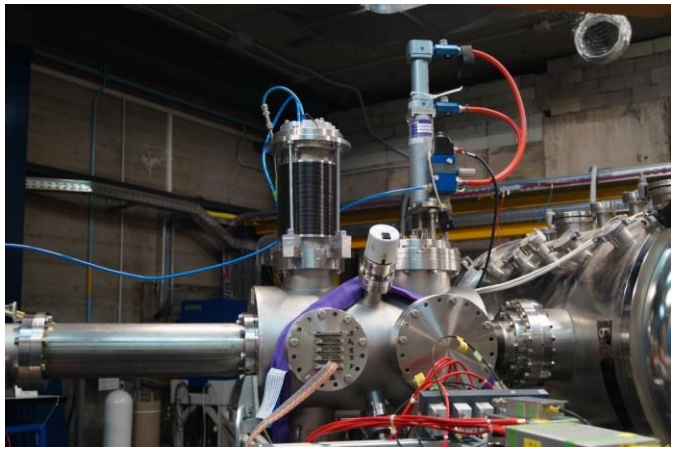




Removable (low rate only)



62 MeV/u ^{12}C @ 2 pnA



IC

1 x SC CVD
Area: 2x2 mm^2
Bias: +100 V
Electrodes: Au 100 nm

1 x 4 Quad PC CVD
Area: 10x10 mm^2
Bias: +300 V
Electrodes: Cr/Au, 50/150 nm

SCALER

DBA -> VFTX & SCALER
DBA -> OSCILLOSCOPE

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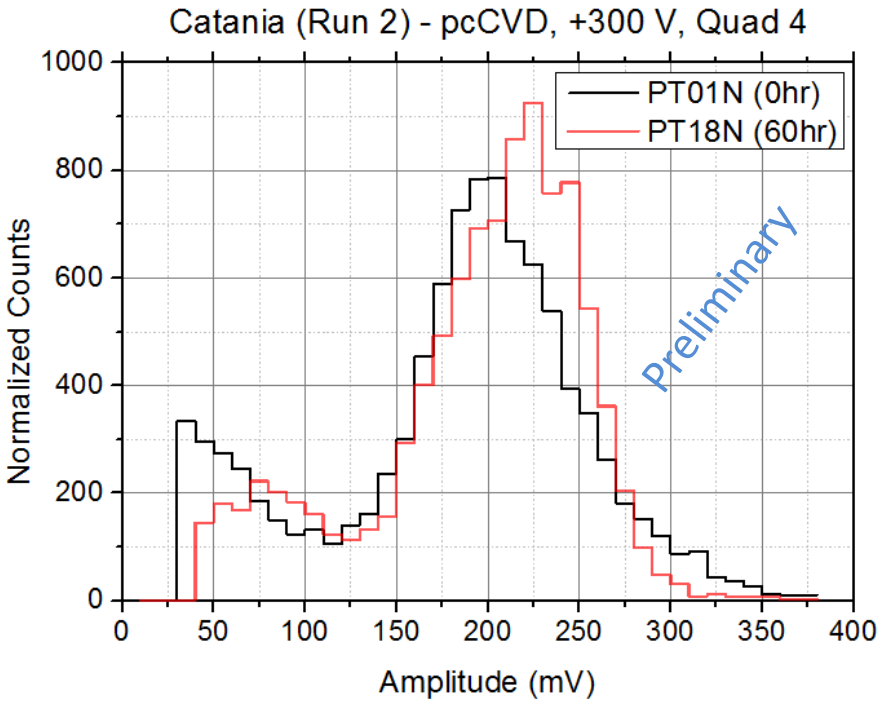
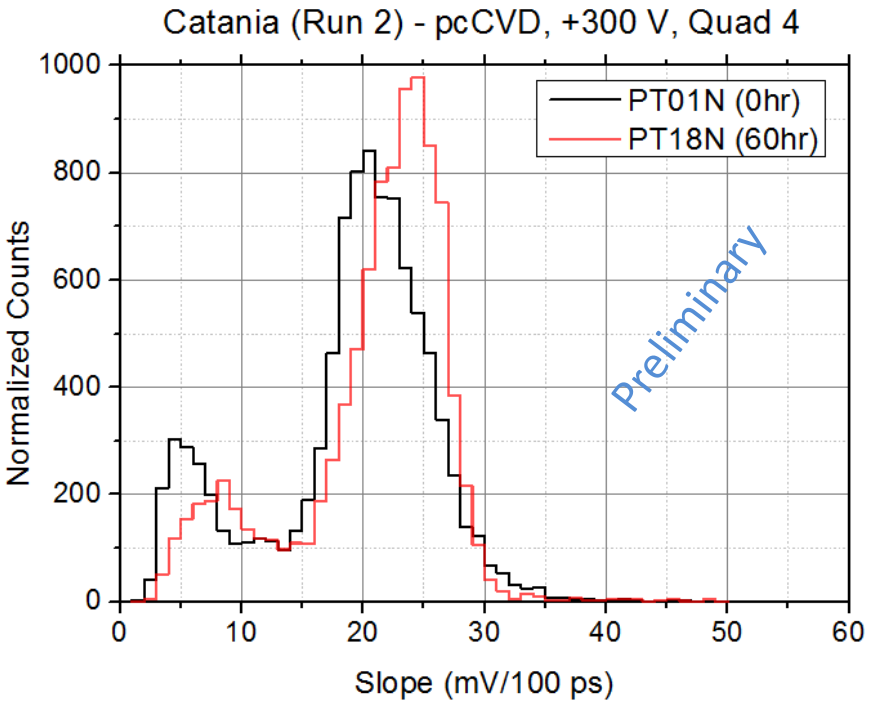
DBA -> OSCILLOSCOPE

Schlemme et al. 2017 under preparation.

Radiation Hardness Tests (LNS, 2015)

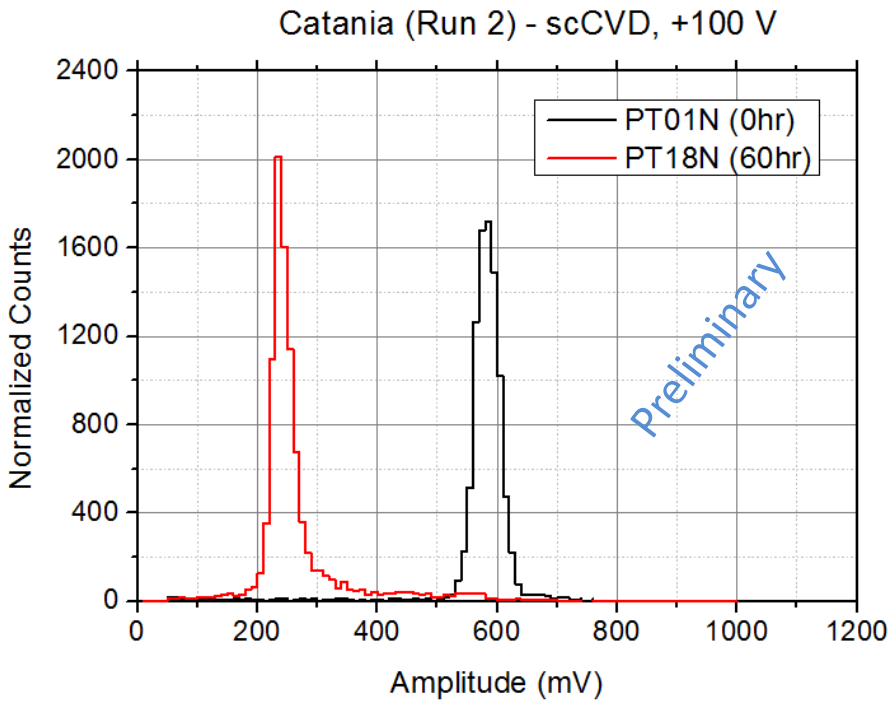


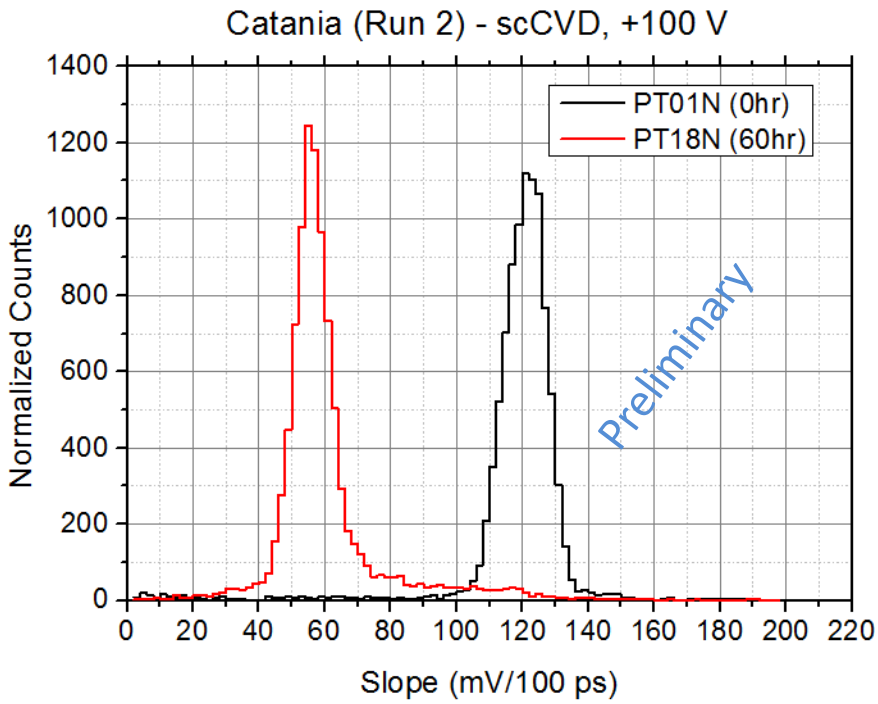


Schlemme et al. 2017 under preparation.

- ❑ The pcCVD showed unchanged signal properties after 40 hours of irradiation.

Radiation Hardness Tests (LNS, 2015)

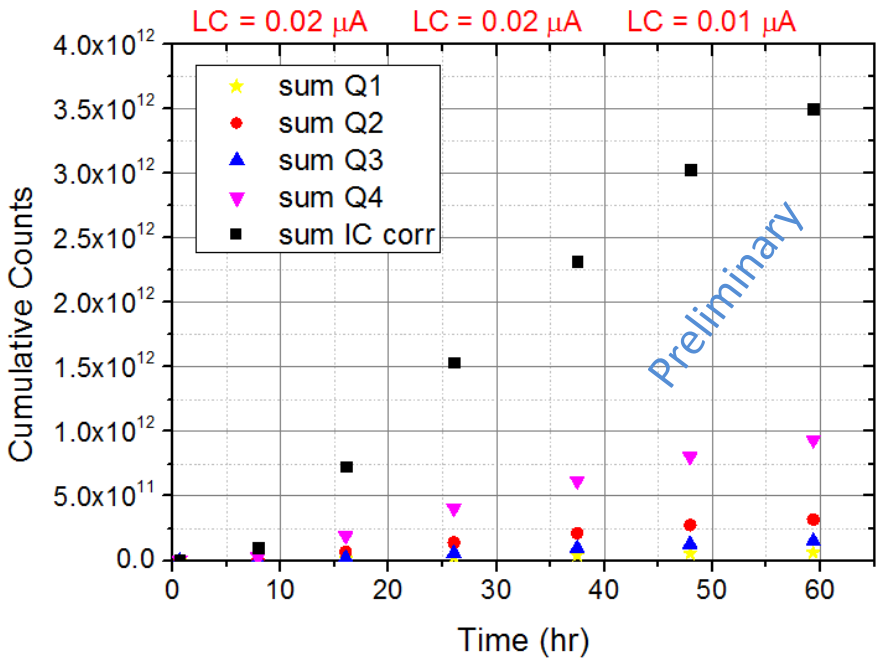


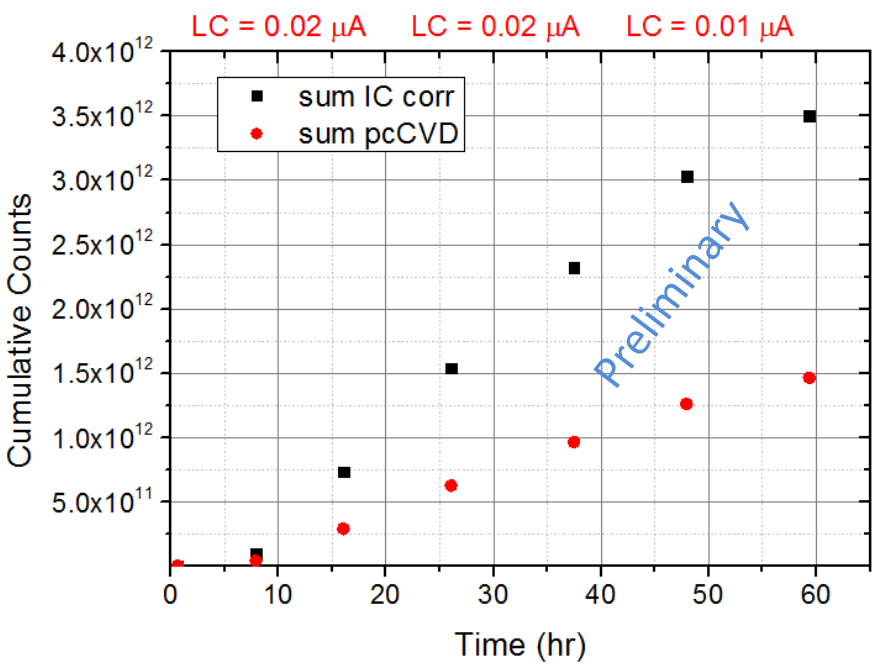


Schlemme et al. 2017 under preparation.

- The scCVD showed a sudden variation in the signal properties after about 12 hours of irradiation.

Radiation Hardness Tests (LNS, 2015)

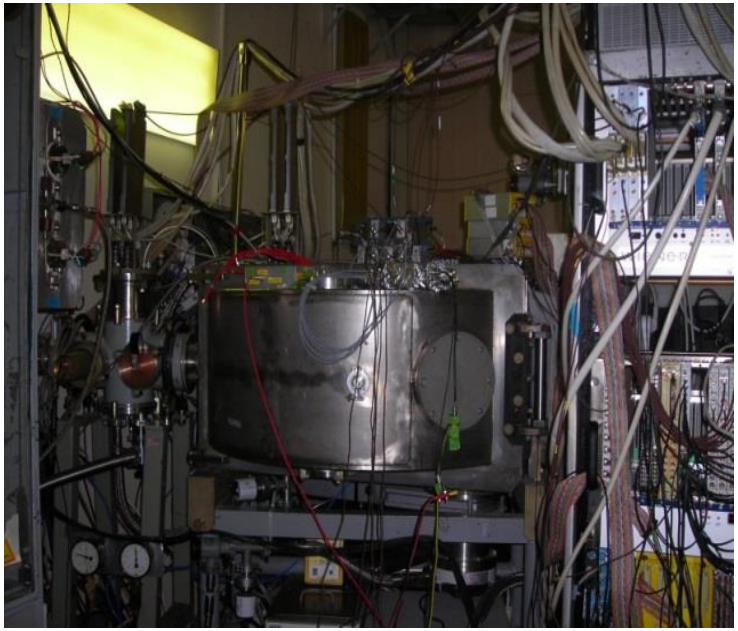




Schlemme et al. 2017 under preparation.

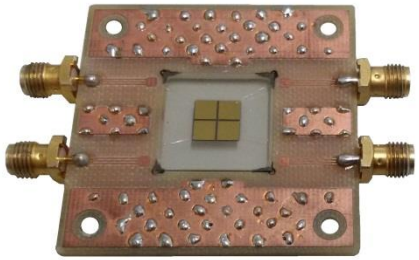
- Deposited dose = 1.8x10^6 Gy (^{12}C@62 MeV/u) equivalent to ~ 400 days of operation at Super-FRS.
- Other characteristics: σ < 45 ps; *rate* > 500 Hz/mm^2 [F. Schirru et al., J. Phys. D: Appl. Phys. **49** (2016)]. **Super-FRS requirements fully met.**

Radiation Hardness Tests (Dubna, 2014)



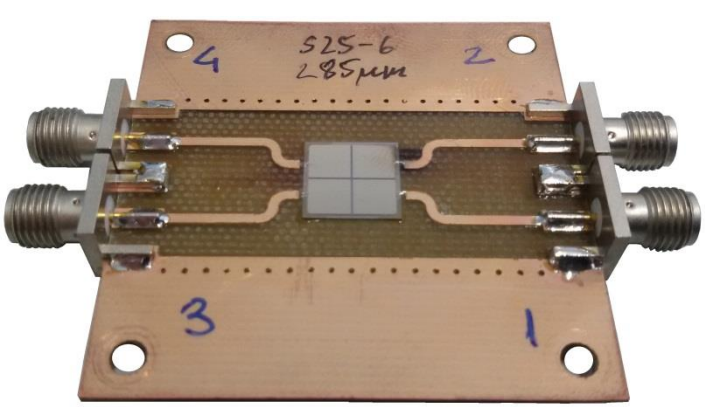
Device	Th. (µm)	Bias (V)	DBA	Gain
DD1_pcCVD	300	+300	IV	2.4
DM1_scCVD	600	-600	III	
SD1_saph	500	-500	III	

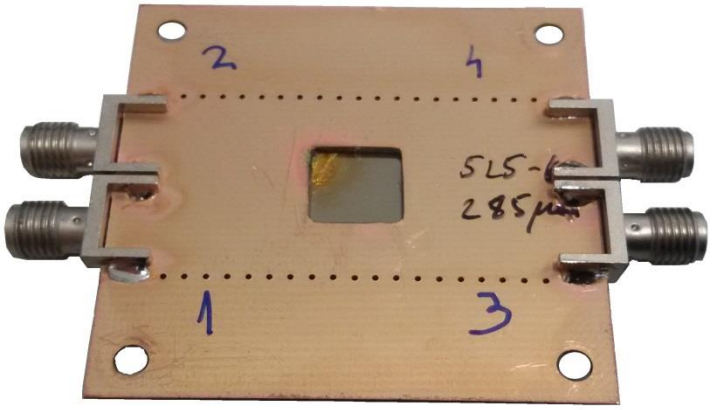
Beam: ^{40}Ar @ 40.5 Mev/u.
Irradiation [1]: $4.8 \cdot 10^{10}$ particles (over 22.5 h), with an average intensity of $2 \cdot 10^{6}$.
Measurement: Alpha particle tests.
Irradiation [2]: 10^{11} particles (over 6h) with an average intensity of $1.7 \cdot 10^{7}$.
Measurement: Alpha particle tests.

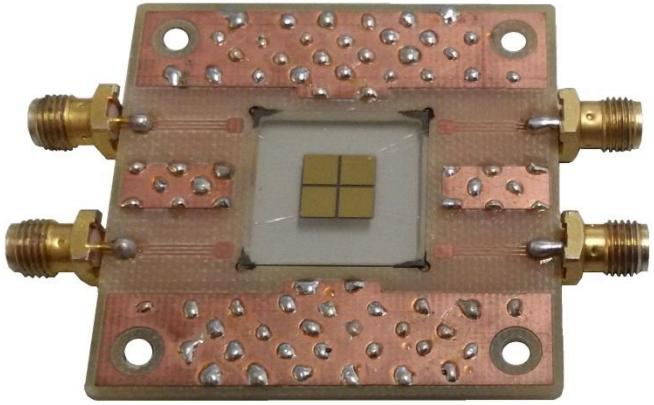


- The pcCVD device did not show remarkable changes in its signal properties under alpha irradiation.
- 4% of particles absorbed respect Catania. However, energy deposited is 600 MeV per ion [~ x20 ^{12}C].

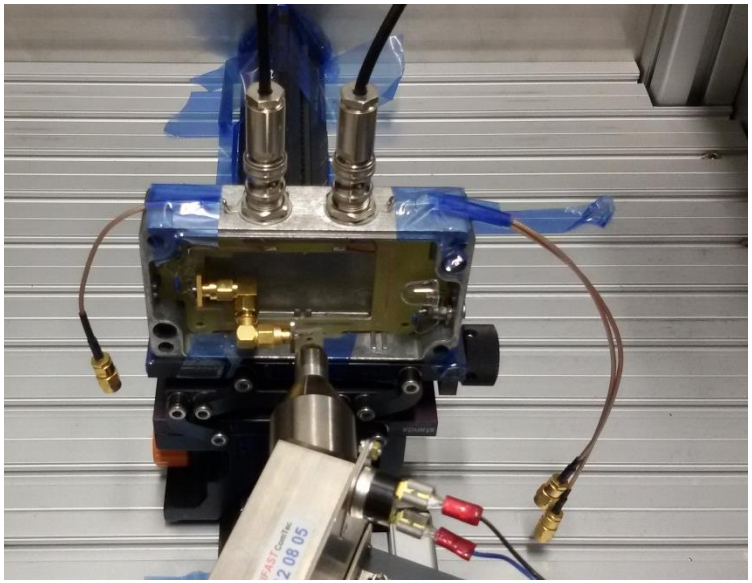
Diamond Devices for X-rays Tests

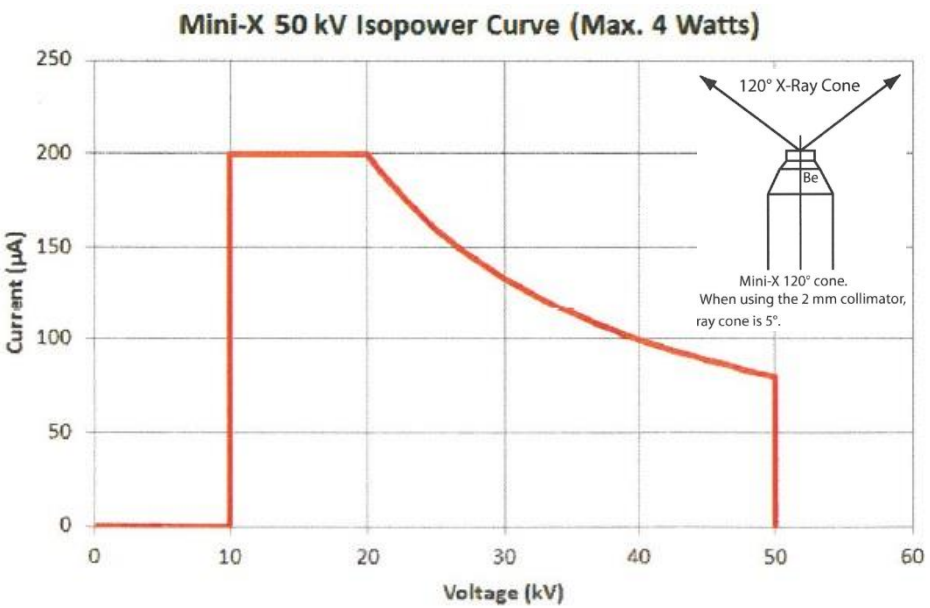






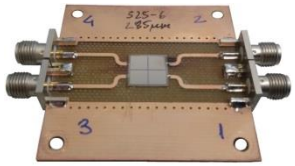
Mini X-rays Setup

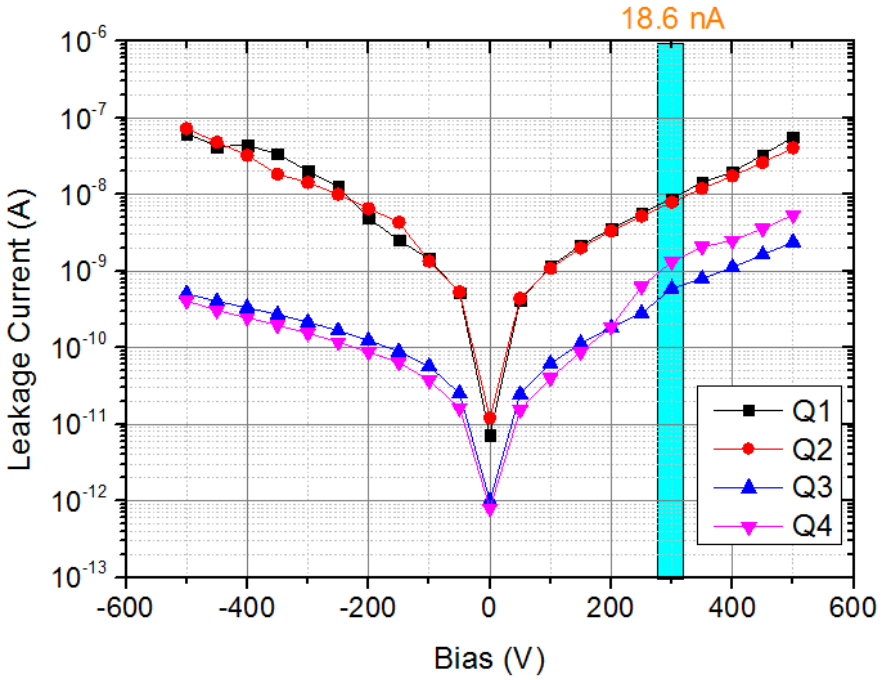


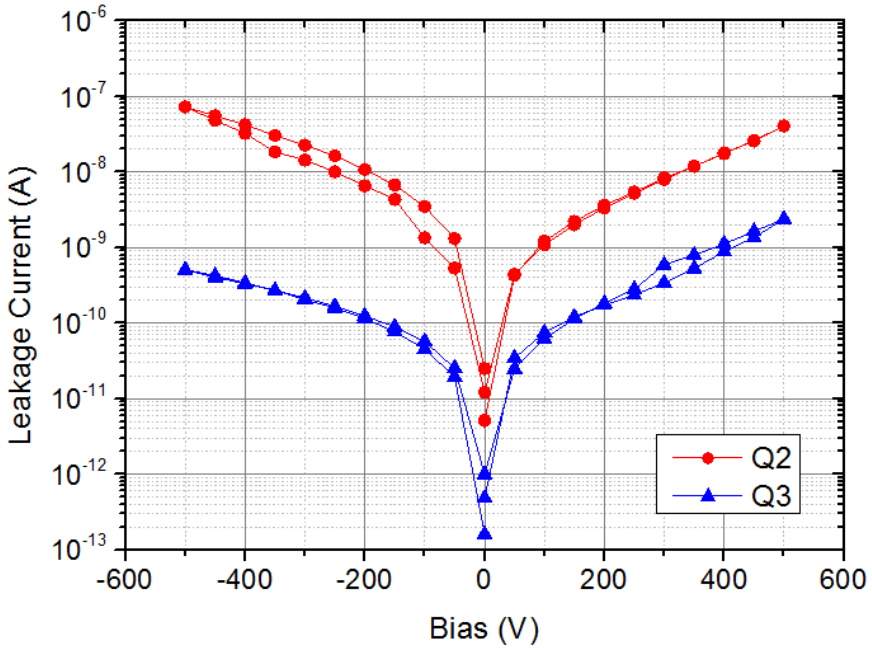


Target thickness	1 µm (Au)
Tube Voltage	10 to 50kV
Tube Current	5 µA min. / 200 µA max.
Approximate Dose Rate	Dose Rate ~1.3 Sv/h @ 30 cm
Collimator	2 mm

Leakage Current [pcCVD_CT]

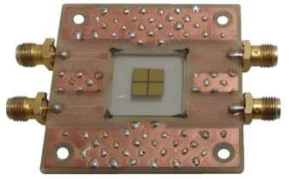


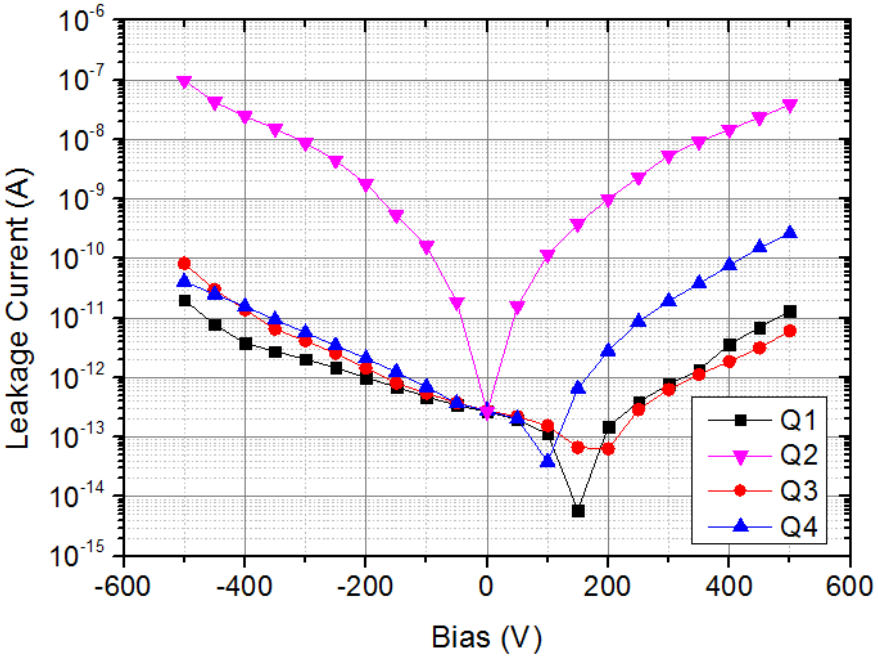


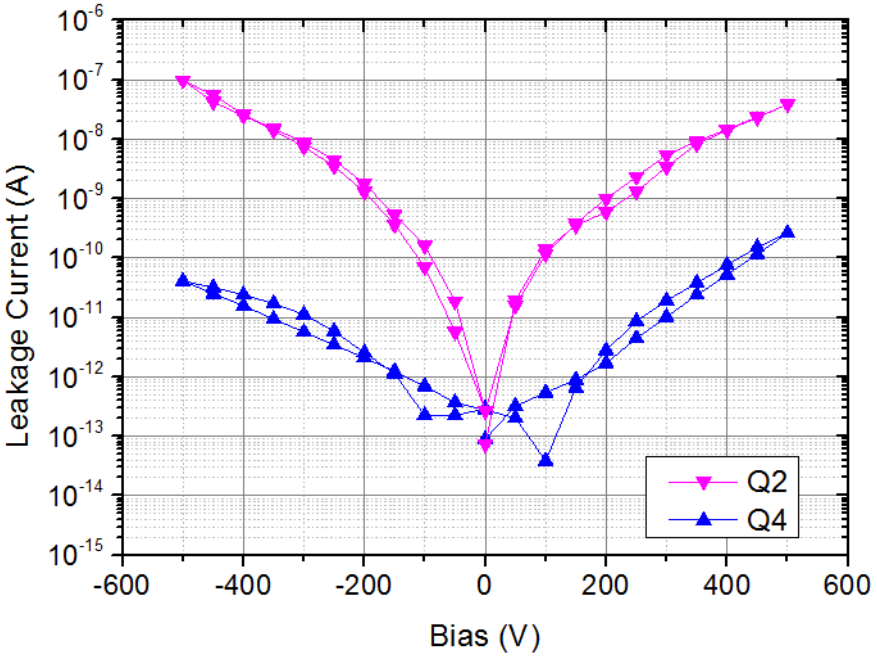


- *I-V* symmetric characteristics for Q1, Q2, Q3, Q4 being Ohmic at lower voltages while having a V^n behaviour at higher voltage.
- Damaged quadrants Q1 and Q2 show higher leakage current. Q4 still looks fine.
- Value of total leakage current matches that found during the experiment.

Leakage Current [pcCVD_DB]



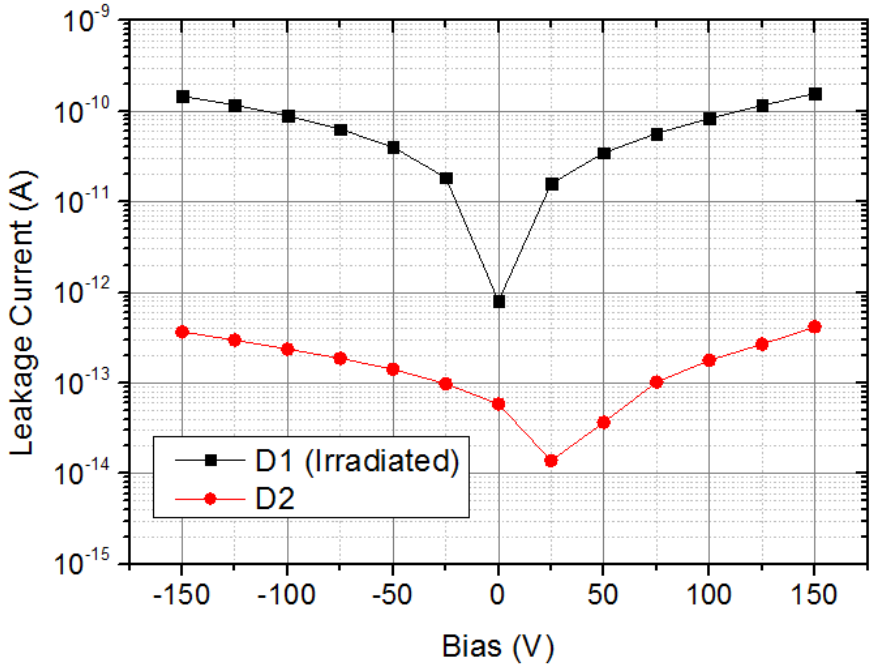


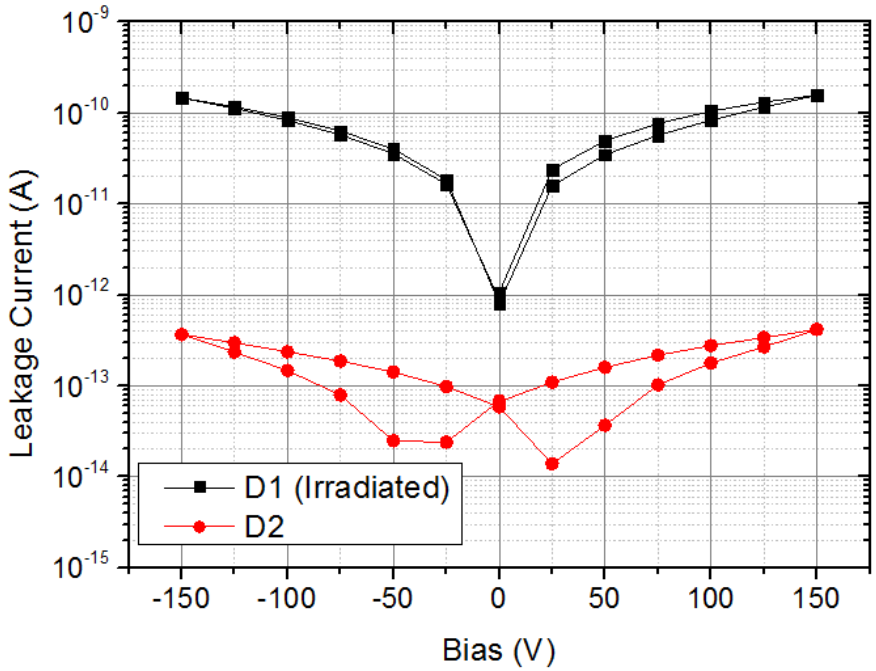


- *I-V* asymmetric characteristics for Q1, Q3, Q4 probably due to a non-uniform material surface or to a surface preparation that gives a non-uniform metal adhesion on diamond, providing slightly different junction barriers.

Ref: Di Benedetto et al. **10** [2001] 698-705

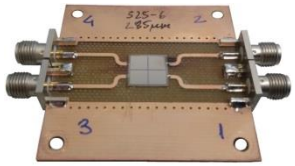
Leakage Current [scCVD_CT]

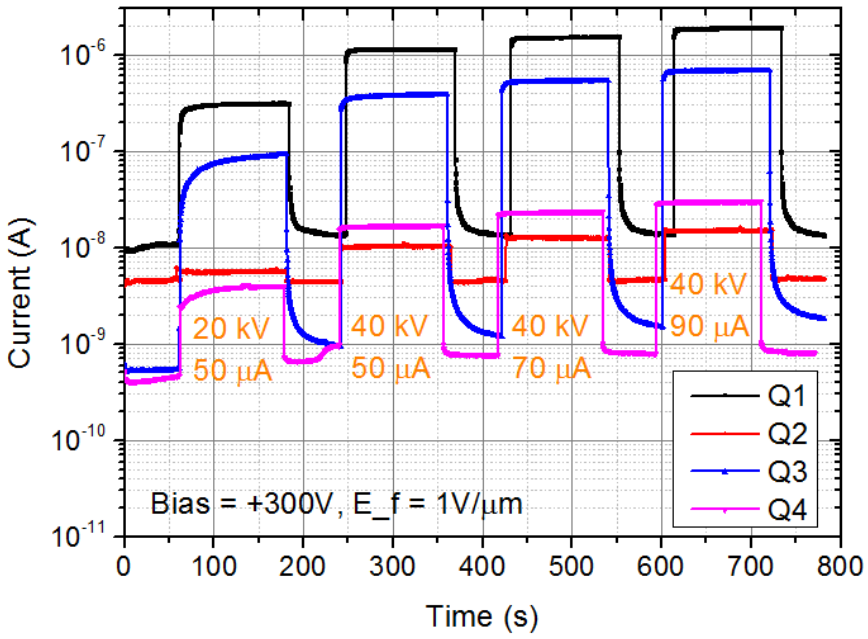


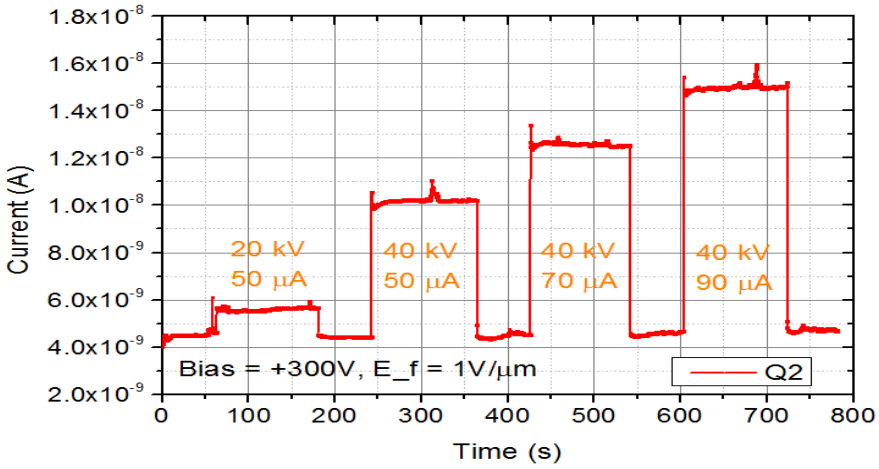


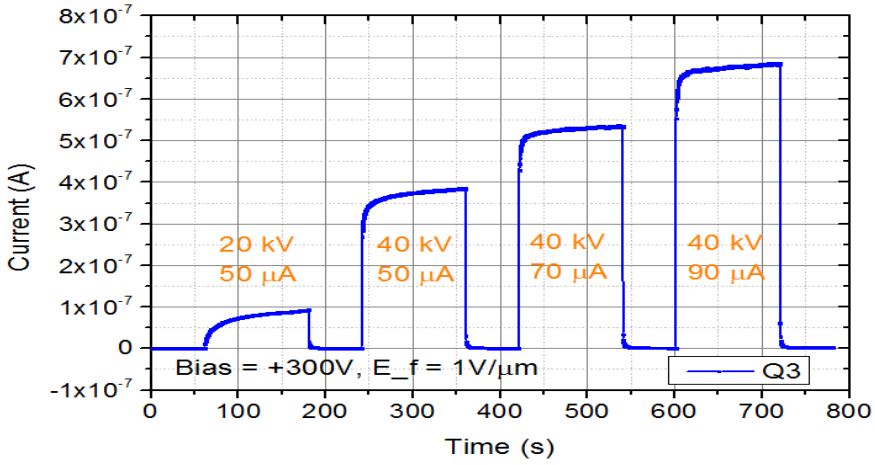
- Hysteresis effect (storing of charge within the material) for the device D2.
- The Irradiated device D1 show higher leakage current and *I-V* symmetric characteristics.
- The device D2 (not irradiated) exhibits an offset.

X-rays Photocurrent [pcCVD_CT]



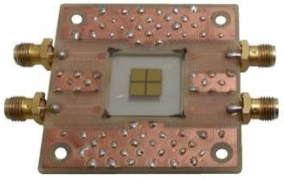


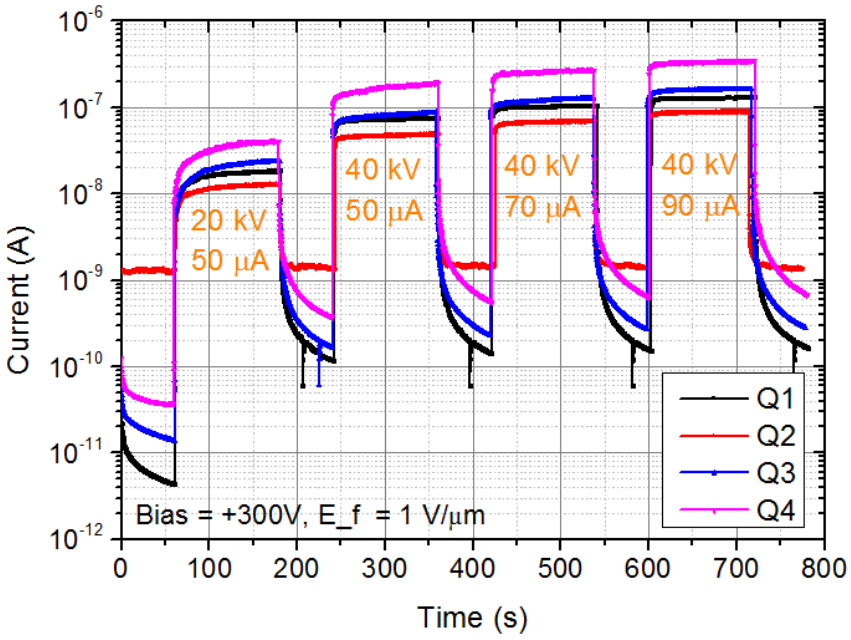


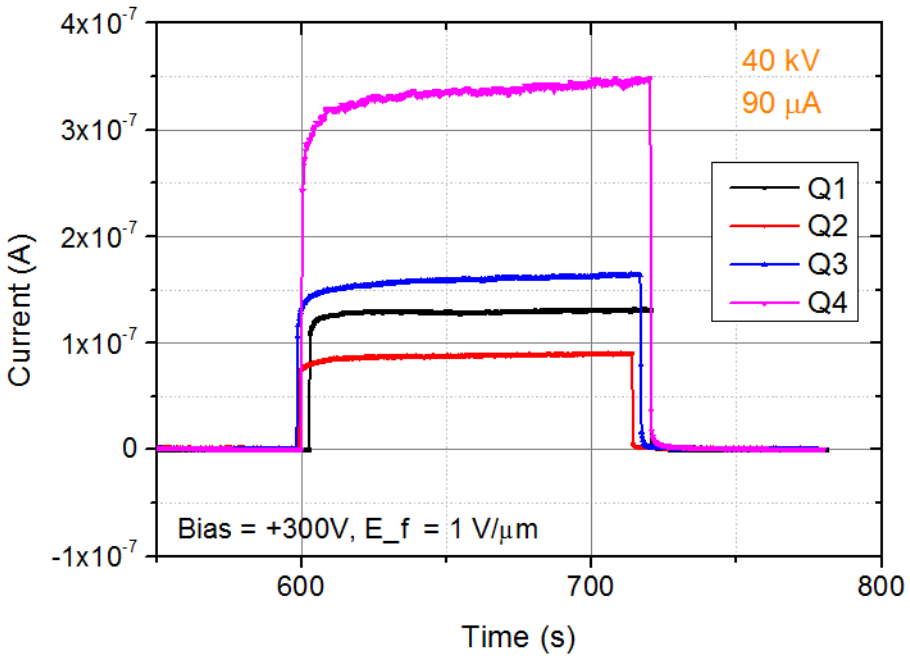


- Q2 and Q4 exhibit the lowest S/N.
- Q3 and Q4 have the lowest leakage current.
- Photocurrent instability from the damaged electrode.
- Photocurrent values saturate for t > 120 s.

X-rays Photocurrent [pcCVD_DB]

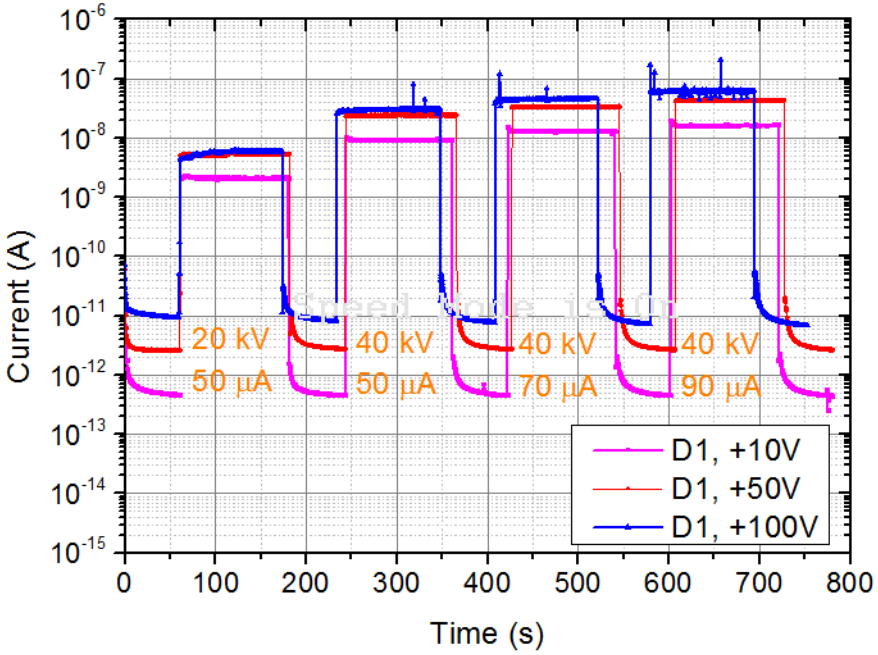


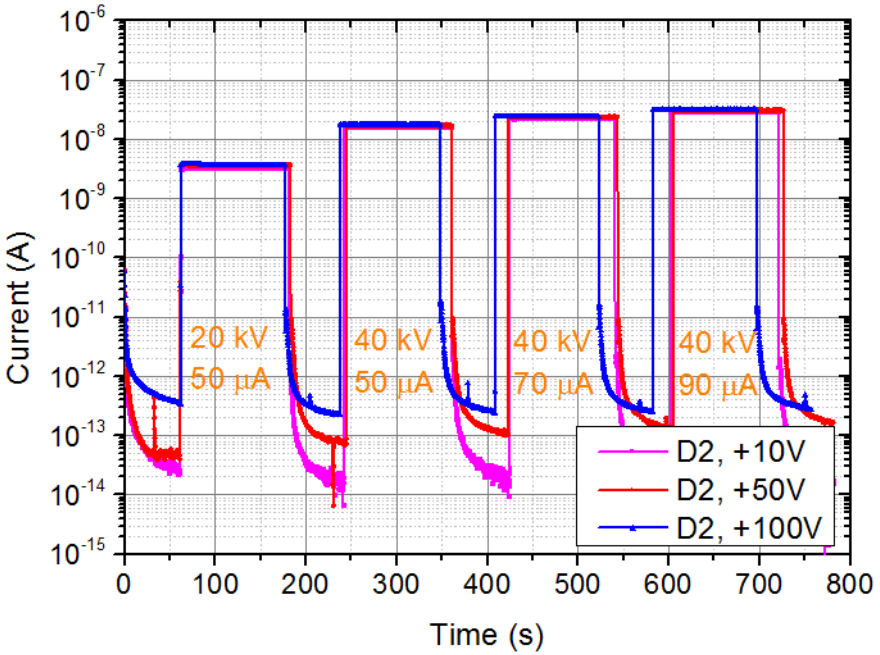




- Q2 exhibits two orders of magnitude higher value of leakage current.
- Photocurrent values are in the same order of magnitude.
- Photocurrent values saturate for $t > 120$ s.

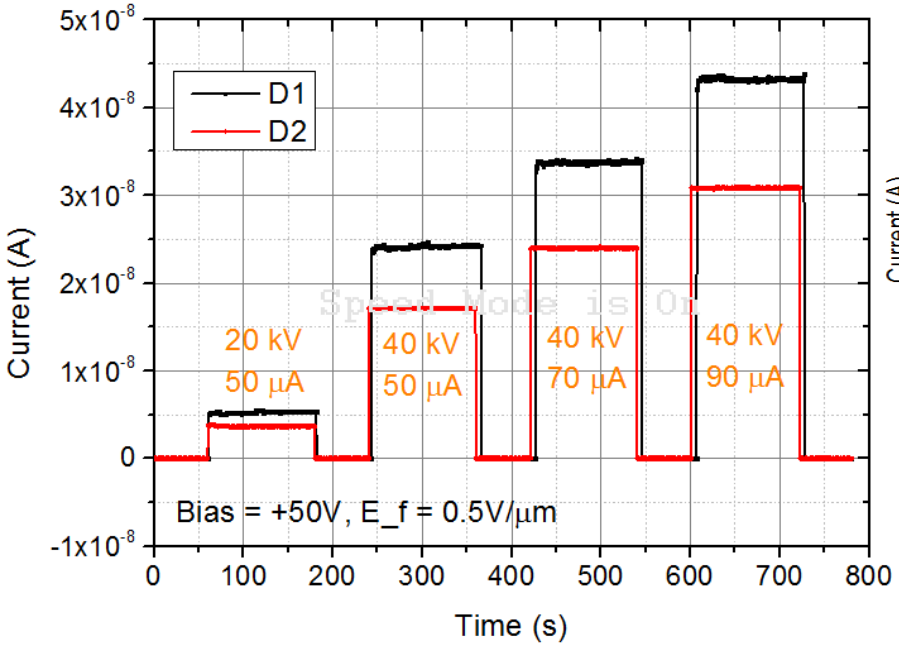
X-rays Photocurrent [scCVD_D1-D2]

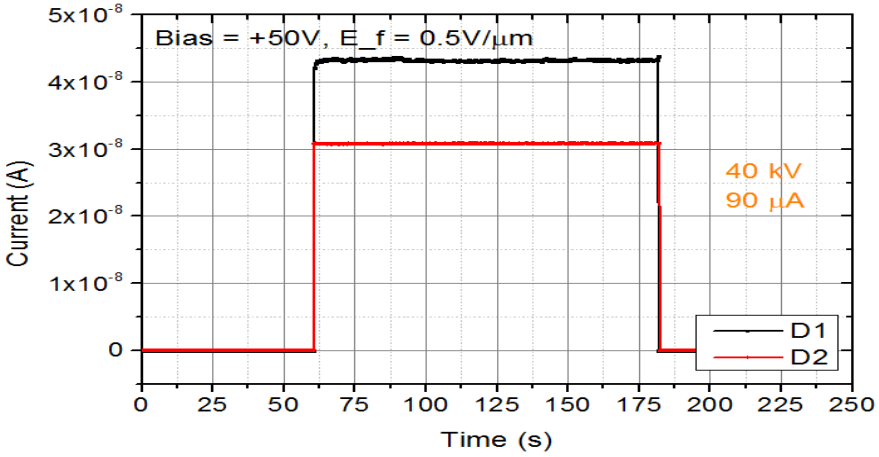


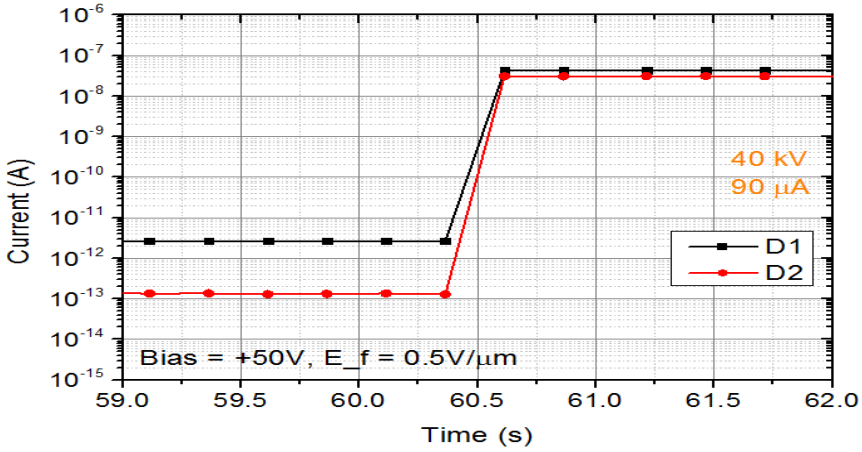


- D1 exhibits the lowest S/N.
- D1 exhibits one order of magnitude higher leakage current.
- For V > +50V, D1 photocurrent instability possibly due to the damaged electrode.
- D2 shows full charge collection efficiency (CCE) for V < +50V.

X-rays Photocurrent [scCVD_D1-D2]



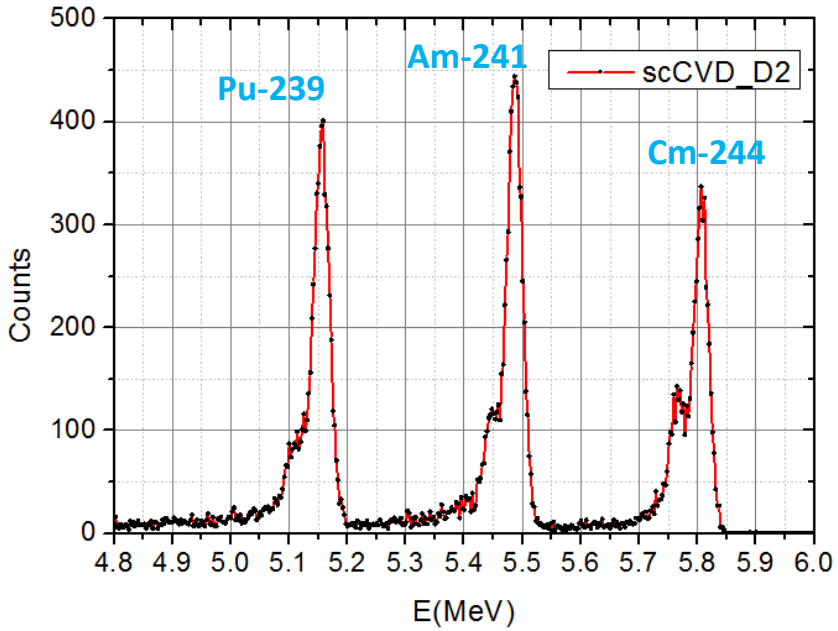




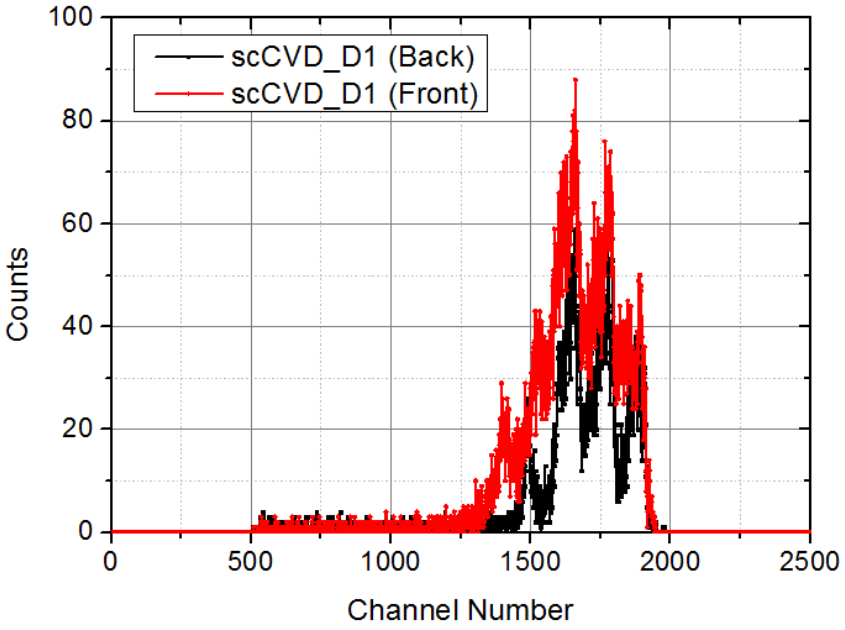
In spite of the rough preparation of the electrodes:

- D2 shows excellent stability of the signal.
- D2 exhibits very fast saturation of the induced signal for t < 0.5 (limit of the electrometer).

Alpha Detection [scCVD_D1-D2]

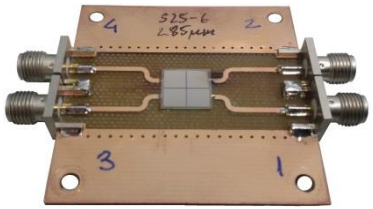


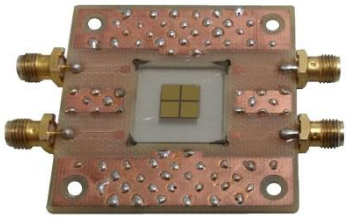
Radionuclide	Alpha particle energy [MeV]	Intensity [%]
Pu-239	5.105	11.5
	5.143	15.1
	5.155	73.4
Am-241	5.388	1.4
	5.443	12.8
	5.486	85.2
Cm-244	5.763	23.3
	5.805	76.7



- Both scCVD detectors were biased at +100V.
- scCVD_D1 shows very low resolution probably linked to the high value of the voltage applied.
- scCVD_D2 exhibits a resolution below 0.8%.

Devices Characteristics



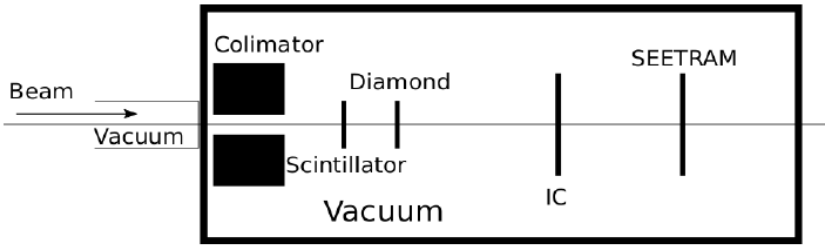


Quad.	L. Current (A)	Current (A)	S/N	Sat. Time (s)
Q1	1.2E-8	1.9E-6	158	> 120
Q2	4.6E-9	1.5E-8	3	> 120
Q3	5.5E-10	6.9E-7	1254	> 120
Q4	4.7E-10	3.0E-8	63	> 120
Q1	4.3E-12	1.9E-8	4418	> 120
Q2	1.3E-9	1.3E-8	10	> 120
Q3	1.4E-11	2.4E-8	1714	> 120
Q4	3.7E-11	4.0E-8	1081	> 120
D1	2.7E-12	4.3E-8	15925	< 5
D2	1.3E-13	3.1E-8	238461	< 0.5

Future Plans [PADCOM, LNS 2017]

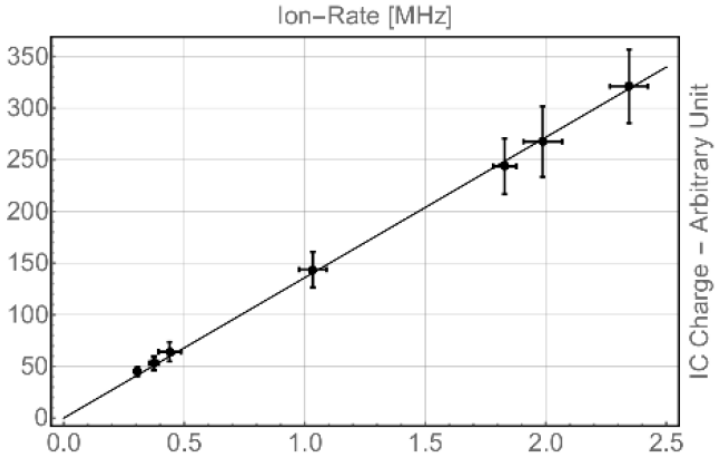
The high primary beam intensities expected at the Super-FRS impose the development of a new device for beam intensity measurements up to 10^{11} Hz.

Since a single device unit is not able to cover the full range of expected beam intensities, a new PArticle Detector COMbination is currently under development at GSI.



The new device will be tested with a ^{12}C @ 62 MeV/u beam at different rates 10^3-10^{10} Hz.

The IC will be precisely calibrated (within few % of uncertainties) by using a scCVD diamond sensor which guarantees radiation hardness and ability to operate up to 10^7 Hz. A SEETRAM, currently under development, is foreseen to measure the highest possible rates up to 10^{11} Hz.



Conclusions

- Radiation damages produce low electric current signals lowering the Signal-to-Noise ratio.
- The leakage current looks mainly affected by the electrode condition. Irradiated electrodes exhibit *symmetryc I-V* characteristics.
- Poor electrode condition leads to instability of the photocurrent.
- scCVD_D1 seems to be not damaged. However its generated photocurrent seems to be slightly instable that is likely due to the low quality electrode preparation. Applying an electric field of 1V/µm, it shows very poor alpha spectroscopy properties.
- scCVD_D2 shows very fast response to the X-rays and stability of the photocurrent during the irradiation which makes it a promising dosemeter for radiotherapy applications. The resolution under alpha irradiation is also very good.
- Further investigation of the bulk properties of the irradiated diamond samples is required to better understand the relation between type of radiation interaction and signal response.

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GSI Helmholtzzentrum für Schwerionenforschung GmbH

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Facility for Antiproton and Ion Research in Europe GmbH