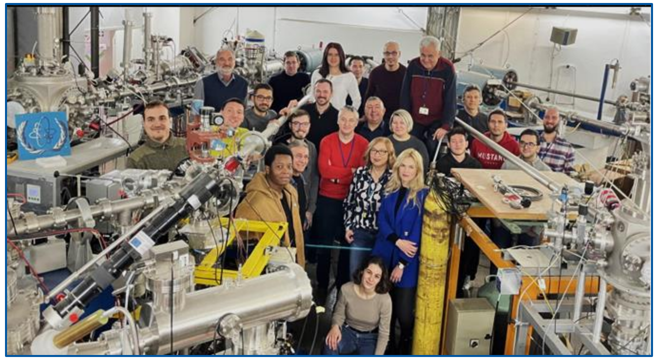
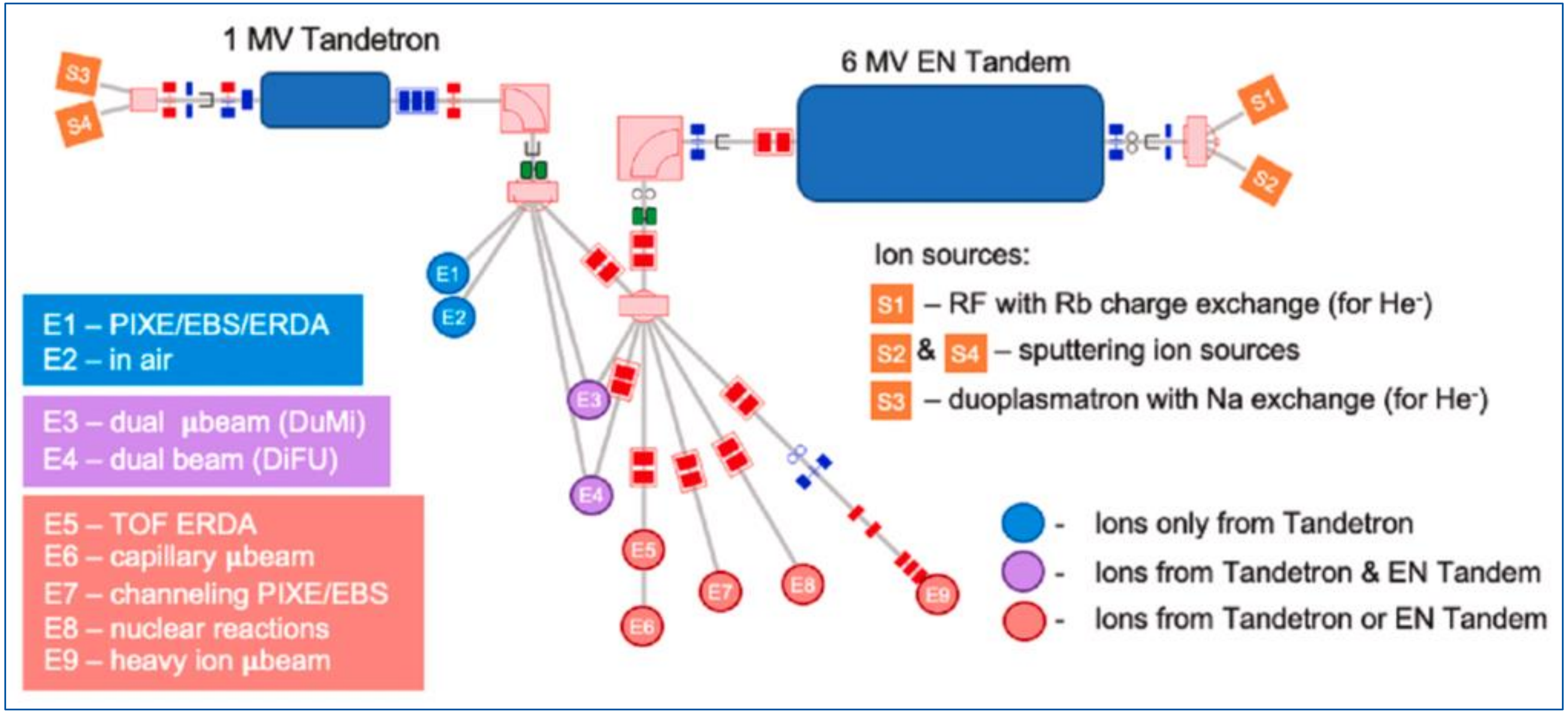
Response of diamond radiation detectors operated at high electric fields

Georgios Provatas, Milko Jakšić, Donny Cosic, Karla Ivanković Nizić and Michal Pomorski

The RBI-AF: Laboratory For Ion Beam Interactions

DRD3





CERIC Central European Research Infrastructure Consortium

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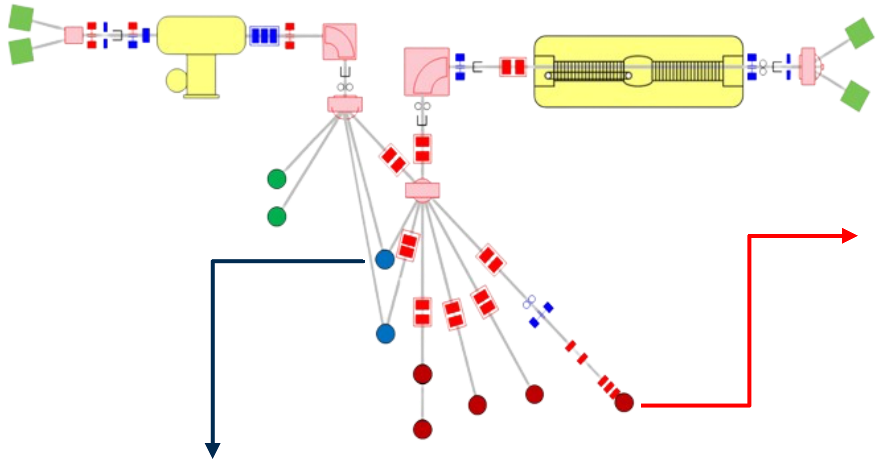
EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

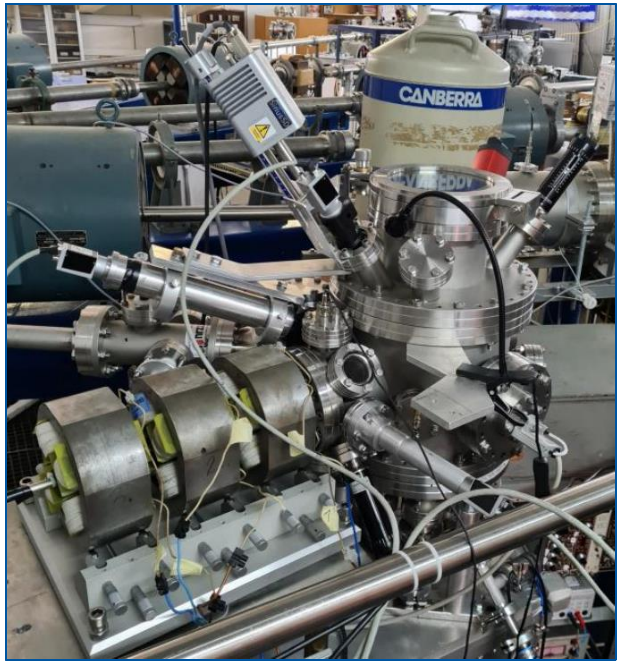
RI ANA

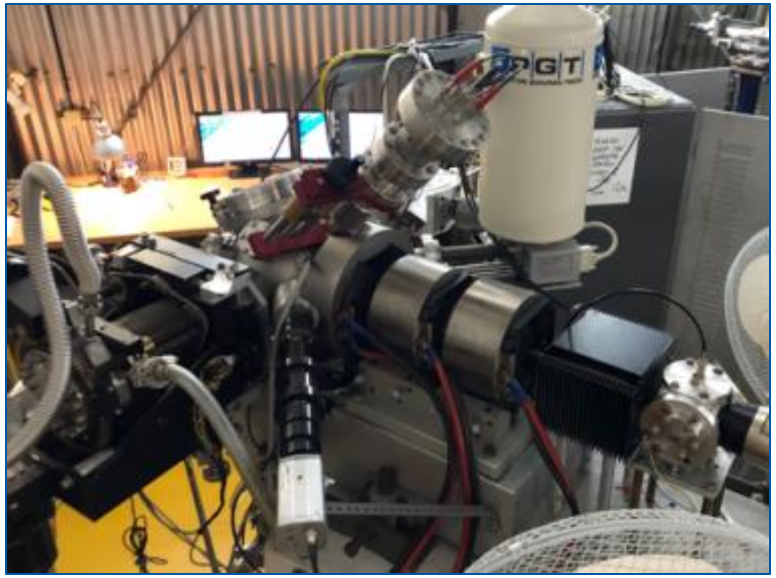
Ion Beam Induced Charge (IBIC) microscopy

DRD3

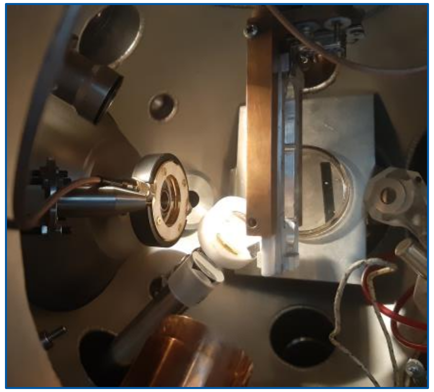


Dual Microprobe





The RBI microprobe

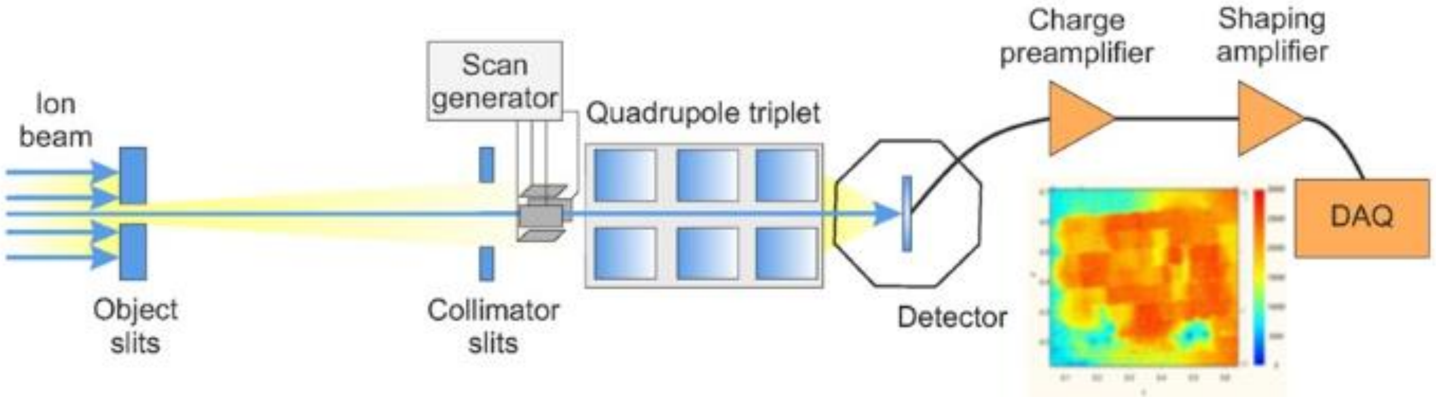


- Beam spots down to 120 nm
- Precise irradiations from low (few Hz) to high current (nA) modes
- Scanning and imaging possibilities of areas up to several mm
- In-house DAQ Software SPECTOR
- Target positioning using nm precise piezo-stages
- Alignment of samples for angular resolved studies/channeling
- Available temperatures from 20K up to 700 ^{o}C
- Probing and damaging using two simultaneous microbeams

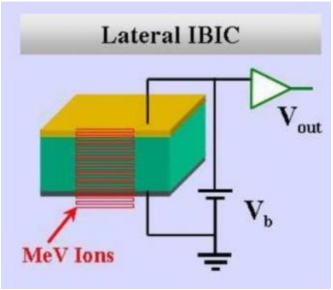
Ion Beam Induced Charge (IBIC) microscopy

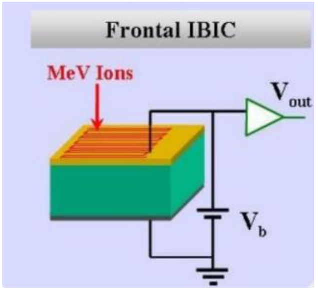
DRD3

In Ion Beam Induced Charge (IBIC) microscopy, the charge collection properties of semiconductor devices are studied. With IBIC the detectors response, i.e. the CCE, is obtained along the whole volume of the device.

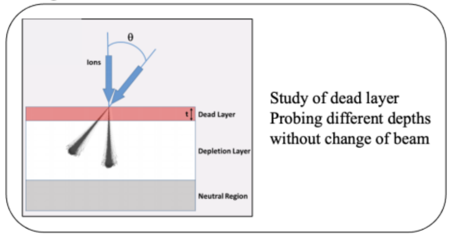


IBIC variations

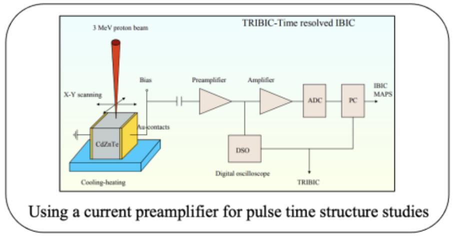


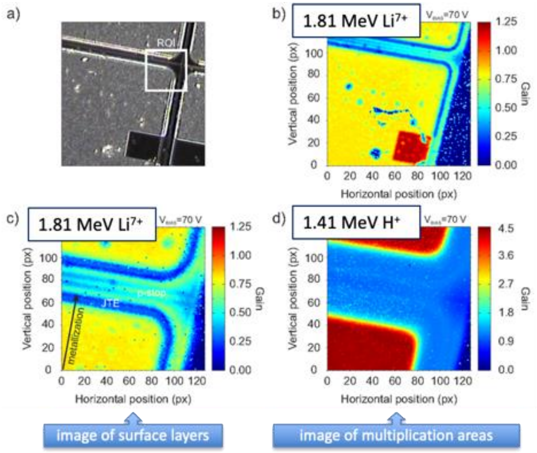


Angle resolved IBIC



Time resolved IBIC





By tuning the beam, **depth-profiling** is possible.

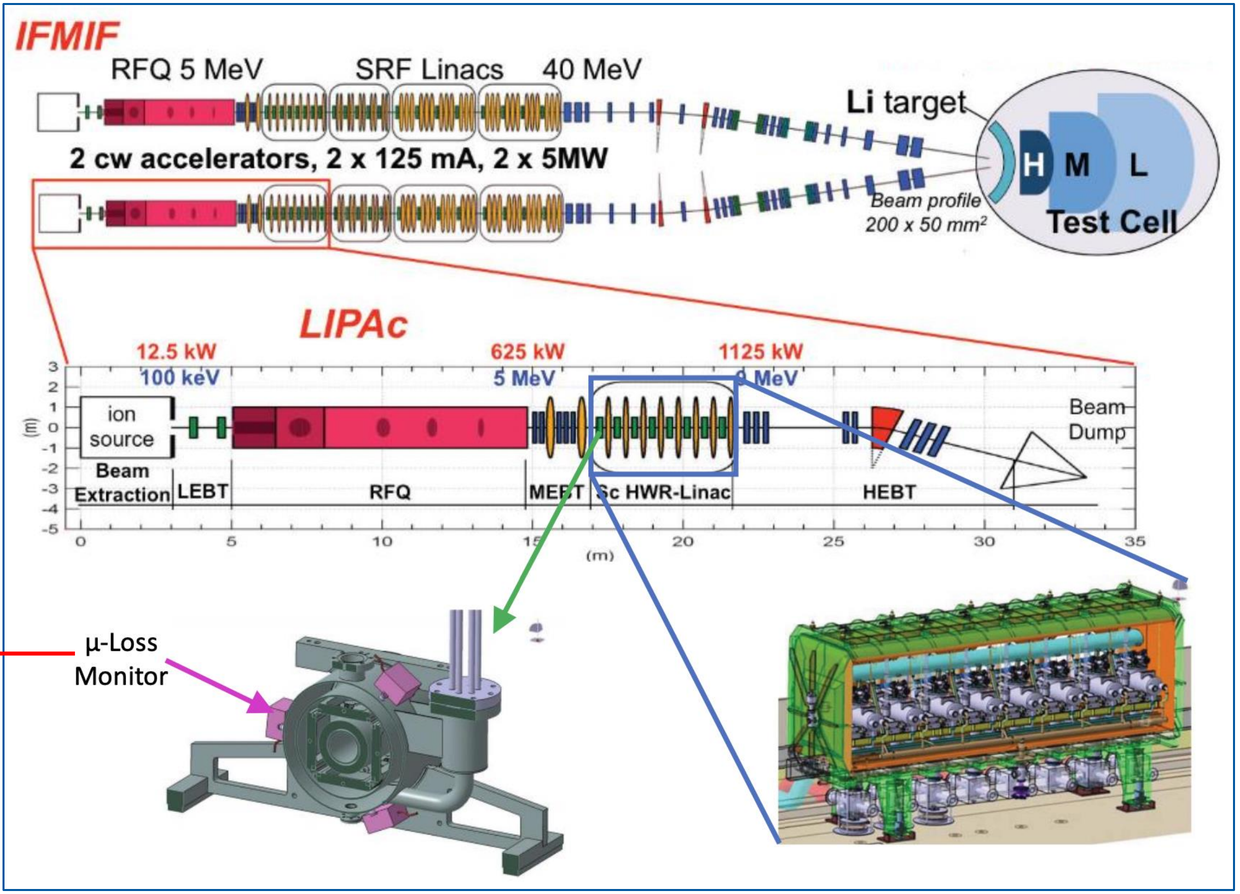
Effective intrepad distance & gain supression LGADs

M. Jakšić et al., Front. Phys., 2022

Study of Diamond detectors at cryogenic temperatures

DRD3

To study effects generated by fusion on materials in the immediate surrounding of the reactor core in ITER, a dedicated International Fusion Material Irradiation Facility – DEMO Oriented Neutron Source (IFMIF-DONES) is being constructed to produce similar neutron fluence of 10^{18} n/sm^2.



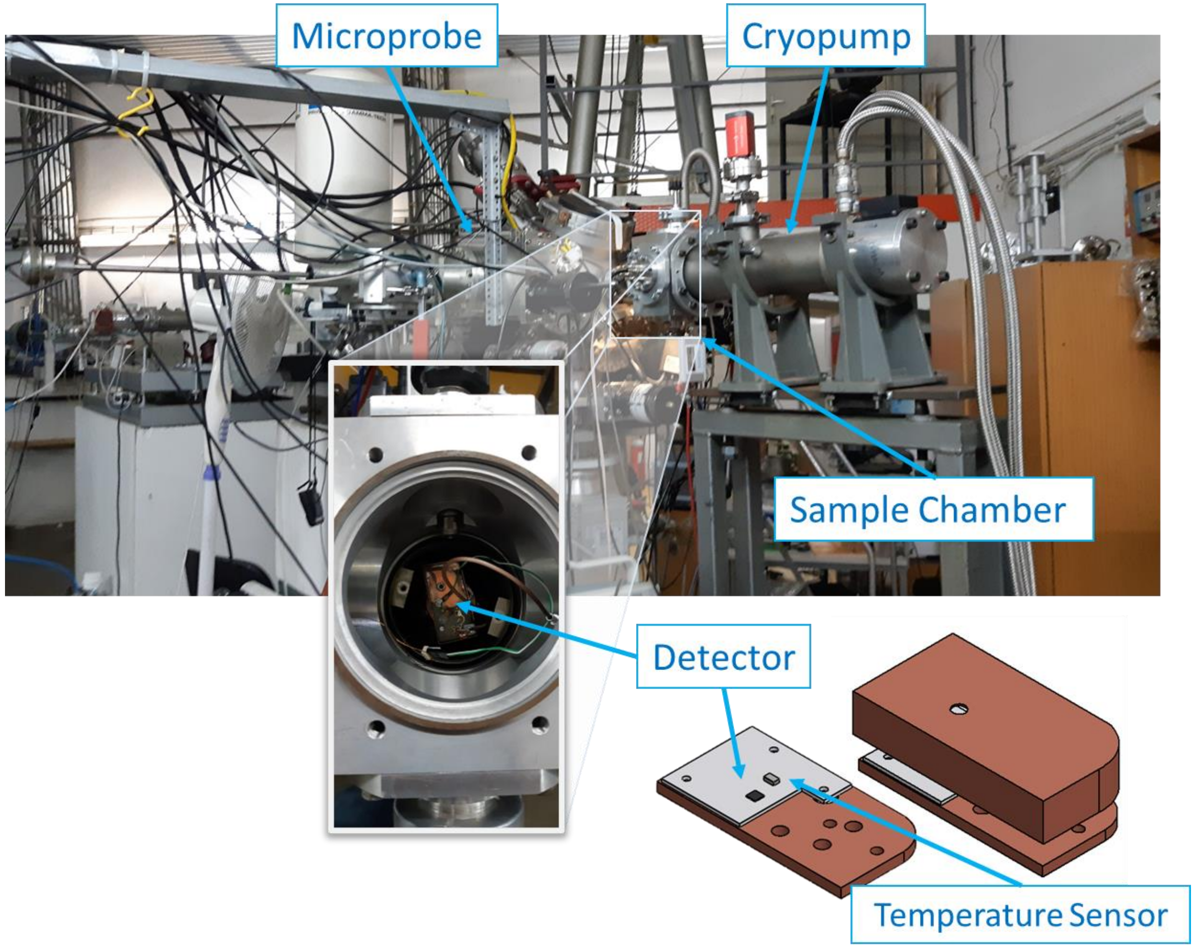
- **High radiation tolerance**
- **Stability at cryogenic temperatures**
- **Fast response time**
- **High sensitivity to neutrons and lower sensitivity to γ-rays**

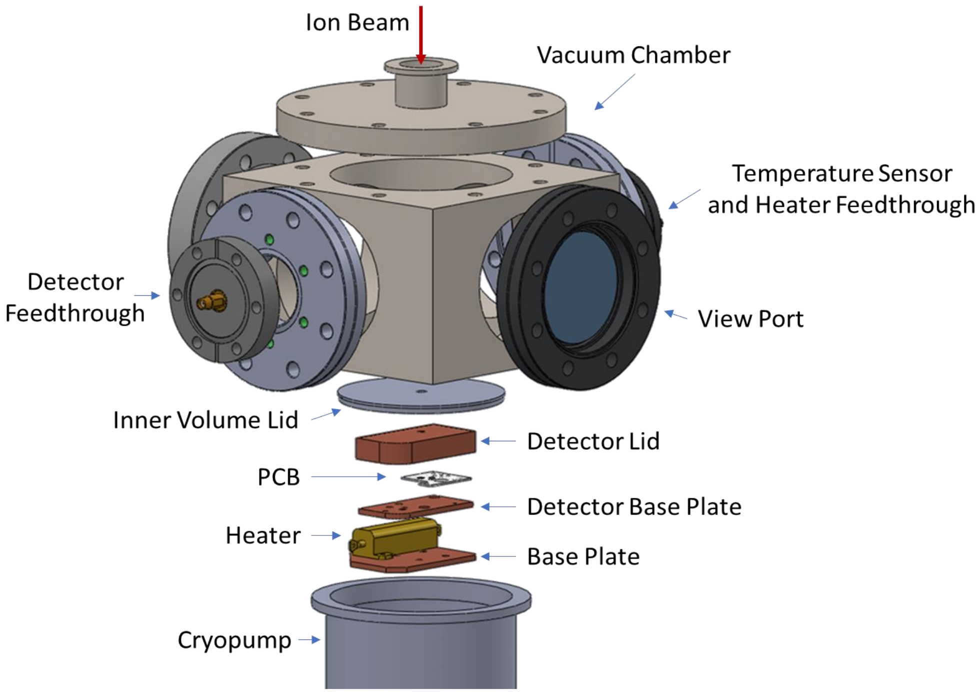
scCVD diamond detectors

Study of Diamond detectors at cryogenic temperatures

DRD3

Two scCVD diamond crystals were obtained. The detectors were fabricated at LIBI and at CEA-LIST. A portable cryogenic setup was developed.





300 um **40 um**

Study of Diamond detectors at cryogenic temperatures

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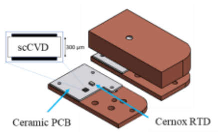
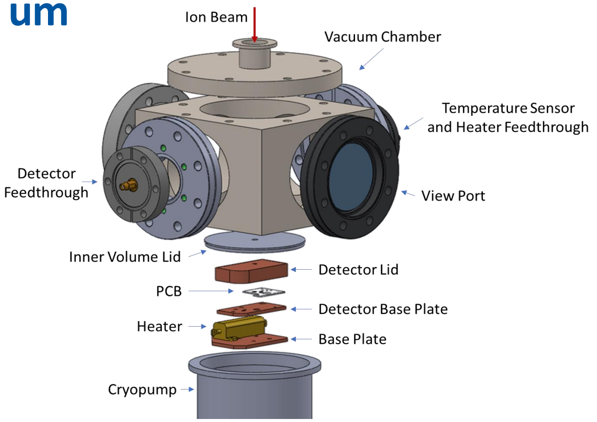
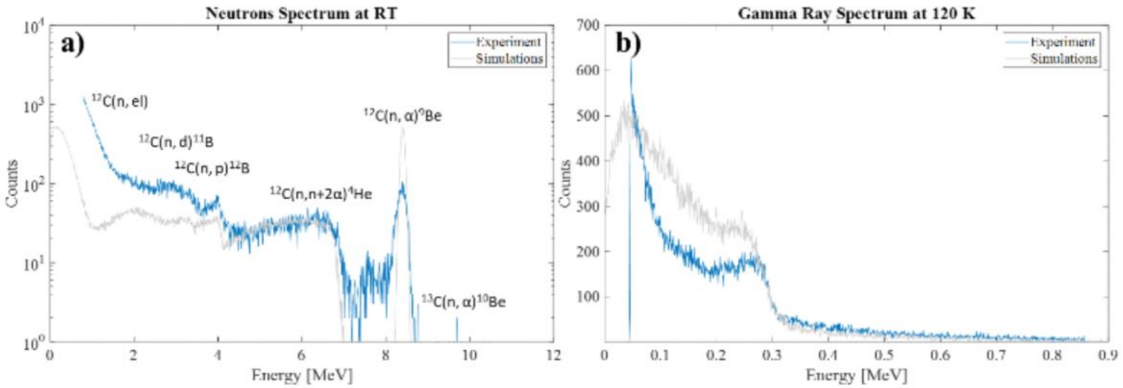
Using the 300 um thick detector, measurements were carried out in neutron and gamma ray fields.

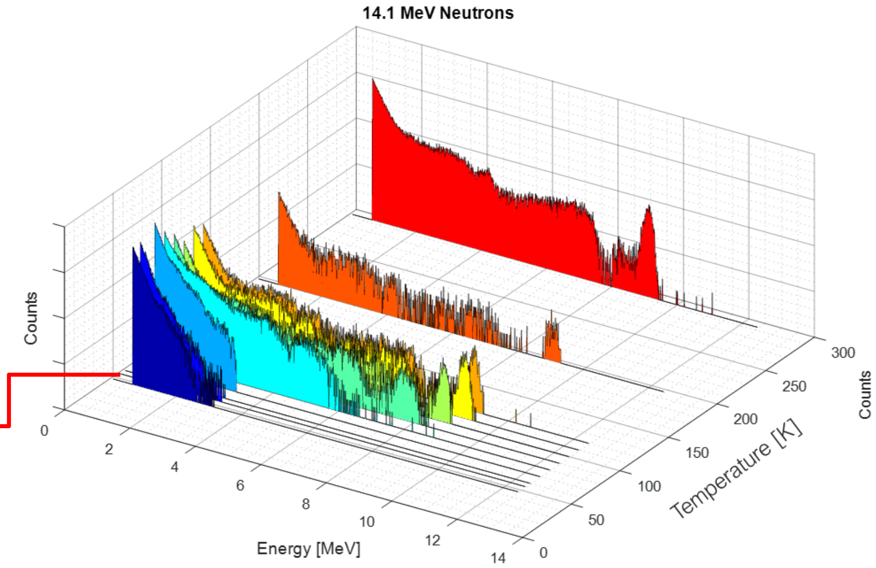


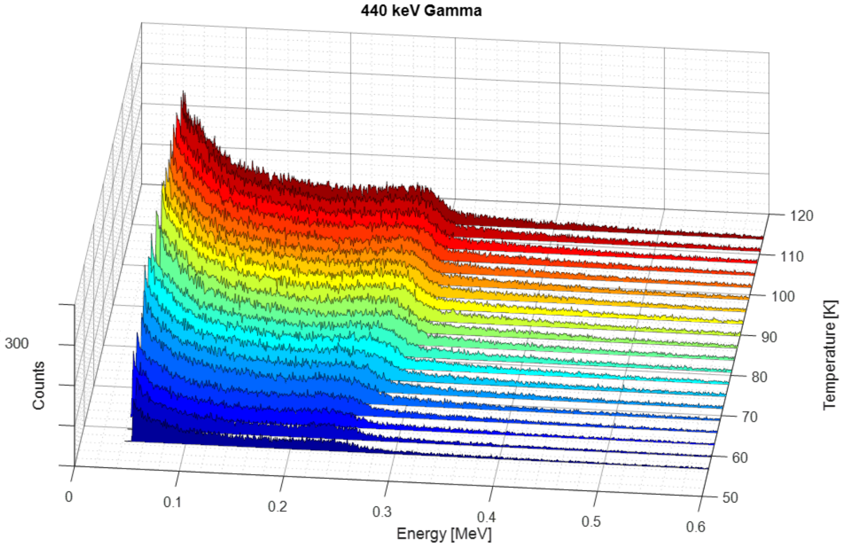
300 um





Room temperature pulse height spectra



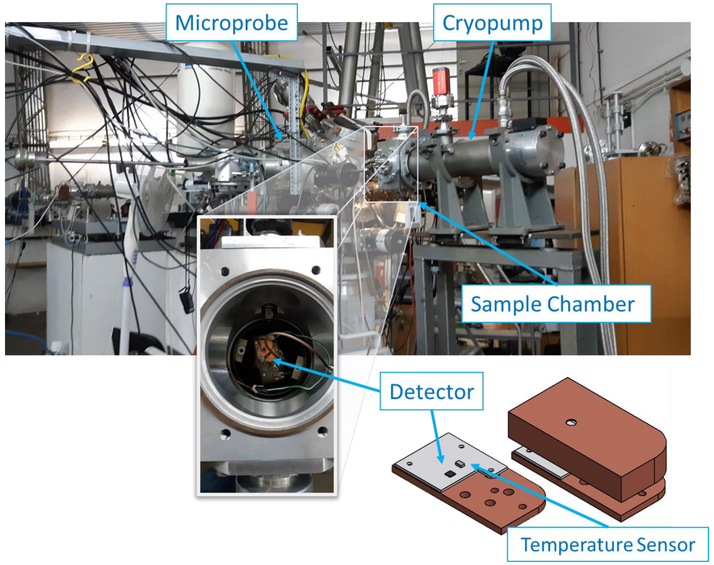


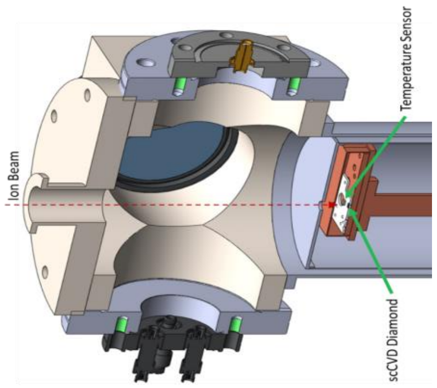
Drastic degradation of detectors signal on neutrons below 120 K !

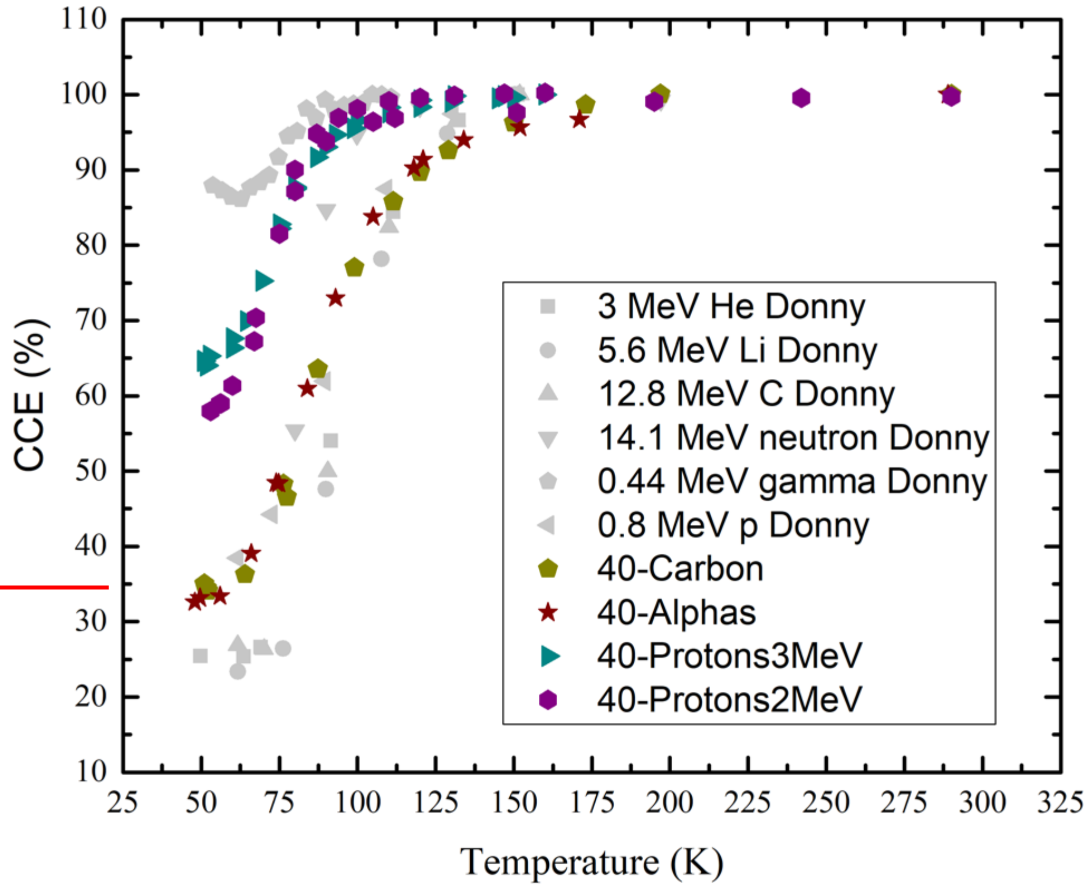
Study of Diamond detectors at cryogenic temperatures

DRD3

A systematic IBIC study was carried out at the RBI microprobe using a thick and a thin detector.





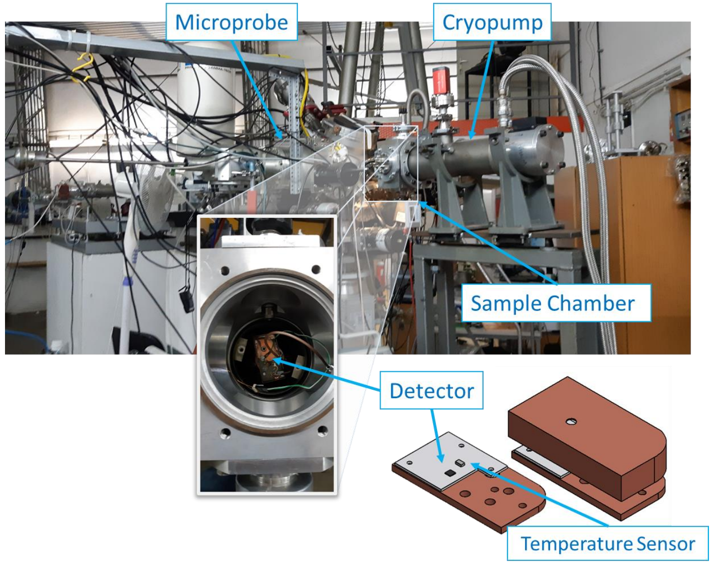


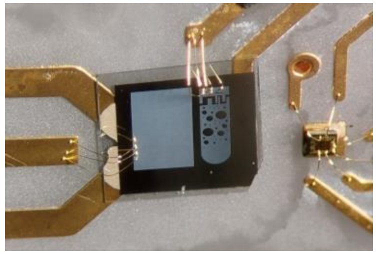
Lattice energy is not enough to break the excitons formed below 120 K. As such less charge is collected.

Signal Recovery at cryogenic temperatures

DRD3

A systematic IBIC study was carried out at the RBI microprobe using a thick and a thin detector.





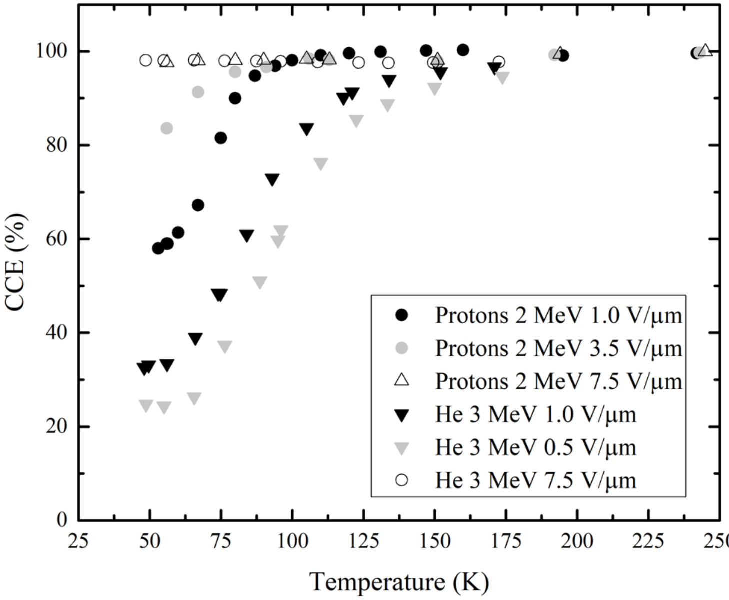
40 um

Voltages up to **10 V/um**

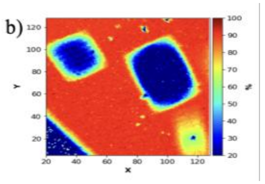
Could be applied

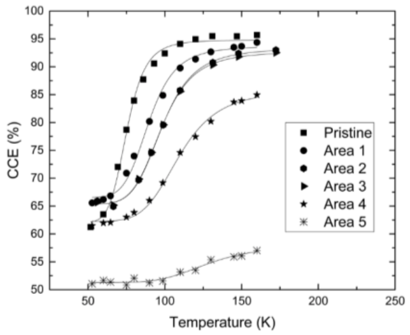
Recovery of signal

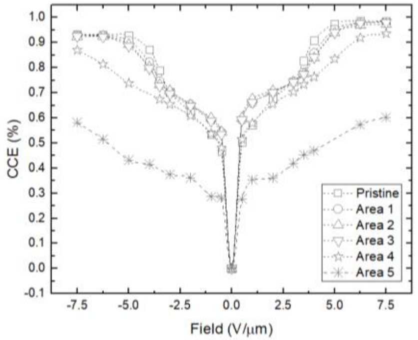
Above 7.5 V/µm

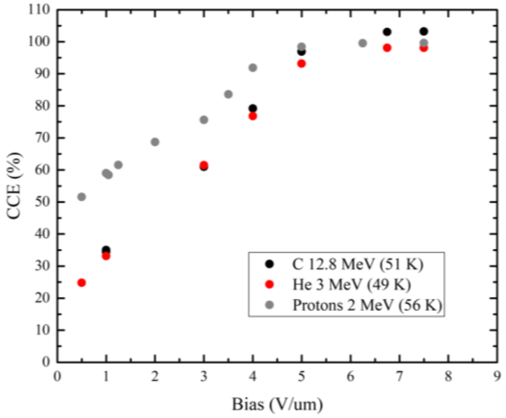


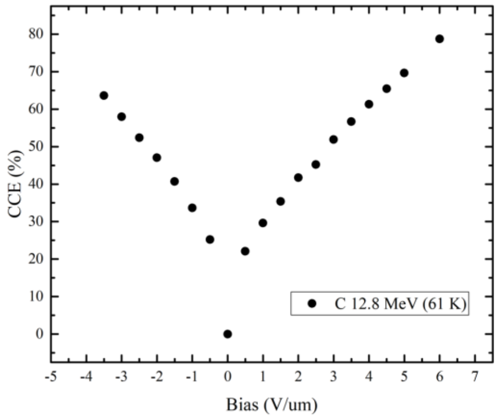
Radiation hardness study of scCVD diamond at cryogenic temperatures











Study of Diamond detectors at cryogenic temperatures

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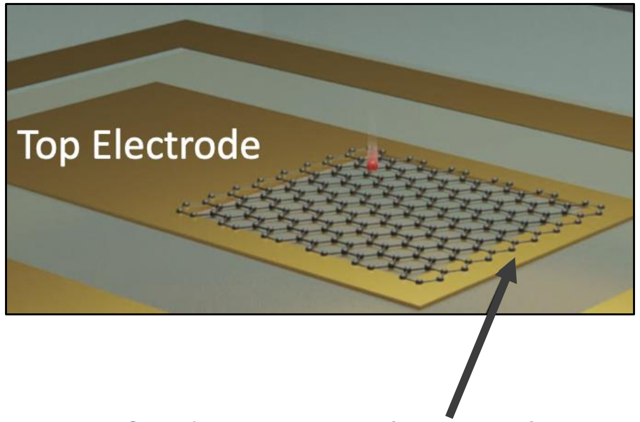
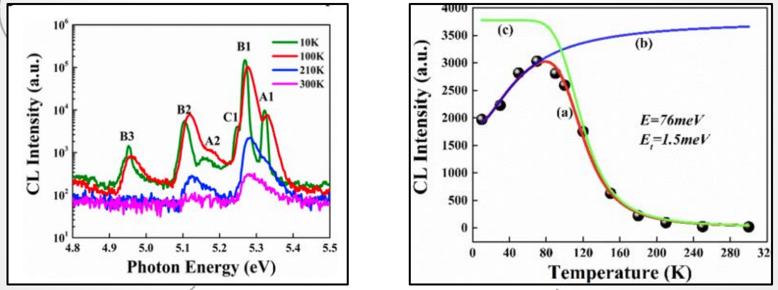
Future steps

Investigation of temperature dependence of ion-luminescence (IBIL) spectra of scCVD under high electric field

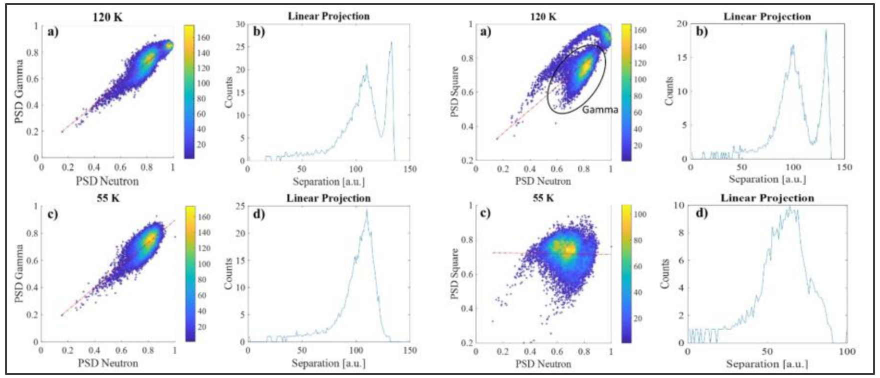


Fabrication of a detector with a graphene top electrode



Y. Chen et al., "Investigation of Excitonic Recombination in Single-Crystal Diamond with Cathodoluminescence spectroscopy", Journal of Luminescence 2020

Investigate the capability PSD methods in mixed neutron, gammas using signals at high (>7 V/um) fields



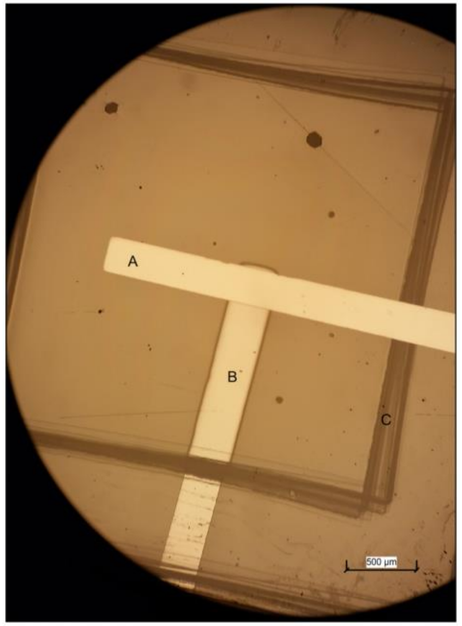
So far, PSD methods can successfully discriminate gammas/neutrons in room temperature. However, are limited below 120 K

D. Cosic et al., "scCVD diamond detector response to fast neutrons and γ-rays at cryogenic temperatures", IEEE 2024

Charge multiplication in thin scCVD membranes

DRD3

N. Skukan et al., Charge multiplication effect in thin diamond films , Appl. Phys. Lett. 109, 043502 (2016)



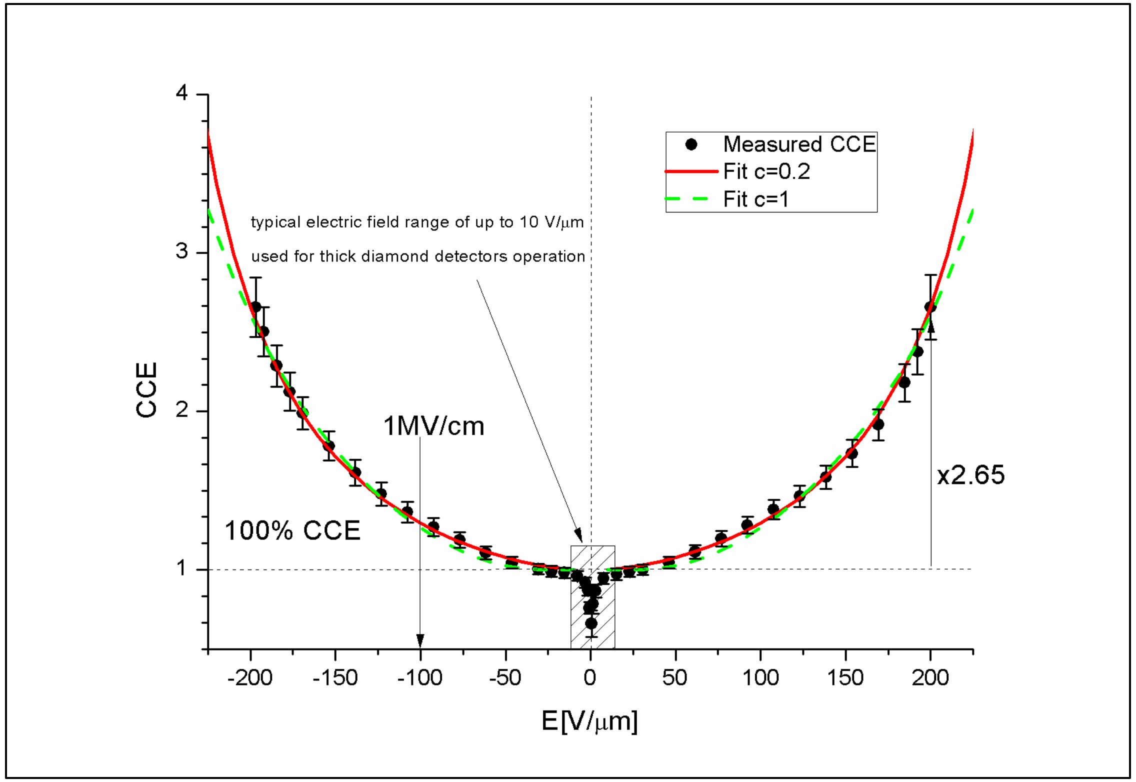
A 3.25 µm thick diamond membrane was used.

Minimize the possibility of uncontrolled dielectric breakdown

Two, 300 µm wide Al strips were used for metallization

Minimize the total number of defects using small area

Charge multiplication occurs for electric fields above 30 V/µm



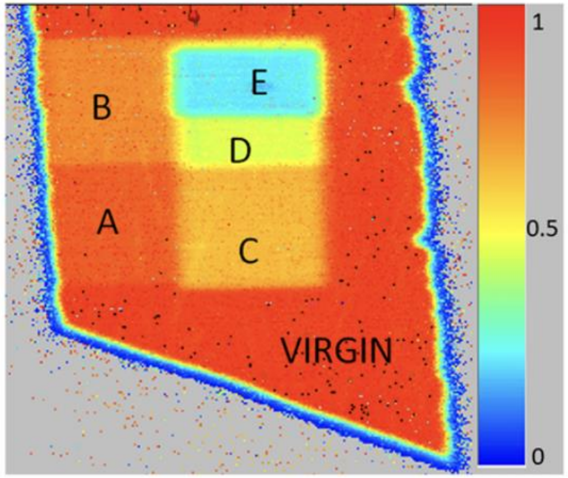
18 MeV Oxygen Ions were transmitted through the detector depositing 10 MeV.

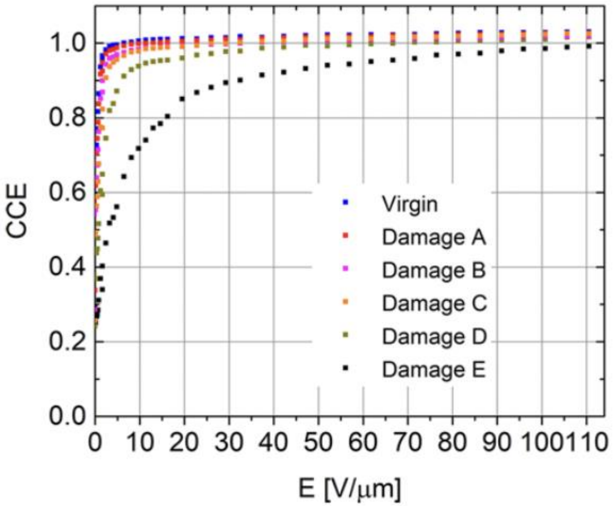
Indicates that high ionization density perhaps stimulates charge multiplication

Charge multiplication in thin scCVD membranes

DRD3

N. Skukan et al., Enhanced radiation hardness and signal recovery in thin diamond detectors , AIP Advances 9, 025027 (2019)





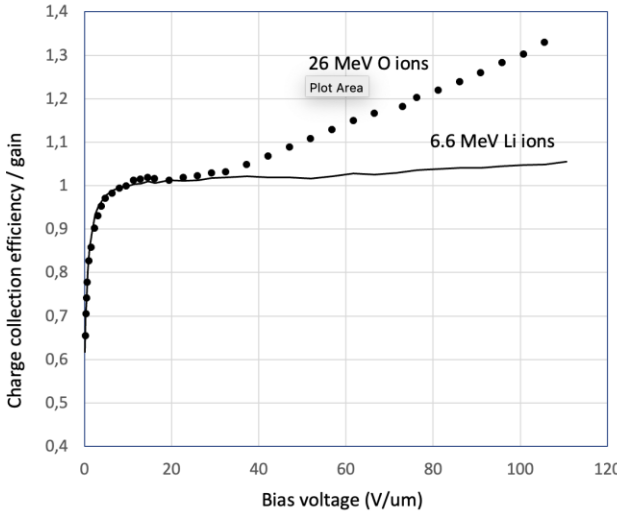
A 6.15 μm thick diamond membrane was used.

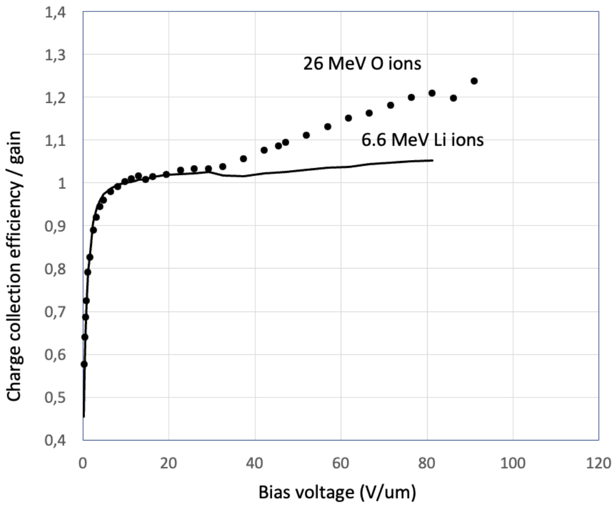
Damaged up to 10^{18} vac/cm^3

IBIC probing with 2 MeV protons shows signal recovery

However, **no multiplication up to 110 V/μm**

Charge multiplication for both polarities above 30 V/μm





Probing with 26 MeV O ions (range 8.71 μm, dE/dx 2600 keV/μm).

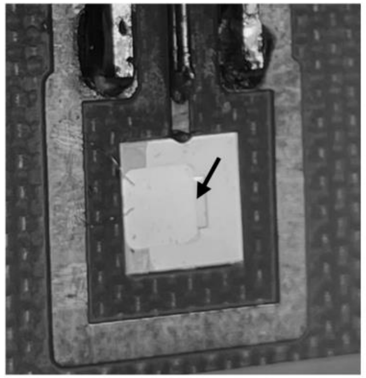
Clear gain of 30% detected for electric field of 100 V/μm

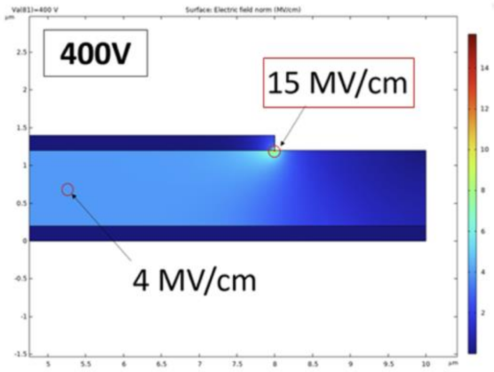
Probing with 6.58 MeV Li ions (range 7.02 μm, dE/dx=740 keV/μm)

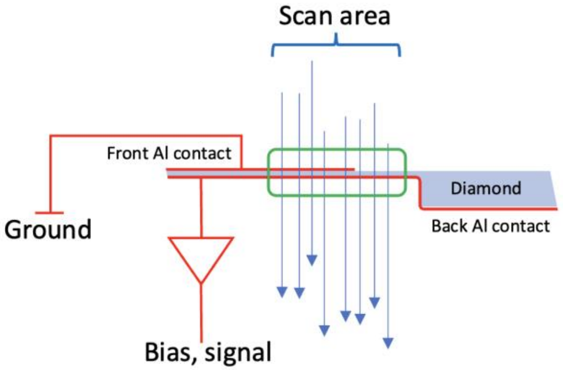
Small statistically relevant sign of charge multiplication (<5%)

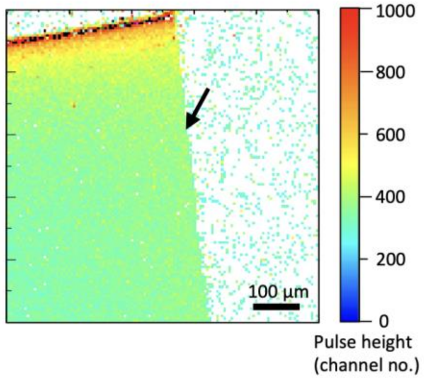
Charge multiplication in thin scCVD membranes

DRD3

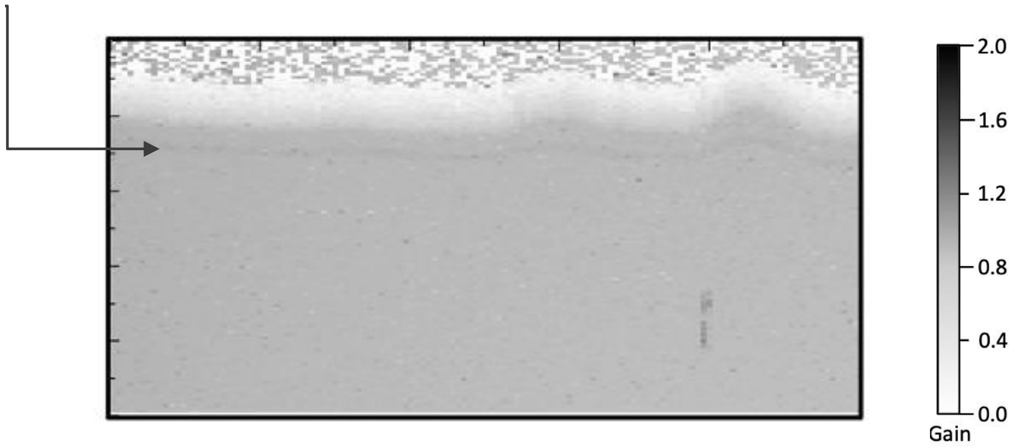


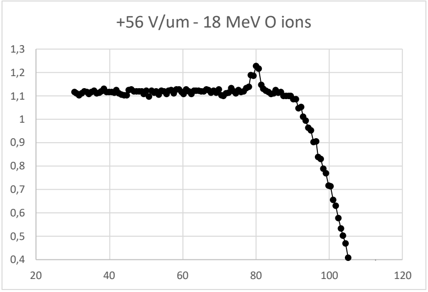


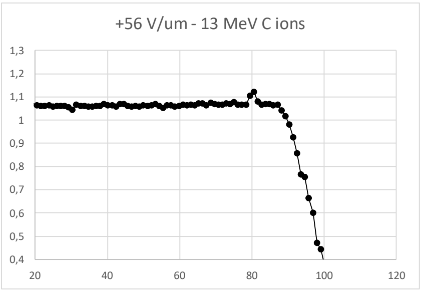


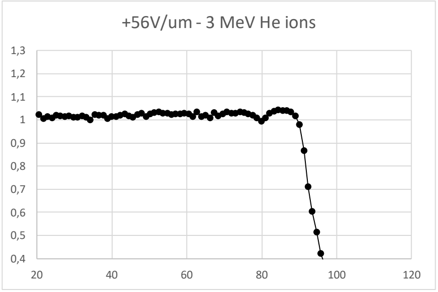


Charge multiplication for positive bias









A 3.55 µm thick diamond membrane was used.

Probed with 18 MeV O, 13 MeV C, 3 MeV He and 1 MeV H

Maximum applied voltage **+70 V/µm** and **-20 V/µm**

Regions of even higher electric field should exist

along the edge of the frontal contact

More than 20% gain for 18 MeV O ions

For 13 MeV C ions the gain is 10%, while no gain for He ions.

The full charge collection efficiency extends almost 10 micrometers into the contact free region

Charge multiplication in thin scCVD membranes

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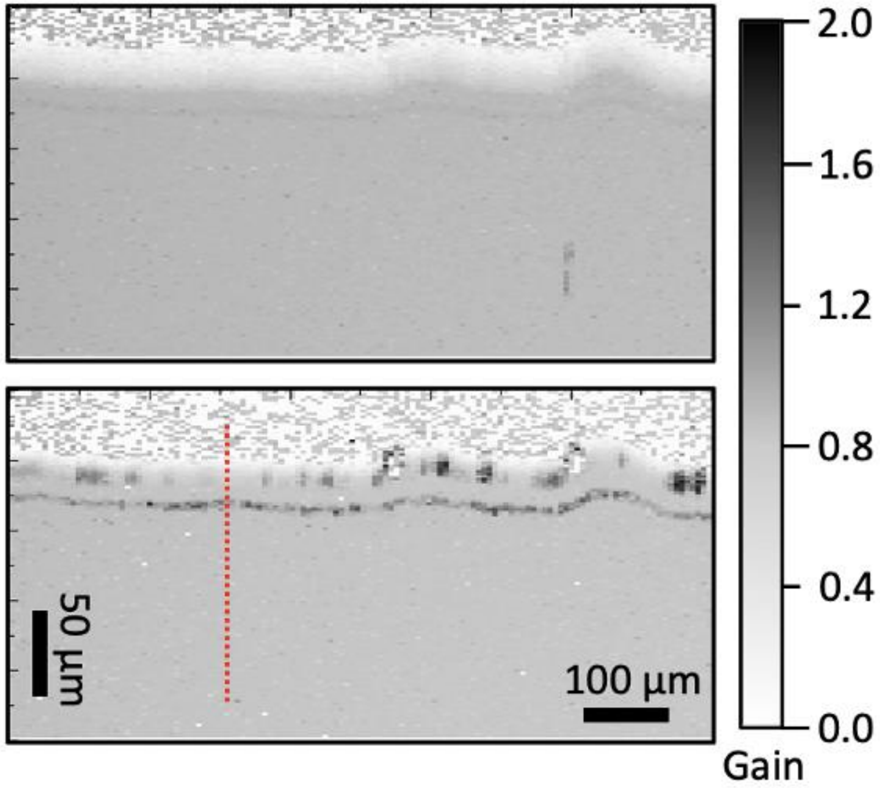
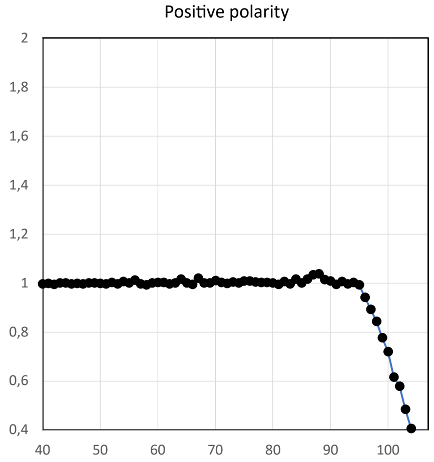
Probing with 13 MeV C ions

+56 V/µm

-22 V/µm

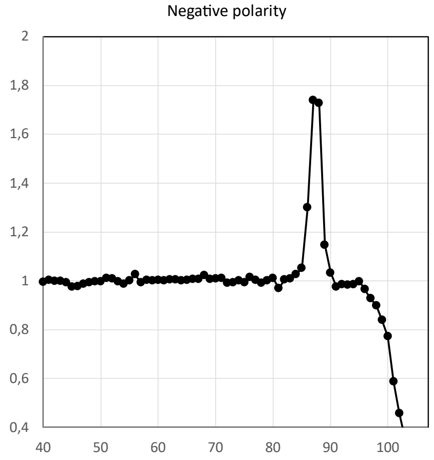


Charge multiplication asymmetry for electrons and holes



holes

Gain 10—20%

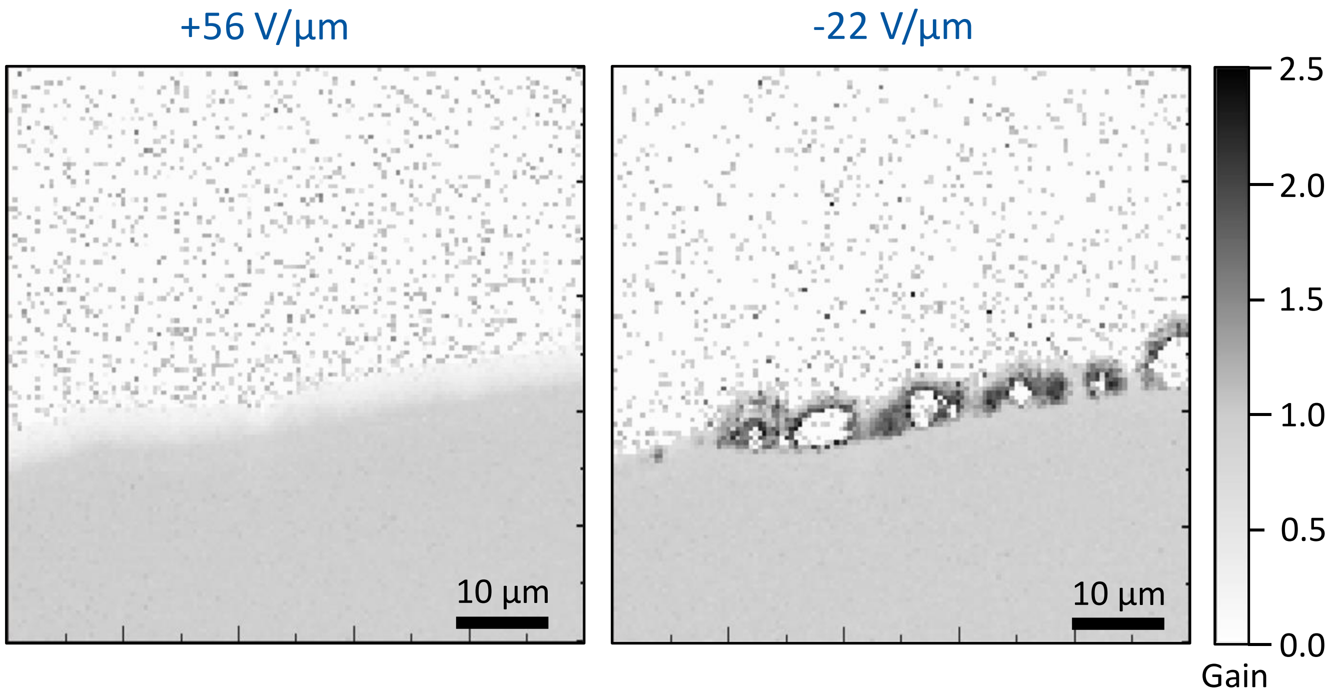


electrons

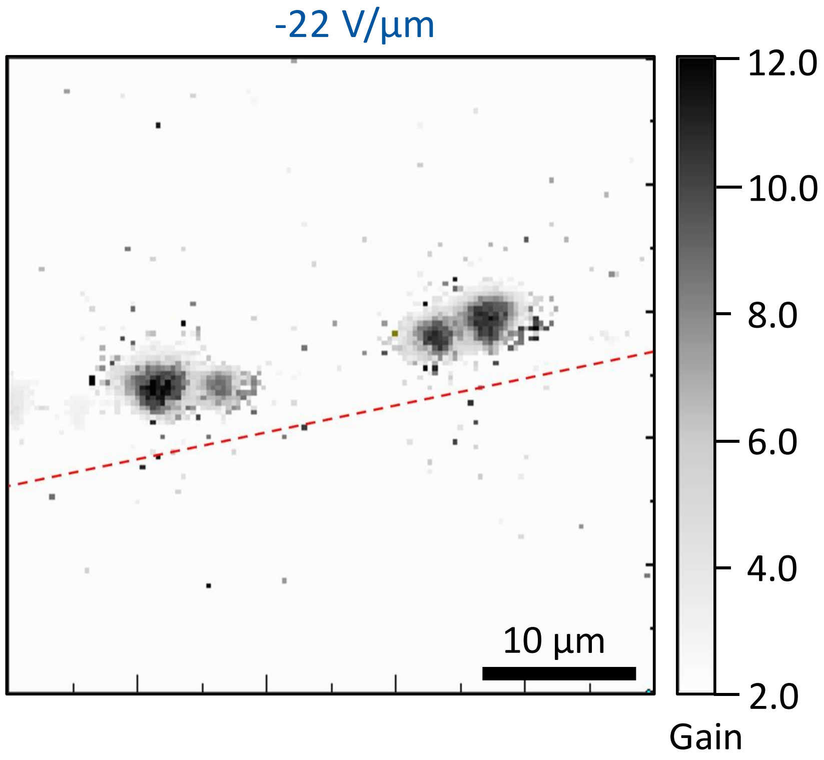
Gain 70—80%

Charge multiplication in thin scCVD membranes

Probing with 3 MeV He ions



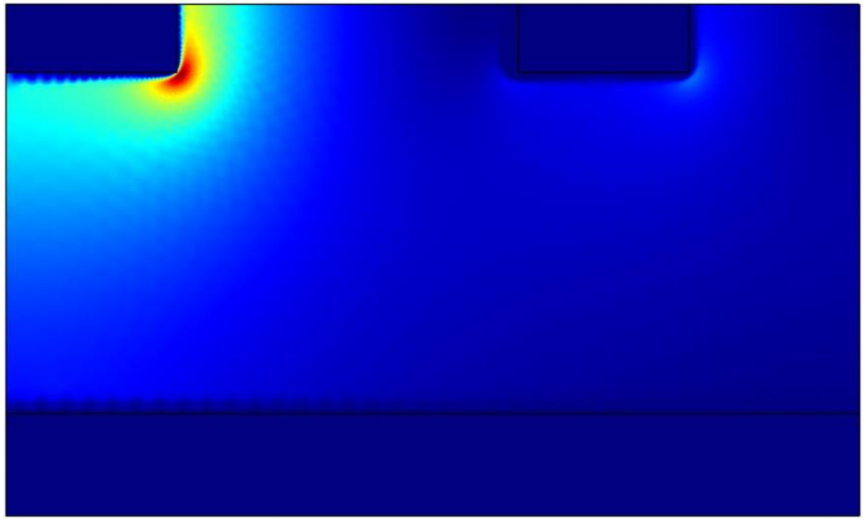
High gain islands are located very near the contact edge

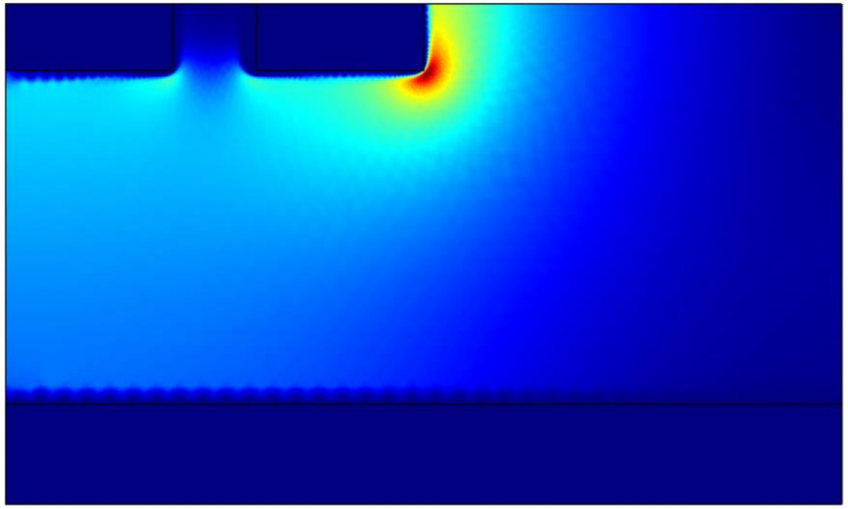


Gain islands along the edge with multiplication as high as 9
were observed.

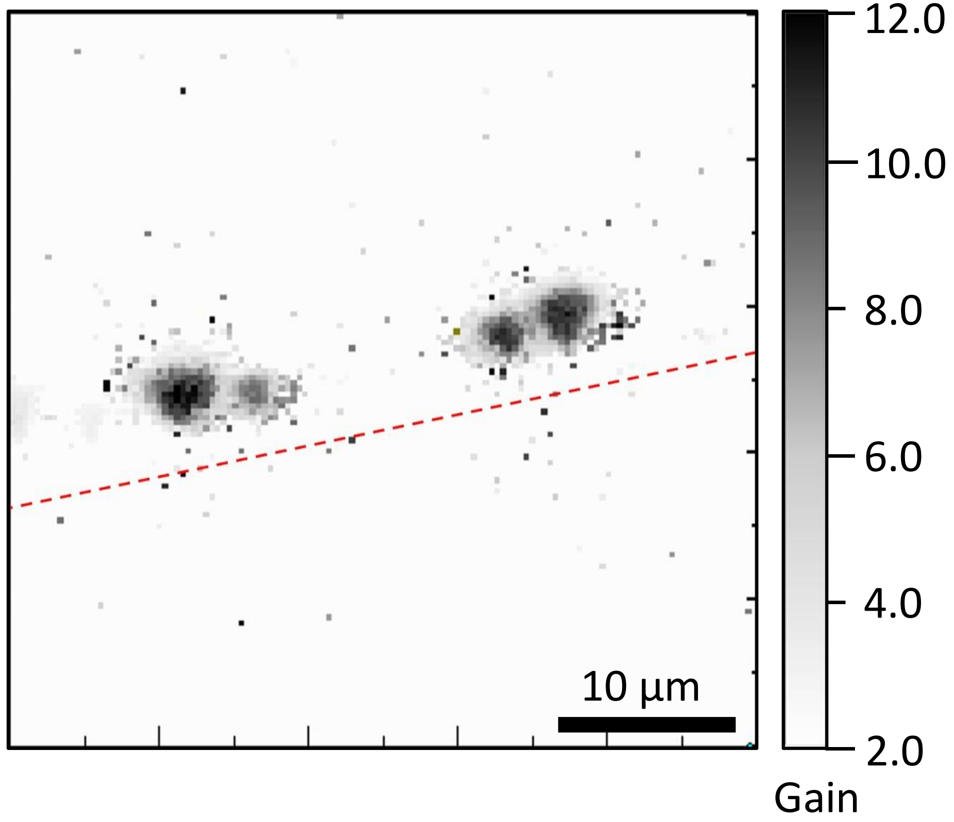
DRD3

Thank You !

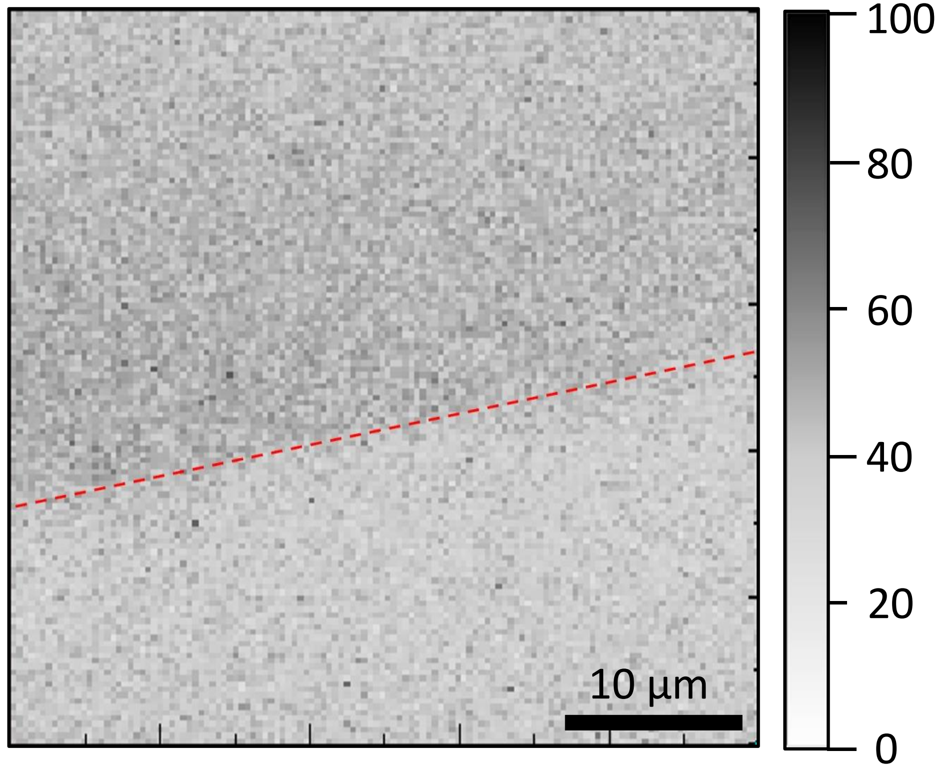




IBIC



STIM



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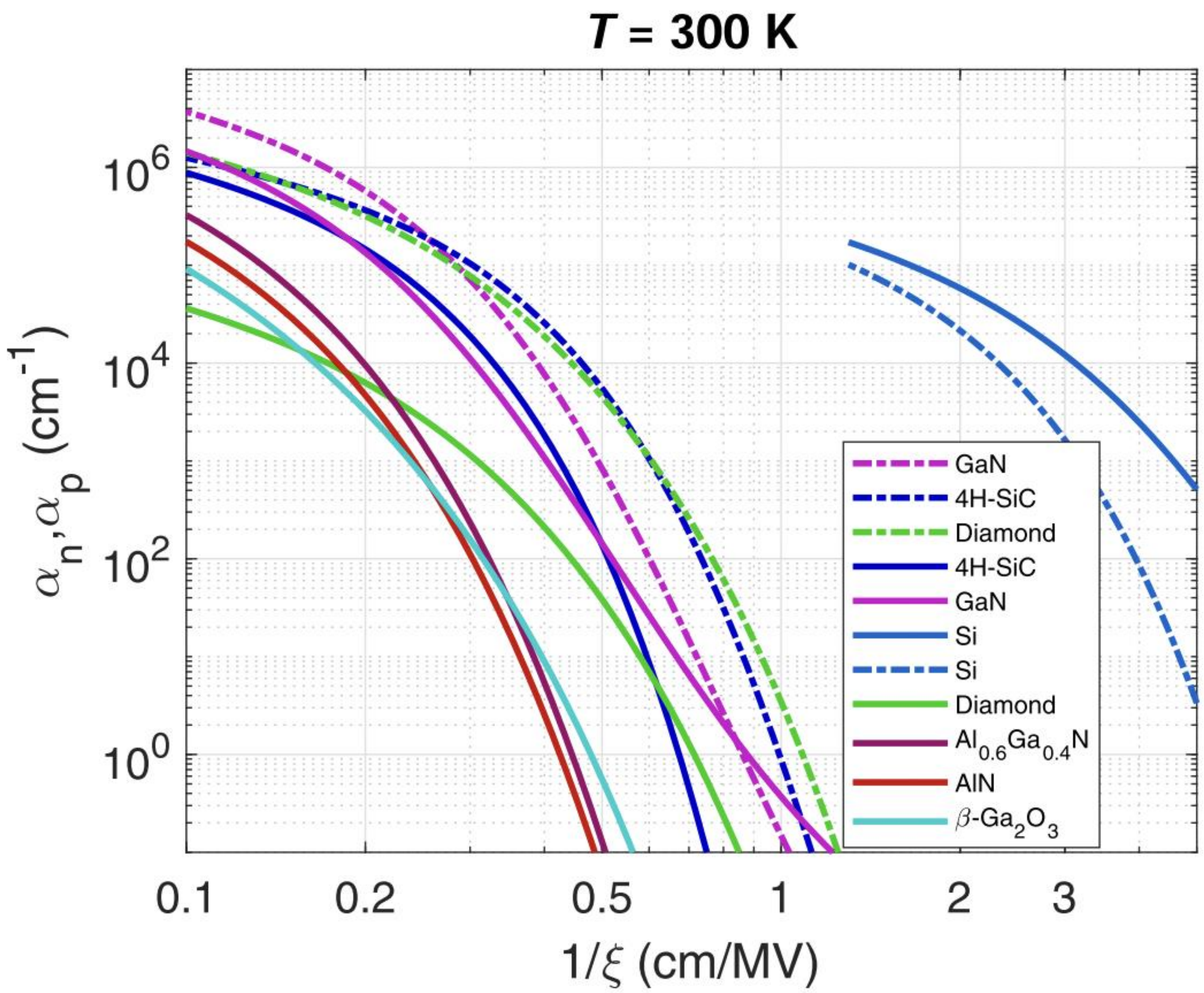

Fig. 3. Room-temperature impact-ionization coefficients for Si and wide- and ultrawide-bandgap semiconductors. The solid lines show α_n, and the dashed lines show α_p. The GA was used to fit the data existing in the literature to the Thornber model.