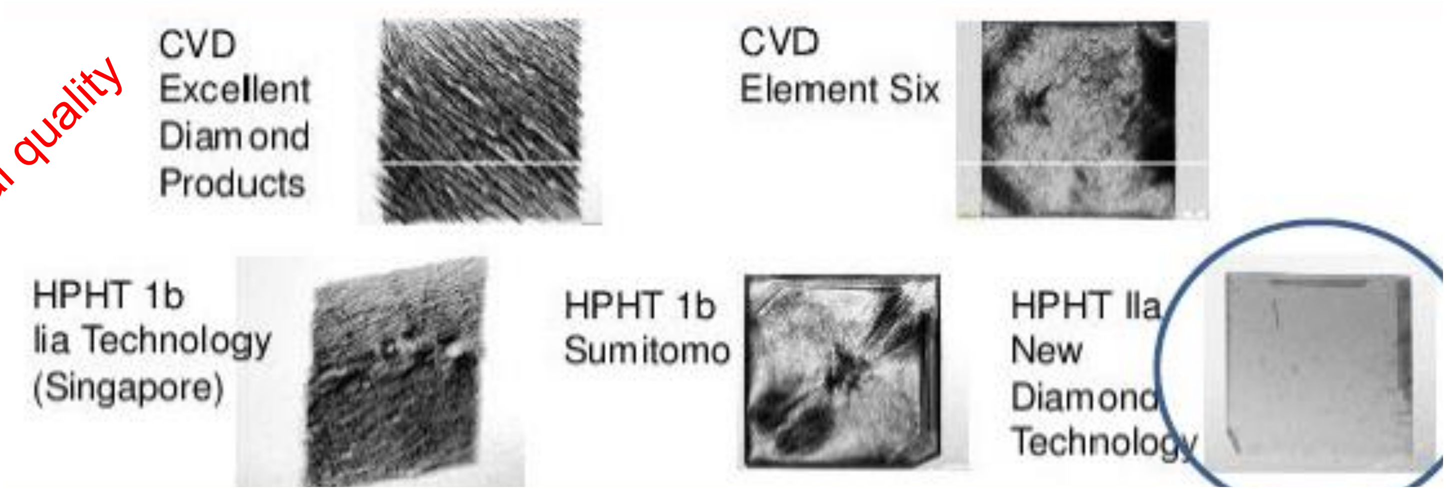
ELECTRONIC PROPERTIES OF IIA HPHT DIAMOND SAMPLES FROM NEW DIAMOND TECHNOLOGY

5th **ADAMAS Workshop, Darmstadt, Germany** 15-16/12/2016 | Pomorski Michal

WHY TO BOTHER WITH HPHT DIAMONDS

excellent structural quality



large size

Affordable price

5.0 x 5.0 x 0.5 mm single-crystal mu
charachteristics are listed below. You
order process.

For special technical applications we
and obtain mono- or multi-sectorial

Price: 630$

? What about electronic quality ?

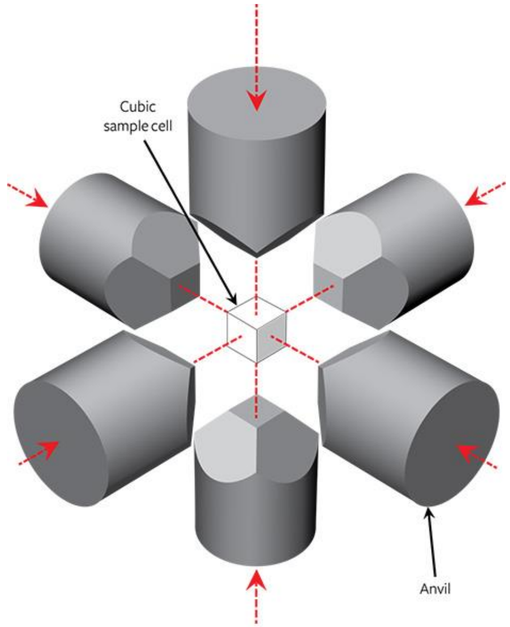
OUTLINE

1. NDT, Samples and Structural Quality
2. Current-Voltage Characteristics
3. Charge Collection Characteristics
4. TCT Characteristics
5. Summary

HPHT DIAMONDS AND NDT

NEW DIAMOND TECHNOLOGY

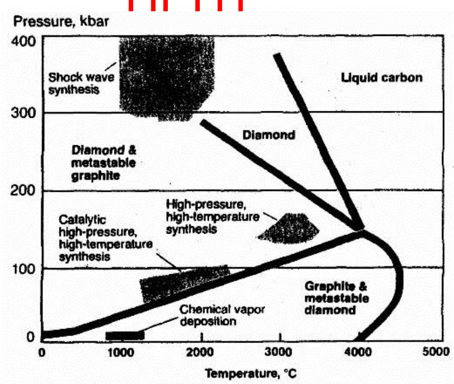
Multianvil cubic press



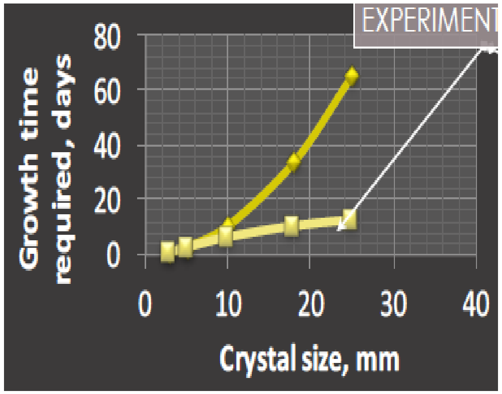
15mm

25mm

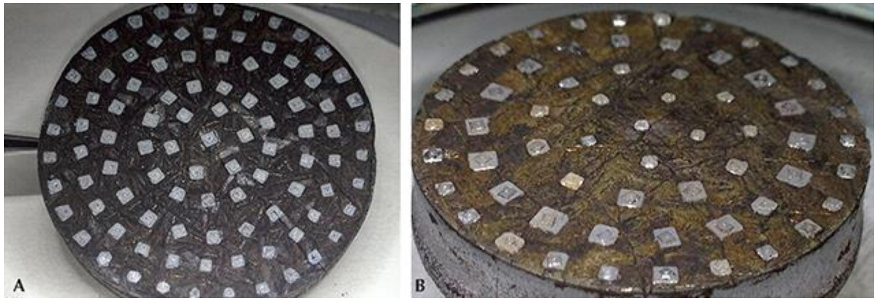
HPHT



growth rate



Multiseeds growth



Diamond cube 4x4 mm → current 200 → in three years 750

Diamond cube 7x7 mm → current 15 → in three years 60

Diamond cube 10x10 mm → current 9 → in three years 25

HPHT DIAMONDS AND NDT

http://ndtcompany.com/

Diamond plates have the potential which shall allow to bring electronics and optics on new level of development.

Available sizes in stock are from 3.0x3.0 mm up to 12.0x12.0 mm with standard thickness of 0.5 mm and orientation (100).

For special technical applications we can provide sizes up to 15.0x15.0 mm and vary thickness, orientations, types and obtain mono- or multi-sectorial plates with different shapes.

Fore special orders you may indicate other crucial characteristics for your researches and devices list ceatech

HPHT DIAMONDS AND NDT

http://ndtcompany.com/

Specification

Size	5.0 x 5.0 мм
Thickness	0.5 мм
Type	IIa
Face orientation	(100)
Crystallography	Multisectorial
Edge Orientation	(110)
Roughness, Ra	≈ 5 нм
Miscut	+/-3°
Lateral Tole	
Thickness T	
Edges	
Edge Featu	
Laser Kerf:	

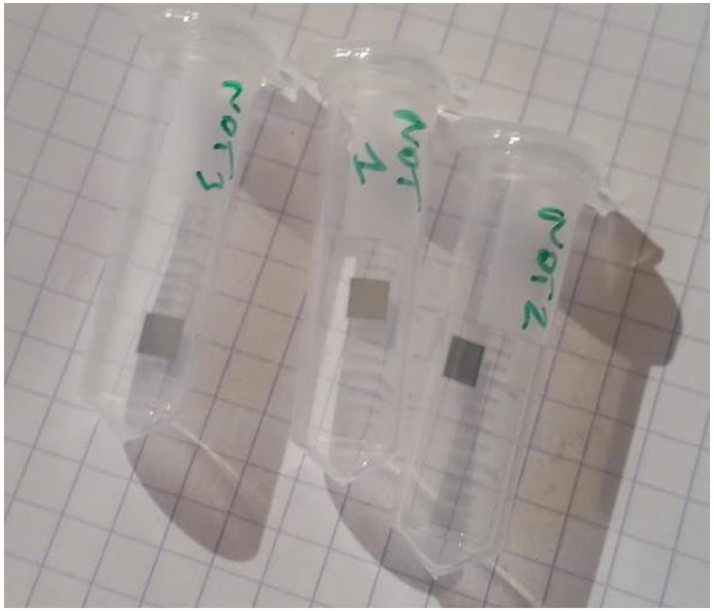
Material properties

Boron Concentration	< 5 ppb
Nitrogen Concentration	< 5 ppb
Dislocations density	$\sim 10^3$ см$^{-2}$
Charge Collection Efficiency	> 95%
Thermal conductivity	~ 2200 Wt/mK

INSTITUT CARNOT CEA LIST

université PARIS-SACLAY

SAMPLES AND STRUCTURAL QUALITY



Six HPHT diamond plates (NDT1-NDT6)

- sizes: 4 x 4 mm and ~**100 µm** thickness
- sizes: 4.5 x 4.5 mm and ~**100 µm** thickness
- <100>, monosectoral, Iia high purity
- from six different production runs

Standard procedure (used for e6 CVD) of samples metallization:

cleaning in hot acid solution → H2SO4+KNO3 (boiling); DI water; IPA; drying

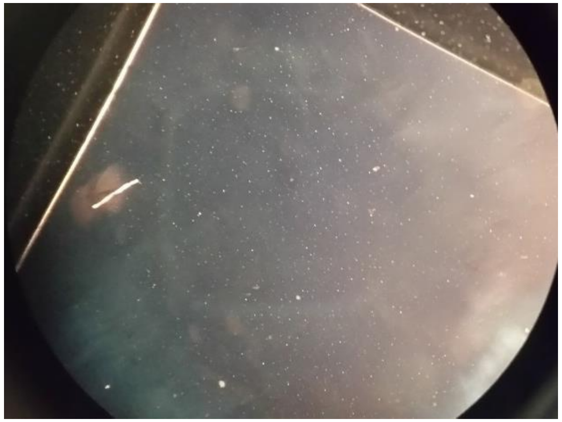
Al contacts by PVD sputtering → power 200W, bias 1000V, Argon 10-3 mbar with shadow masks, parallel plates

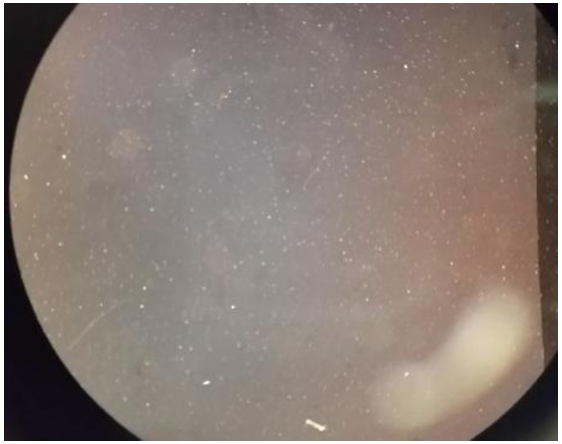
only two (NDT2 and NDT6) samples give promising results

SAMPLES AND STRUCTURAL QUALITY- BIREFRINGENCE

Crossed-polarizers imaging before metallization

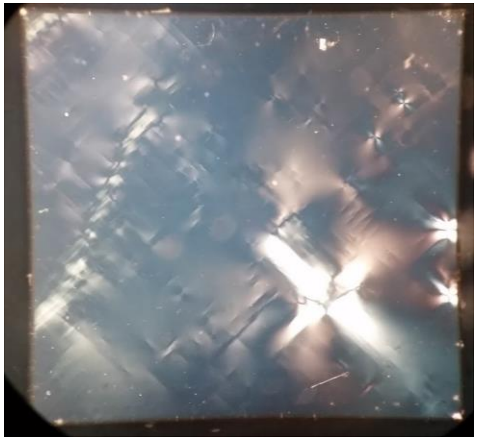
NDT Iia HPHT





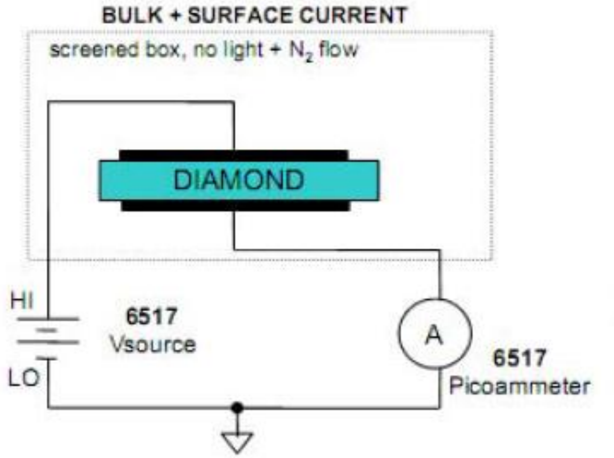
no birefringence contrast
for all six samples

E6 CVD (recently processed)



strong to moderate
biref. contrast

CURRENT VOLTAGE CHARACTERISTICS



some general observations IIa HPHT for I-V @ RT (more than six samples):

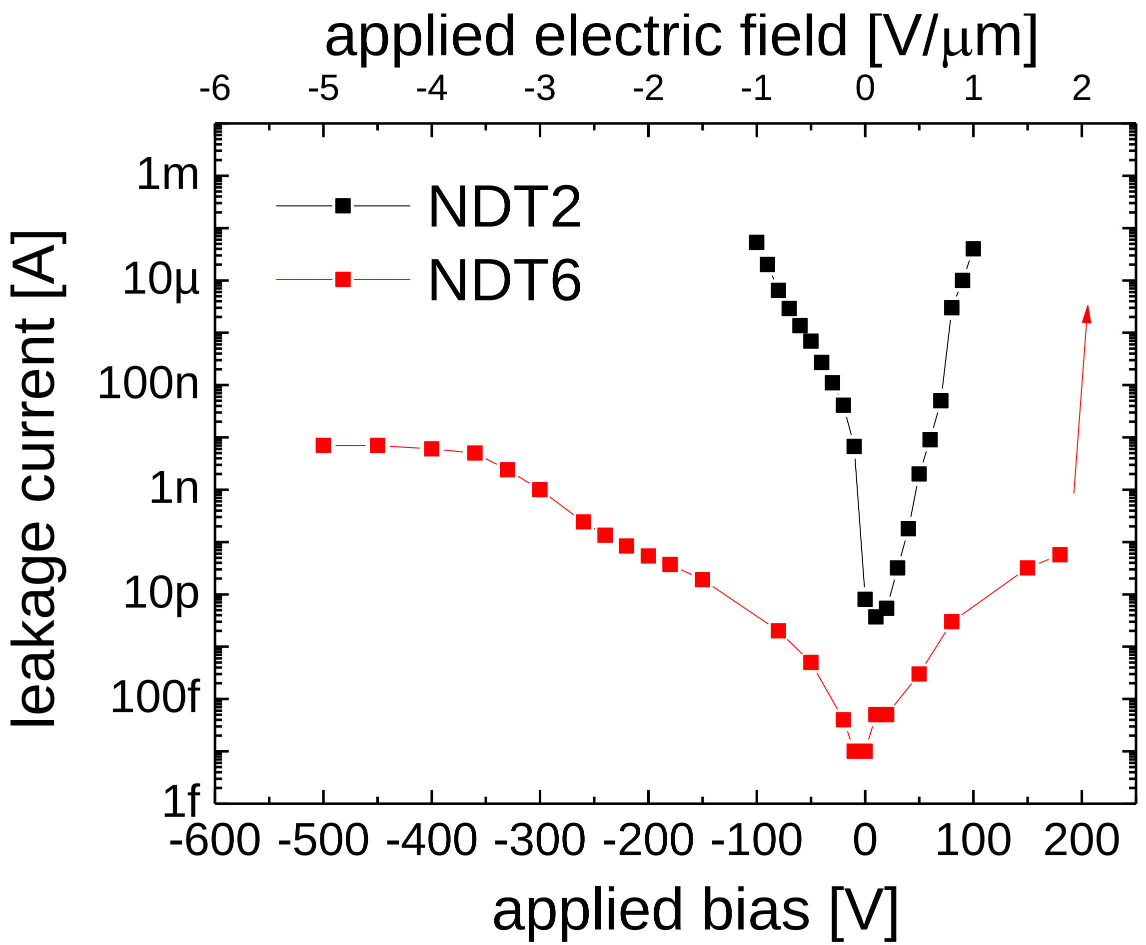
- majority of the samples are not resistive, high leakage current (µA) at low bias (0.1V/µm

- some samples are highly resistive but gives no sign of charge transport

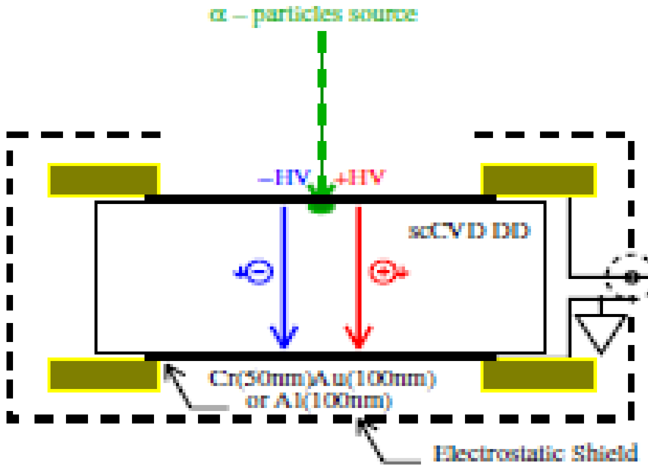
- some samples 'leak', but give moderate to high quality charge transport properties

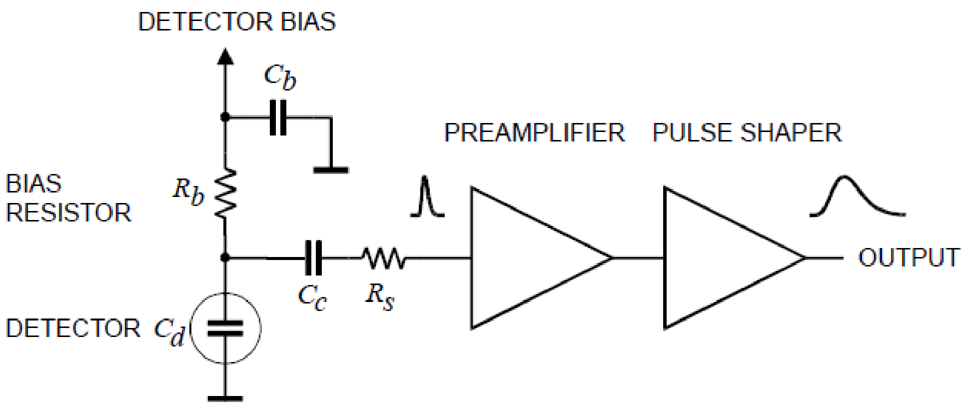
- one sample gives high resistivity and very good charge transport properties

CURRENT VOLTAGE CHARACTERISTICS



CHARGE COLLECTION PROPERTIES





Measurement conditions:

- 5.5 MeV α-particles (Am-241 source, 4kBq)

- collimated elctrodes

- measurements in primary vacuum, dark

- majority of e or h drift (polarity of HV)

Set-up:

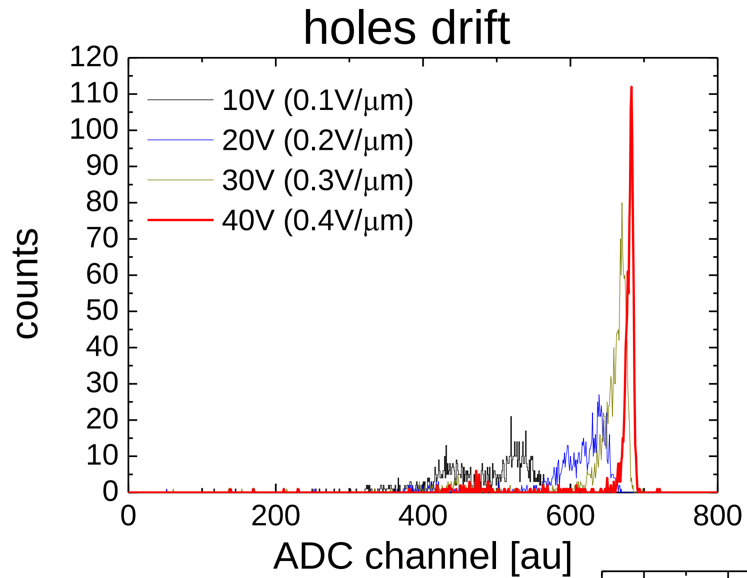
- coolFET A250 amptek preamp. (2.5 ns rise)

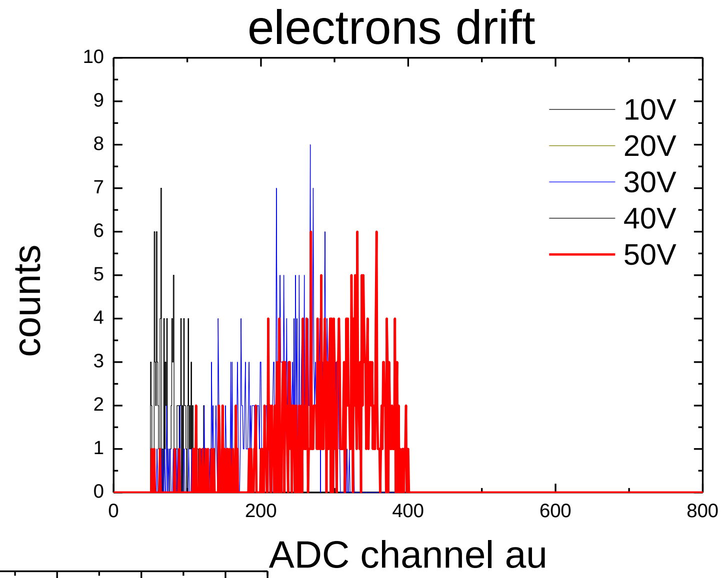
- 3 µs shaping time

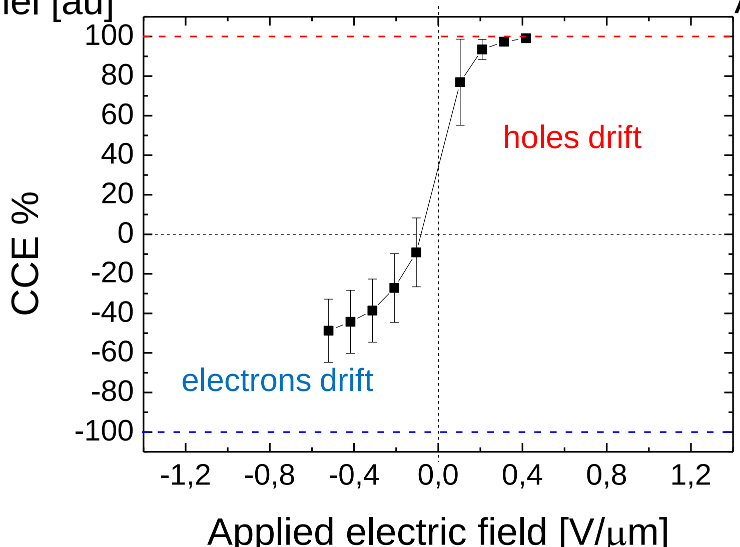
- pocket MCA or DSO as DAQ

CHARGE COLLECTION PROPERTIES - NDT2

5.5 α-particles spectra vs. detector bias



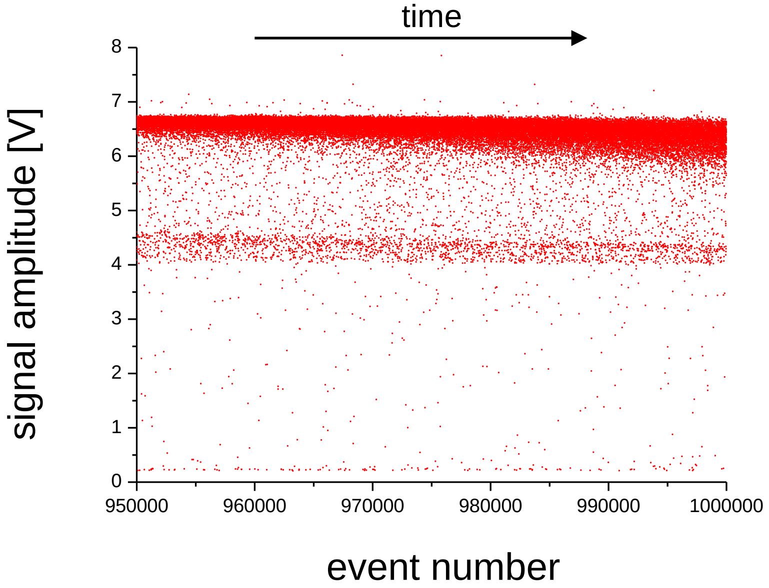




CHARGE COLLECTION PROPERTIES - NDT2

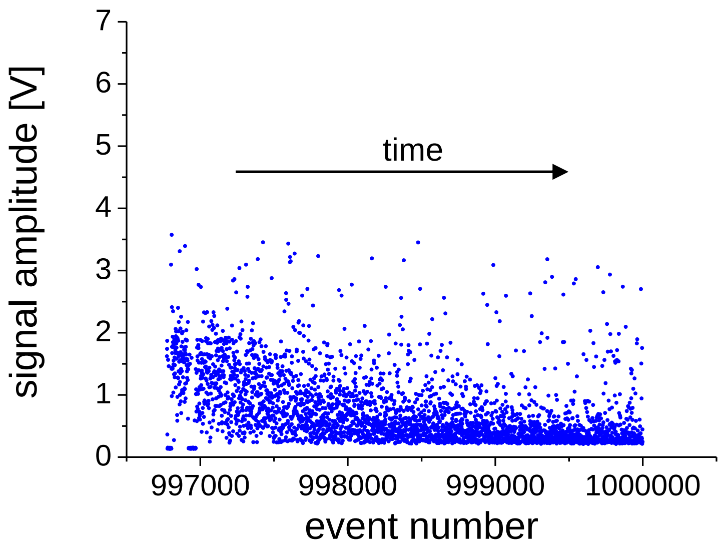
long term stability under 5.5 α-particles irradiation

holes drift



weak polarization

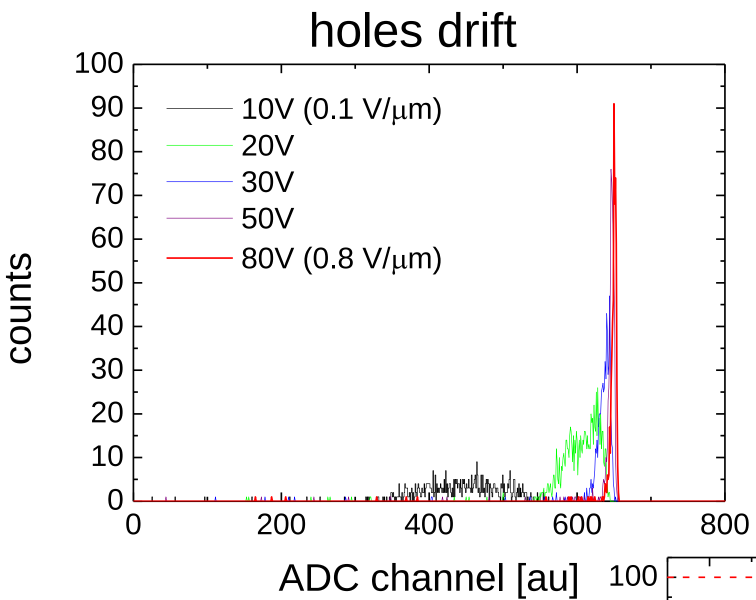
electrons drift

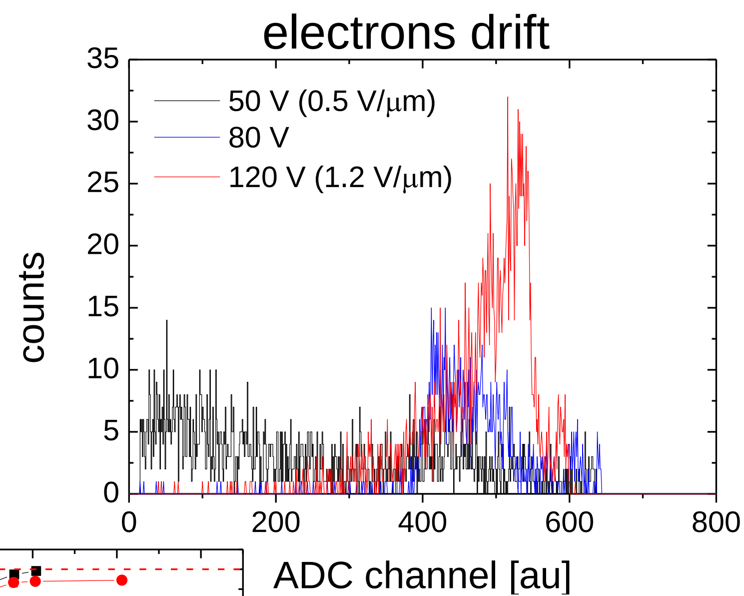


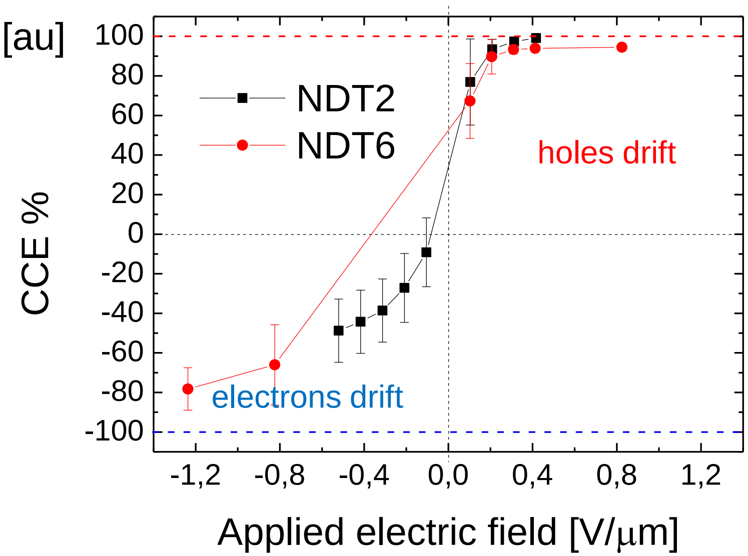
strong polarization

CHARGE COLLECTION PROPERTIES - NDT6

5.5 α-particles spectra vs. detector bias



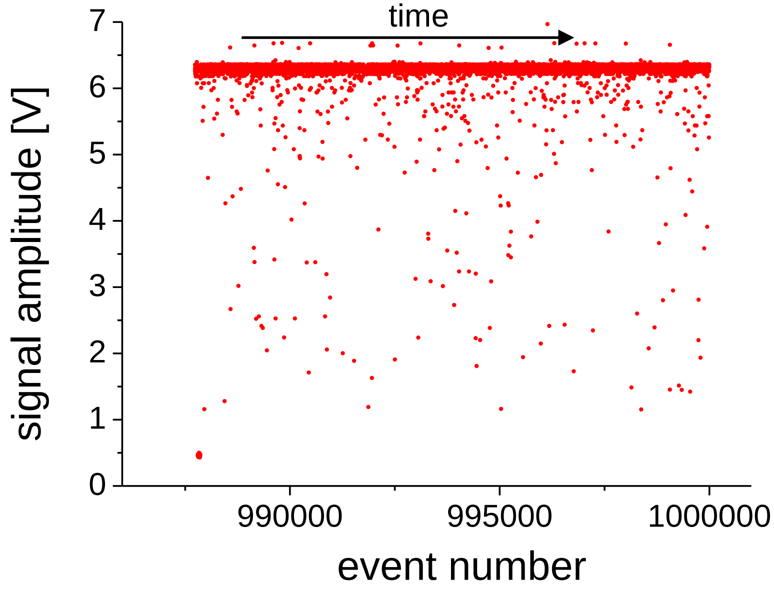




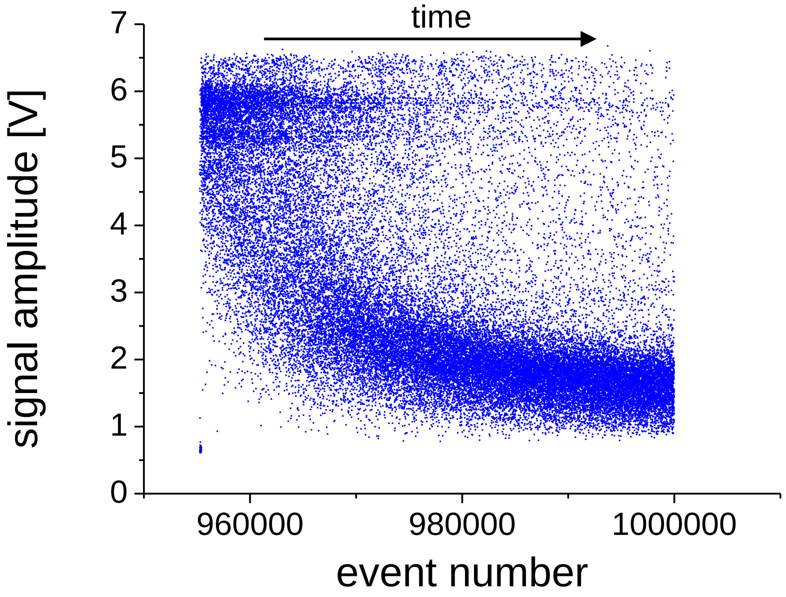
CHARGE COLLECTION PROPERTIES - NDT6

long term stability under 5.5 α-particles irradiation

holes drift



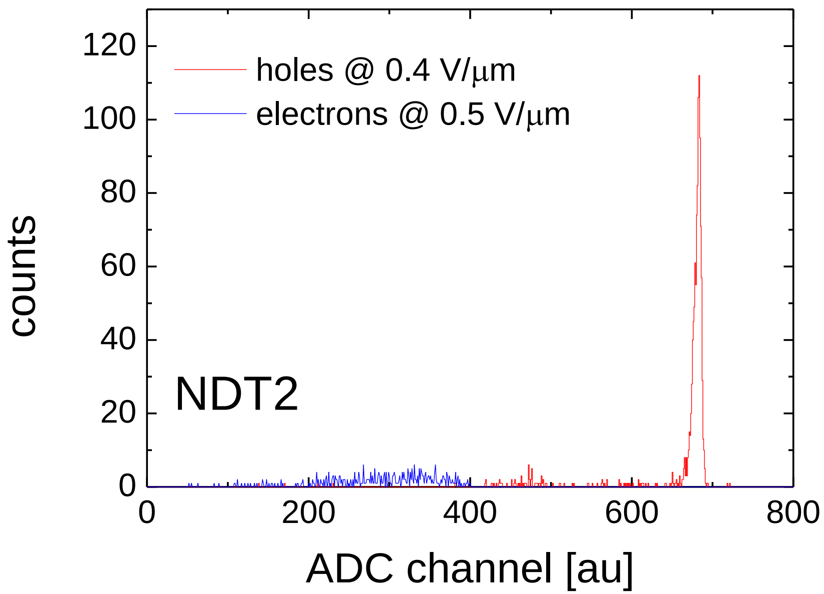
electrons drift

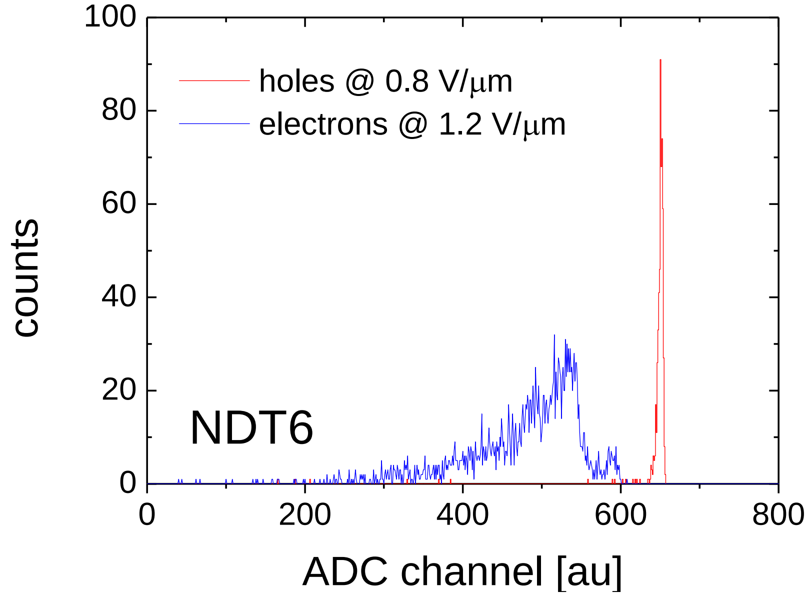


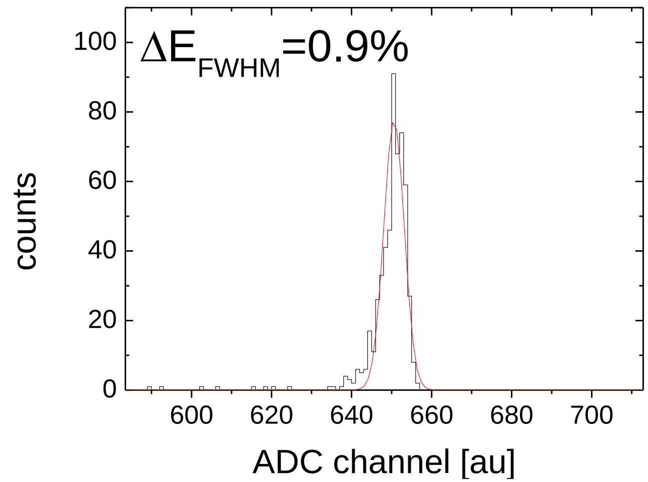
stable - no polarization

strong polarization

CHARGE COLLECTION PROPERTIES – BEST OF NDT2 NDT6



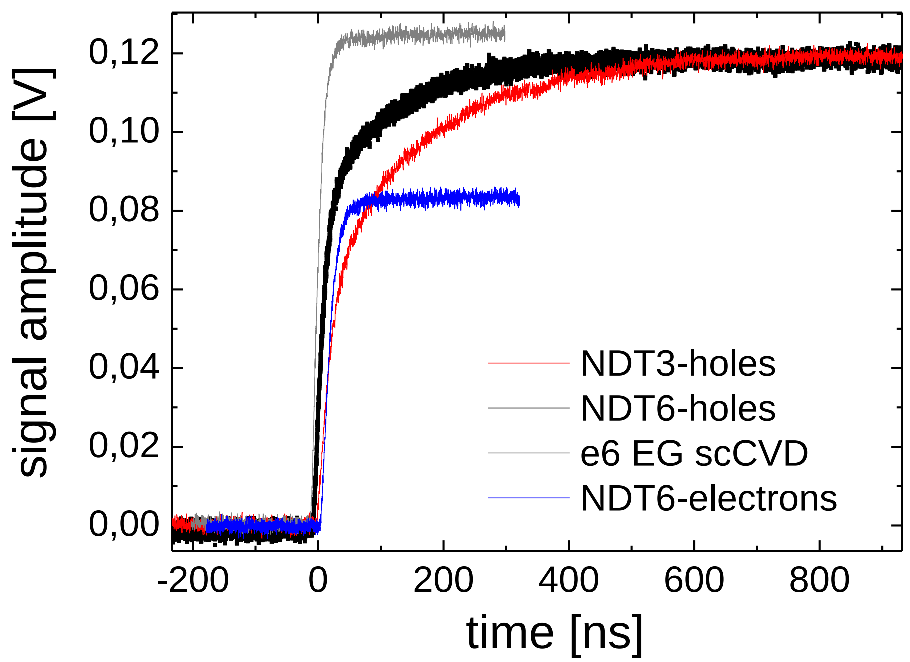




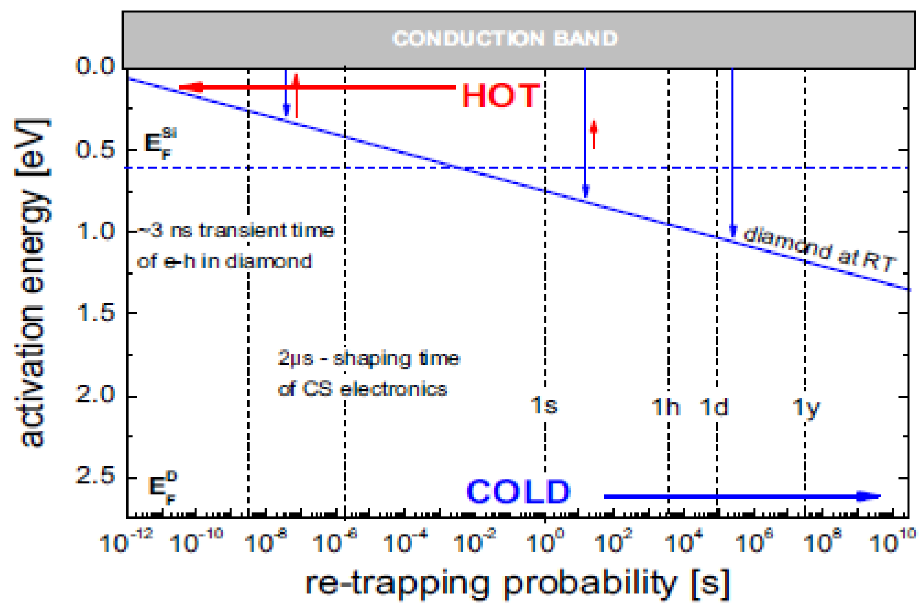
NDT6
spectroscopic grade
(holes drift)

CHARGE COLLECTION PROPERTIES

CoolFET A250 Amptek preamp



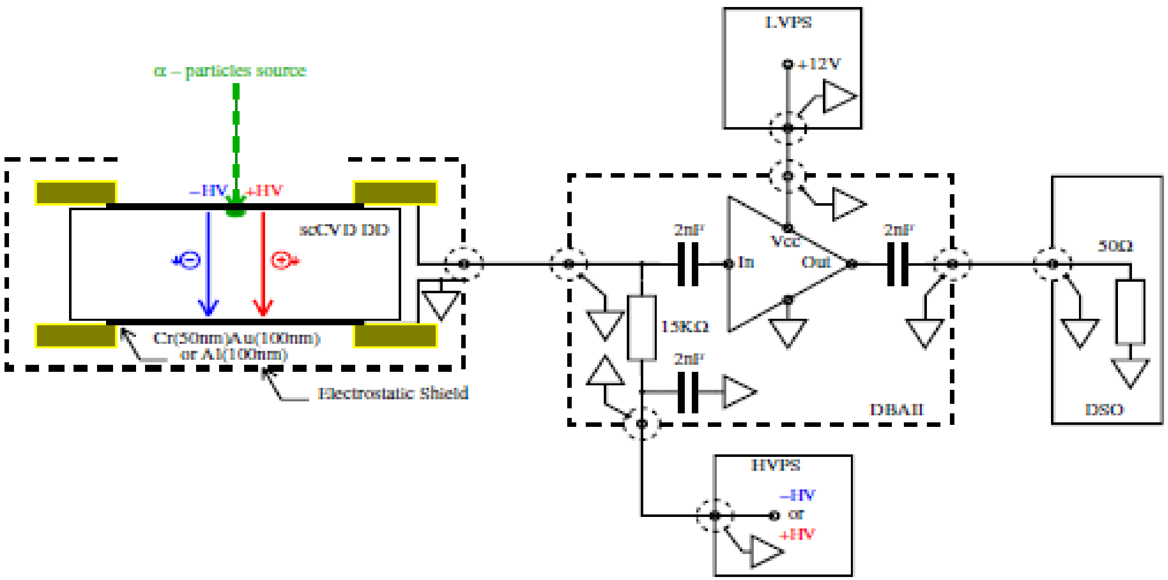
de-trapping probability @ RT



deep trapping for electrons → polarization

shallow trapping for holes→ all de-trapped within 3 µs @ RT (~0.3 eV)

TCT



Measurements conditions:

- 5.5 MeV α-particles (Am-241 source, 4kBq)

- collimated elctrodes

- measurements in primary vacuum

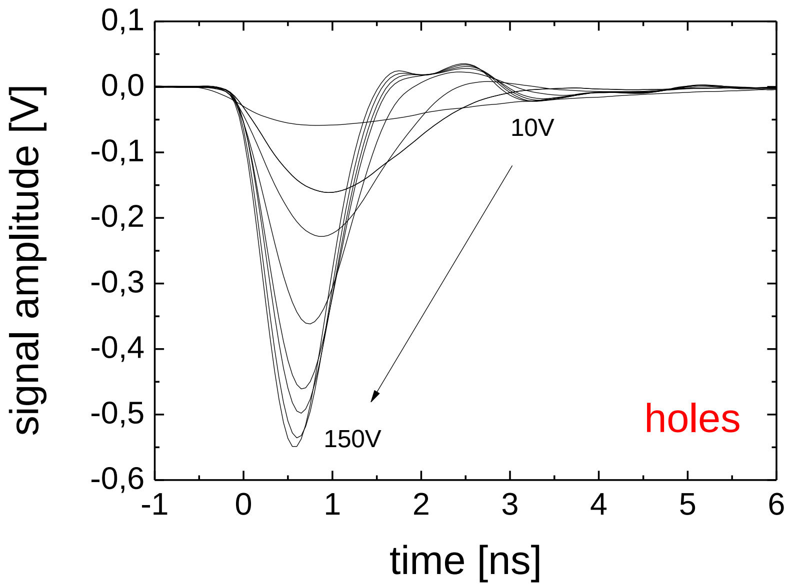
- majority of e or h (polarity of HV)

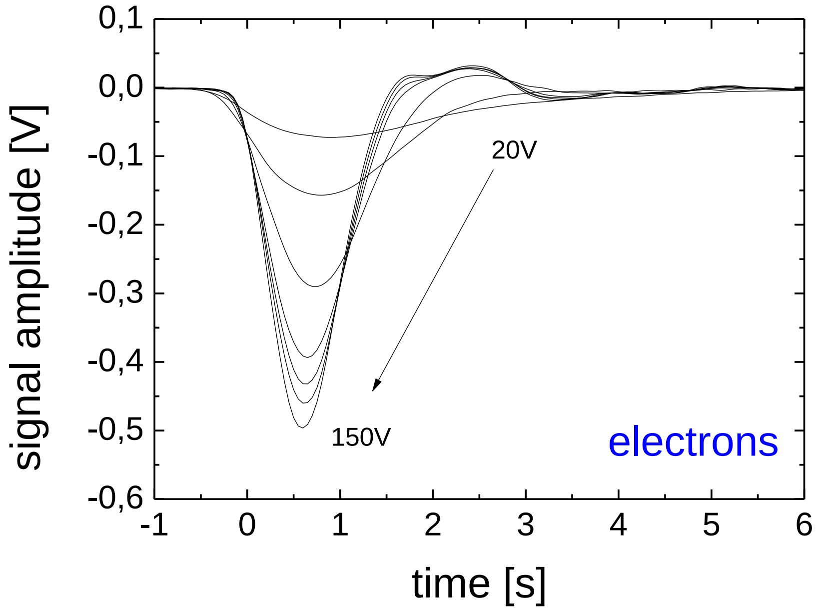
Set-up:

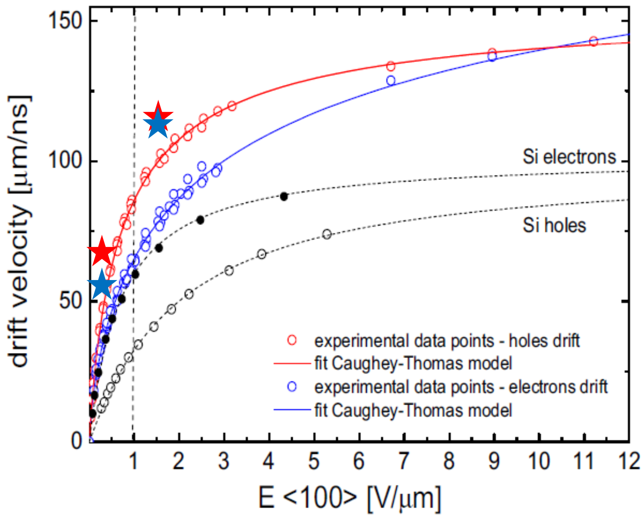
- CVIDEC C2 fast amplifier

- DSO as DAQ

TCT – NDT6

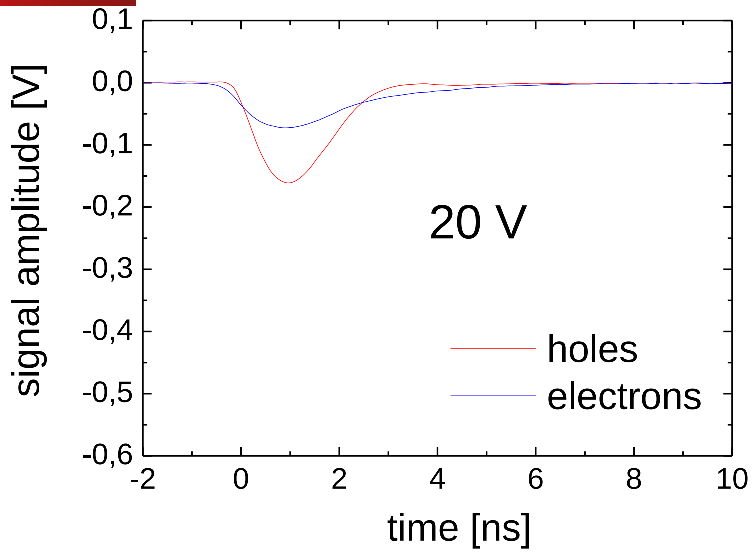


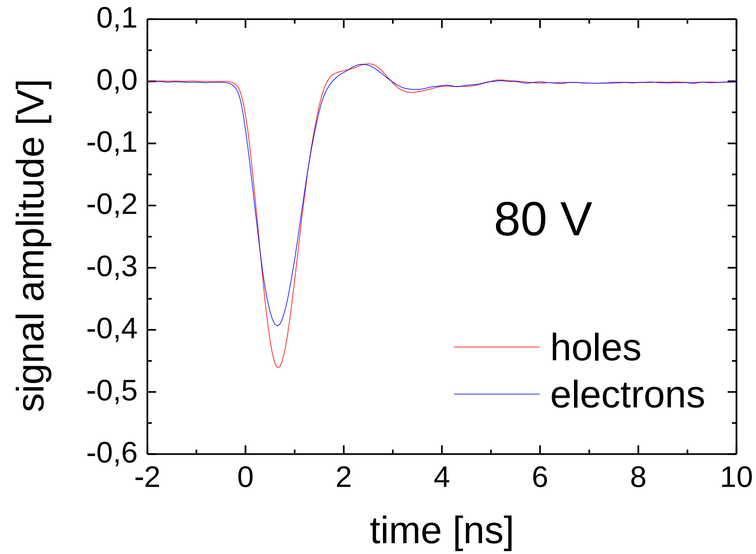


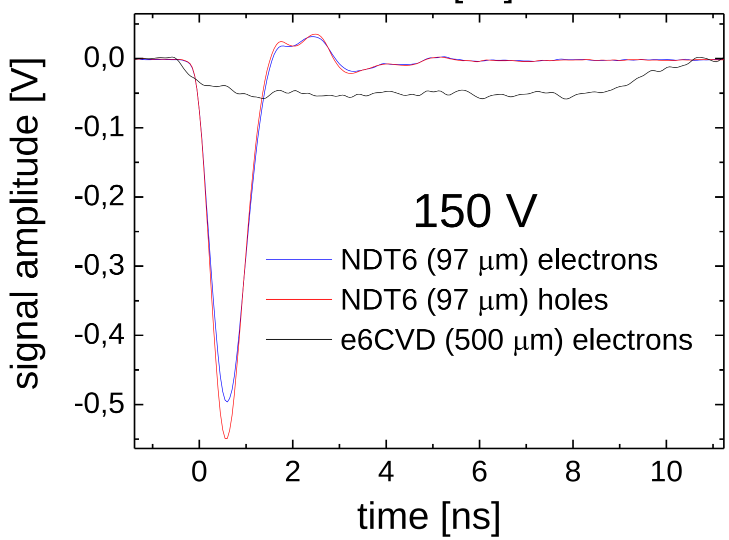


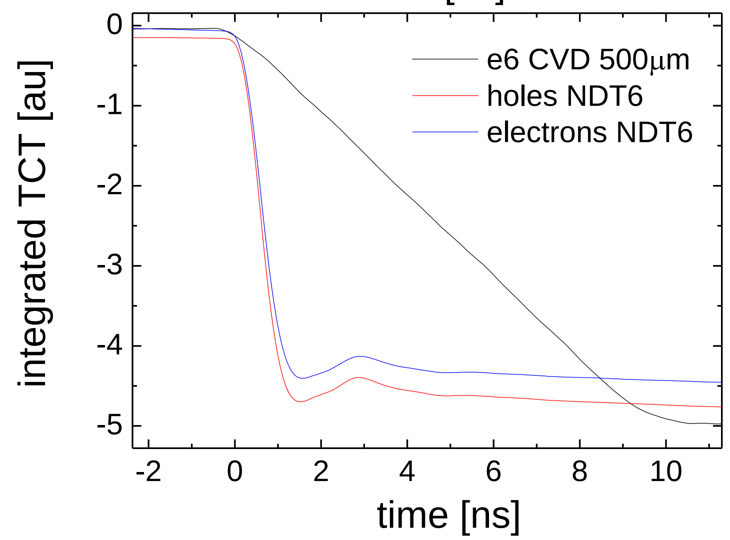
- fast rise and decay times – nice time detector
- no de-trapping visible
- no flat top, high amplitude (built-in field)
- drift velocity seems faster than CVD (but thin sample, internal field → need tct on thicker samples)

TCT – NDT6









puzzling: no de-trapping visible

SUMMARY

(Very) Preliminary characteristics of Iia HPHT samples from NDT were performed:

Only two samples out of six give promising results

I-V: majority of the samples are conductive (impossible to apply bias)
- some of them have acceptable level of leakage current
- rarely samples are highly resistive

CCE: - for holes drift reaches 100%; for electrons drift reaches 80%
- stable operation for holes drift, with spectroscopic quality

deep trapping for electrons leads to polarization, shallow trapping for holes
all charge released @ RT within shaping time used (3micros)

TCT: - fast signals including rise and decay time (no slow component)
- holes faster than electrons, drift velocity seems higher than CVD

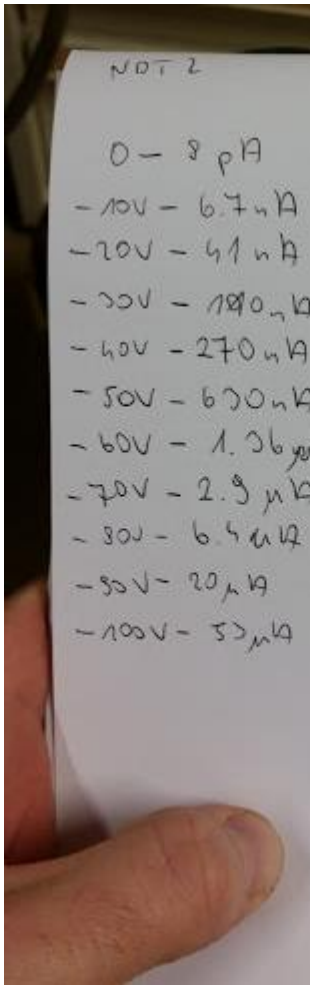
In current state NDT samples can be used for some detector applications (if same or better quality than NDT6): eg. traversing particles, time measurements, tagging, spectroscopy with majority of holes drift

Thank you very much for your kind attention !

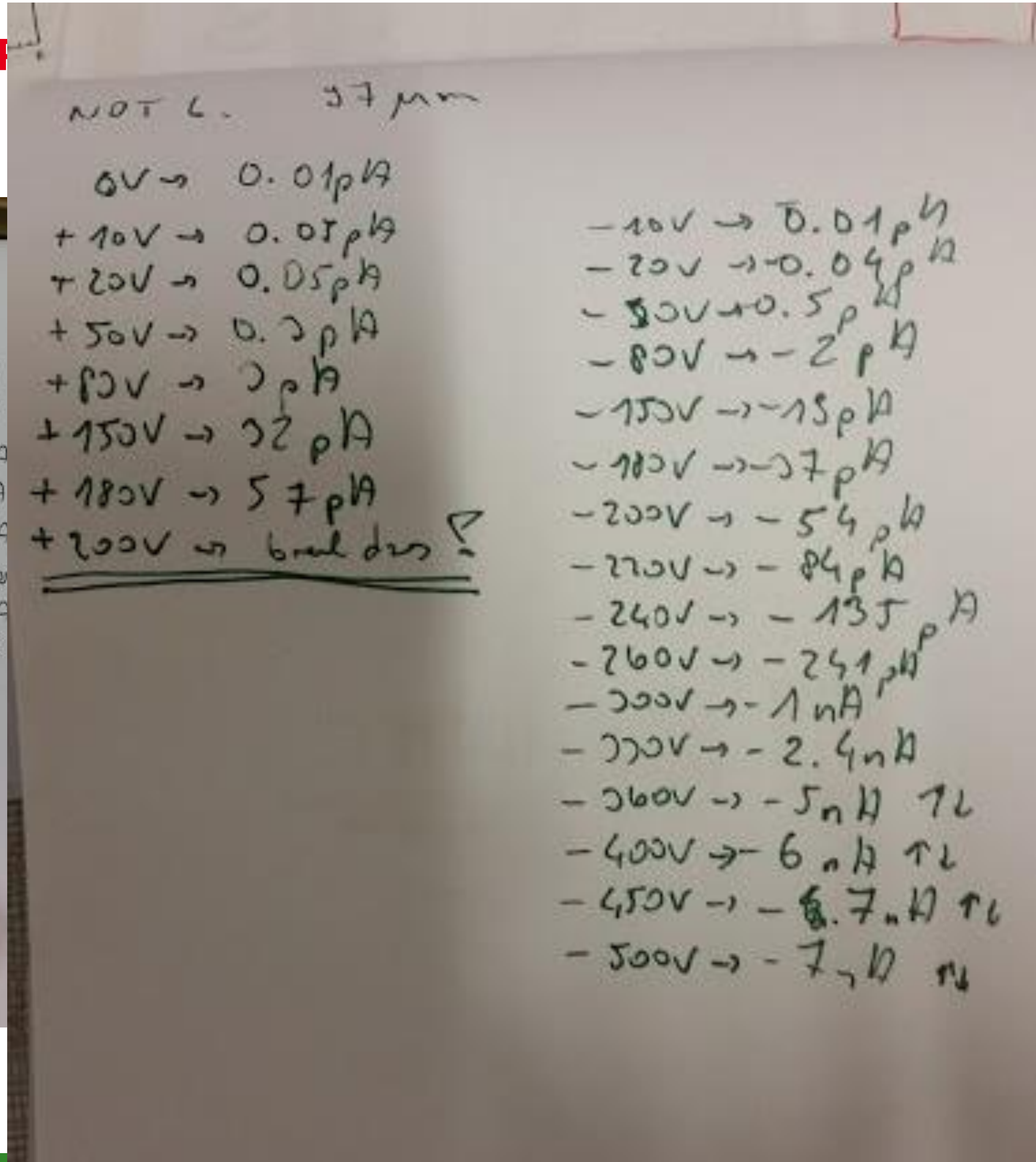
Commissariat à l'énergie atomique et aux énergies alternatives
Institut List | CEA SACLAY NANO-INNOV | BAT. 861 – PC142
91191 Gif-sur-Yvette Cedex - FRANCE
www-list.cea.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019

SAMP

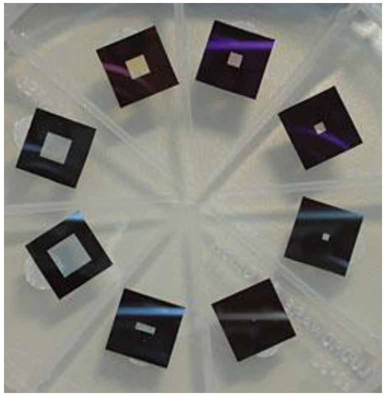


NOT 2
0 – 8 pA
–10V – 6.7 nA
–20V – 41 nA
–30V – 180 nA
–40V – 270 nA
–50V – 630 nA
–60V – 1.36 µA
–70V – 2.9 µA
–80V – 6.4 µA
–90V – 20 µA
–100V – 53 µA



NOT 4. 37 µm
0V → 0.01 pA
+10V → 0.05 pA
+20V → 0.05 pA
+50V → 0.3 pA
+80V → 3 pA
+150V → 32 pA
+180V → 57 pA
+200V → breakdown ?
–10V → 0.01 pA
–20V → –0.04 pA
–50V → 0.5 pA
–80V → –2 pA
–150V → –13 pA
–180V → –37 pA
–200V → –54 pA
–220V → –84 pA
–240V → –135 pA
–260V → –241 pA
–300V → –1 nA
–330V → –2.4 nA
–360V → –5 nA ↑↓
–400V → –6 nA ↑↓
–450V → –6.7 nA ↑↓
–500V → –7 nA ↑↓

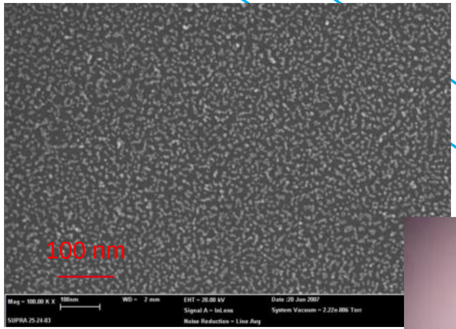
BNCD SEE MEMBRANES



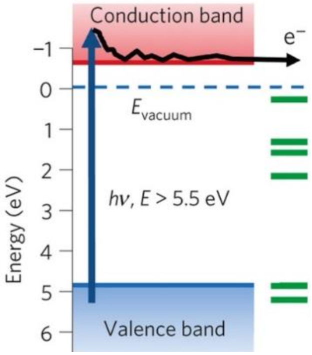
Silicon nitride windows

- commercial product
- not expensive
- 150 nm thick membrane

nanoseeding

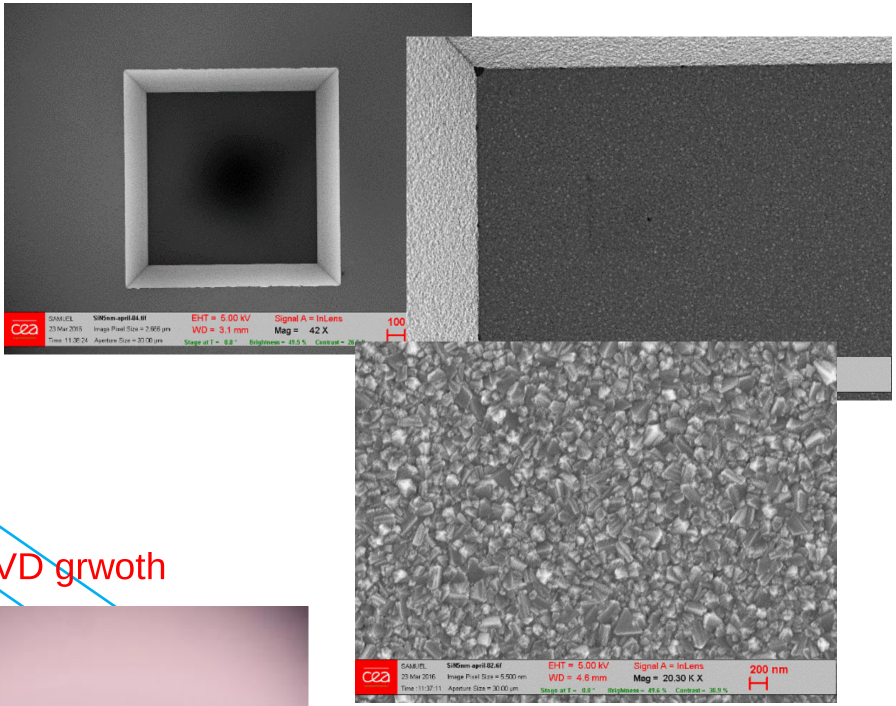


- seeding with diamond nanoparticles 5-20nm in PDDAC



NEA

CVD grwoth

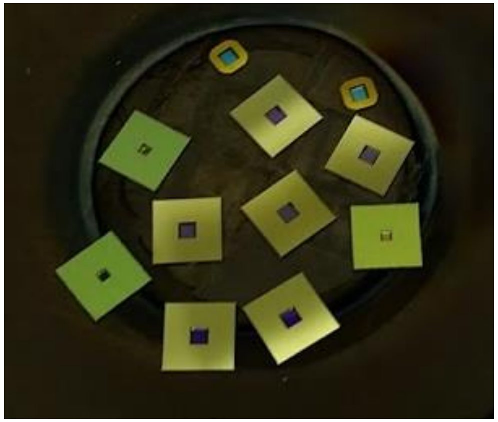


- MVCVD diamond growth (H_2/CH_4)
- temperature ~ 500-800 C

- boron doping (TMP) up to metallic conductivity

- few hours processing

BNCD coated silicon nitride windows



ACTIVE SCCVD DIAMOND MEMBRANE – 3 MEV PROTONS

measured values   a wish list

Table 1. Important properties of diamond for high energy physics applications [2]

Property	Silicon	Diamond	Effect in Diamond
Band gap [eV]	1.12	5.45	Leakage current is very small and No cooling required
Electron mobility[cm^2/V-sec] Hole mobility[cm^2/V-sec]	1450 500	2200 1600	Signal is very fast
Dielectric constant	11.9	5.7	Low Capacitance and noise
Atomic displacement energy [eV]	21	43	Radiation hardness is high
Electron-hole pair creation energy[eV]	3.6	13.6	Smaller signal
Mean electron-hole pair by MIP (Minimum Ionizing Particle) in 1 μm	89	36	Smaller signal
Charge collection efficiency (%)	100 (Single crystal)	100% for Single Crystal & 50% for Polycrystalline	Smaller signal
Thermal conductivity [W/cm-K]	1.5	22	No c

diamond as a solid-state ionization chamber