Charge transport properties of heavily irradiated SC CVD diamond detectors

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Content

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- Samples and TCT
- Non irradiated detectors
- Heavily irradiated detectors
    - priming
    - annealing

Motivation

- a lot of data on RH PC-CVD diamond detectors.... RD42

- a lot of data on radiation related defects in diamond,
  but studied with optical methods or EPR
  no information on charge transport

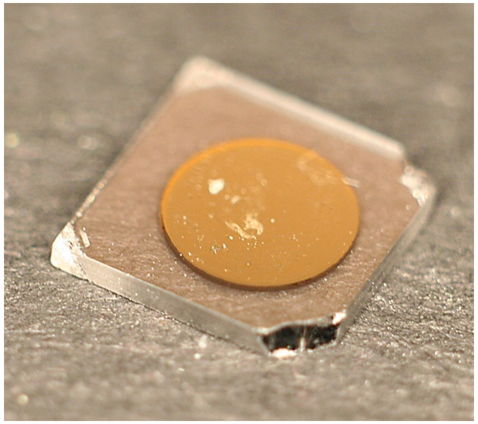
-some data on irradiated SC (natural, HPHT) diamond
  detectors

... no data on SC-CVD diamond detectors(?)

Samples - SC CVD diamonds

PRODUCER: Element Six, Ascot, UK

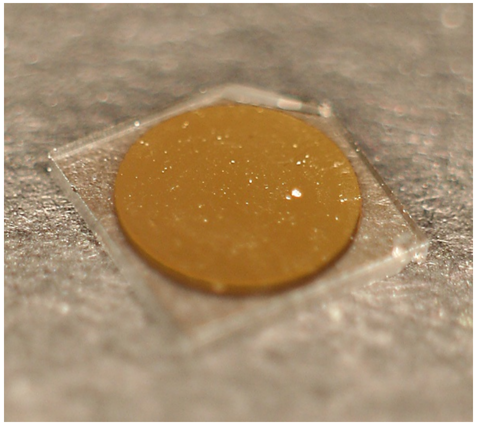
free standing <100> oriented diamond films
size - 5 x 5 x 0.3-0.5 [mm^3]



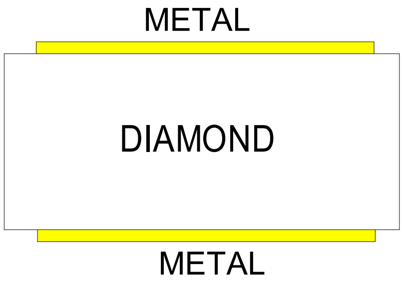
DETECTOR FABRICATION

surface cleaning and oxidation --> H_2SO_4 + KNO_3 (boiling), **DI water**

sputtered circular electrodes (parallel plate geometry)
annealing at 600°C (if Cr+Au)



mounting into holder



CONTACT:

Cr(50nm)+**Au**(100nm);

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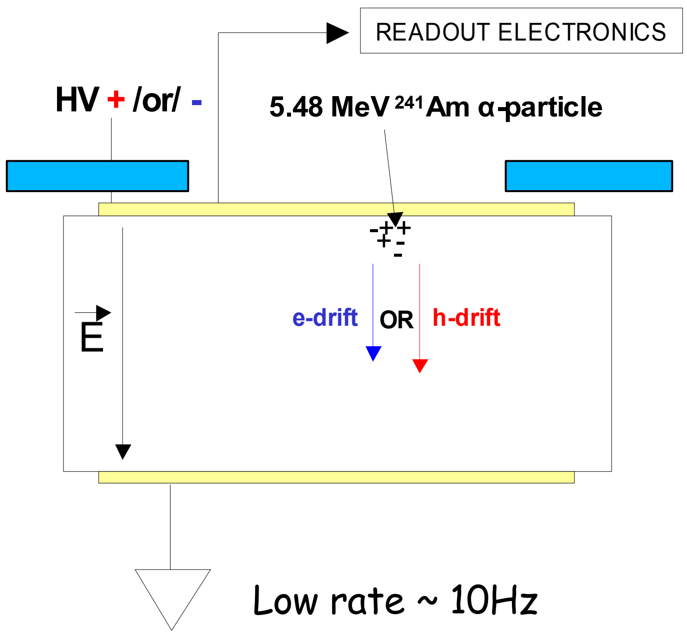
TCT-Transient Current Technique



α-particle's ENERGY (5.48 Mev)
range in diamond **~14μm;** detector thickness ~**300μm - 500μm**

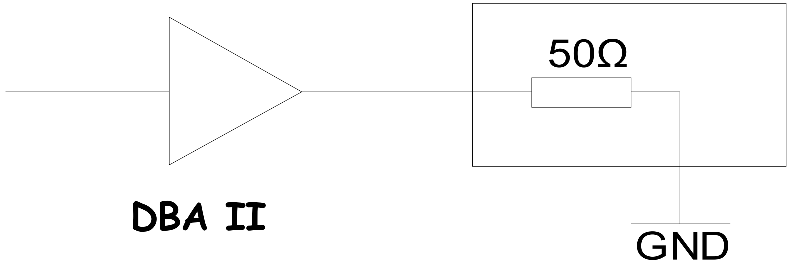
GENERATED CHARGE ~ **430 000 e-h --> 68 fC << UC_D**
operation in non space charge limited regime

SIGNAL INDUCED DUE TO **e** or **h** DRIFT

INFORMATION ON:

- charge carriers drift velocity vs. E, saturation velocity
- effective mobility and low field mobility
- charge collection
- Effective trapping time
- N_{eff} – effective space charge

Readout electronics



BROAD BAND ELECTRONICS:

50Ω impedance DBA II, bandwidth **2.4 GHz**, gain ~120

Digital Scope, bandwidth **3GHz**, 20GS/s, signal proc.

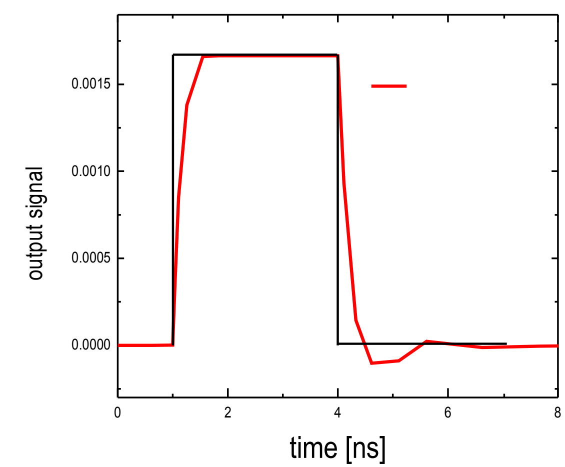
Limitation at low bias due to electronic noise (rms~5000 e)

INFLUENCE OF **ELECTRONICS BANDWIDTH** AND **INTEGRATING EFFECT OF $R_{50}(C_D+C_p)$**

LIMITATION: t_r=150 ps
R ~ 50 Ω
C ~ 3-5 pF

For 300-500µm and 2.9mm electrodes low influence

DOES NOT AFFECT t_{tr} (at FWHM)



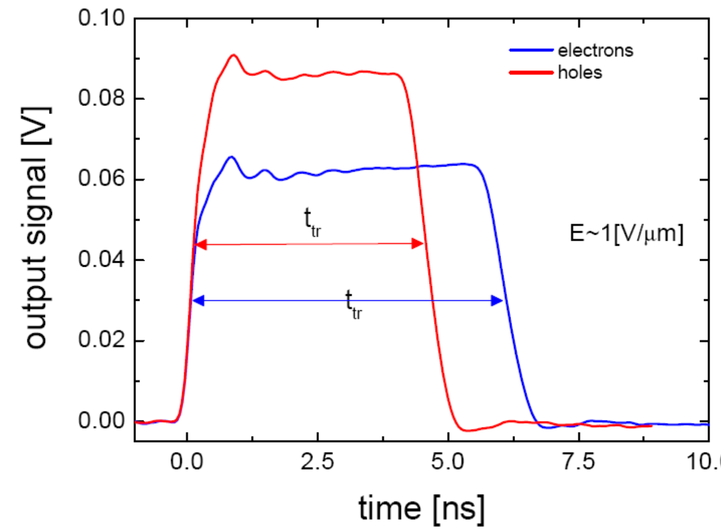
Transient current signals

Simplified parallel plate 1D geometry

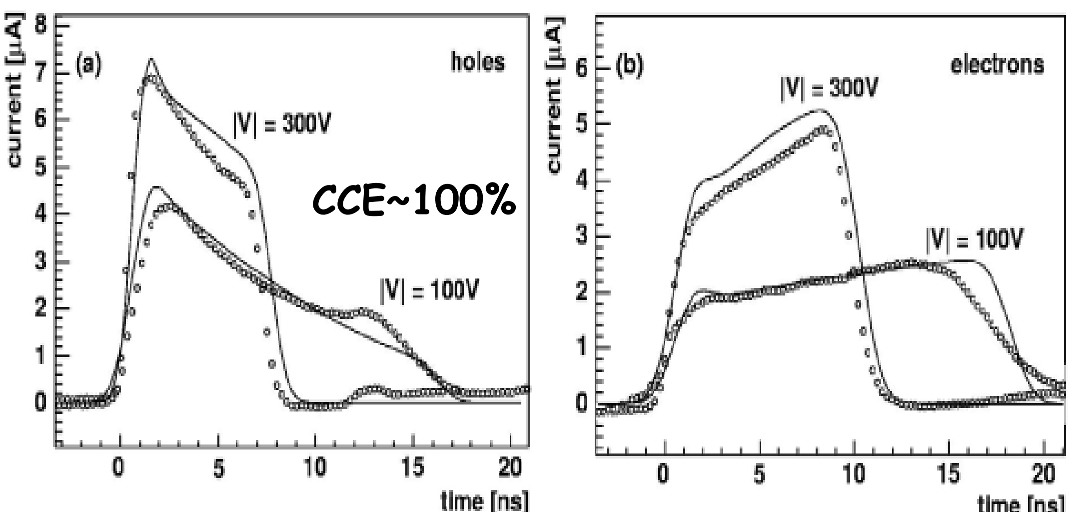
$$i_{tr}(E) = \frac{Q_0}{d} \cdot v(E(x)) \cdot \exp(-t/\tau_{eff-h,e})$$

$$E(x) = E(extr) - \frac{q_0}{\varepsilon \varepsilon_{diam}} \int_0^d N_{eff}(x')dx'$$

close to "IDEAL"

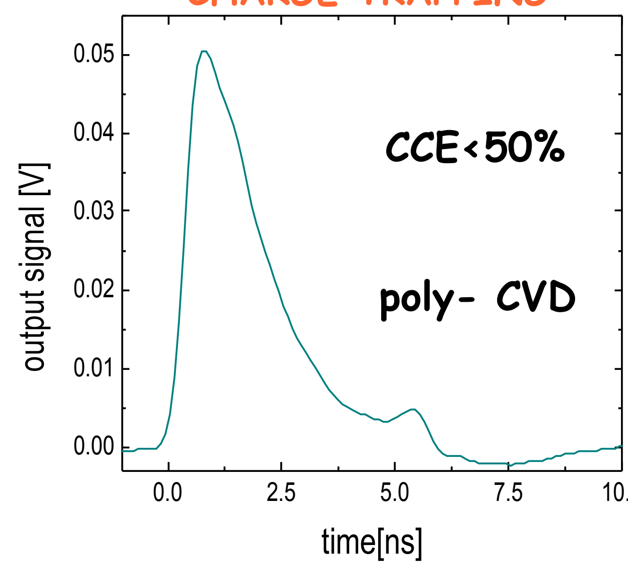


NEGTIVE SPACE CHARGE **(N_{eff}~$2.8X10^{11}$ cm^{-3})**



H. Pernegger Journal of Applied Physics 97, 073704 (2005)

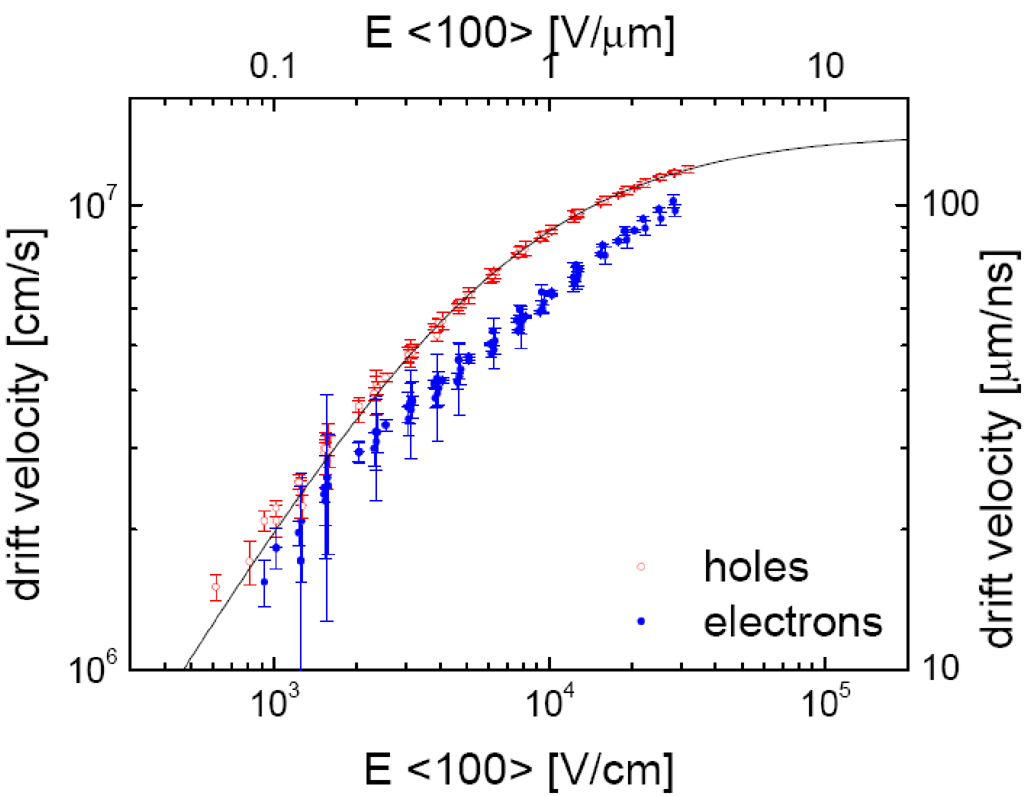
CHARGE TRAPPING



$$V_{dr} = \frac{\mu_0 \cdot E}{1 + \frac{\mu_0}{v_{sat}} \cdot E}$$

Velocity and mobility

DATA POINTS FROM 6 SAMPLES



holes (one fit)

$\mu_0 \cong$ **2400 [cm²/Vs] (±300)**

$V_{sat} \cong$ **140 [µm/ns]**

electrons (individual fits)

$\mu_0 \cong$ **1400 – 3100[cm²/Vs] (±600)**

$V_{sat} \cong$ **120 - 190 [µm/ns]**

most probable

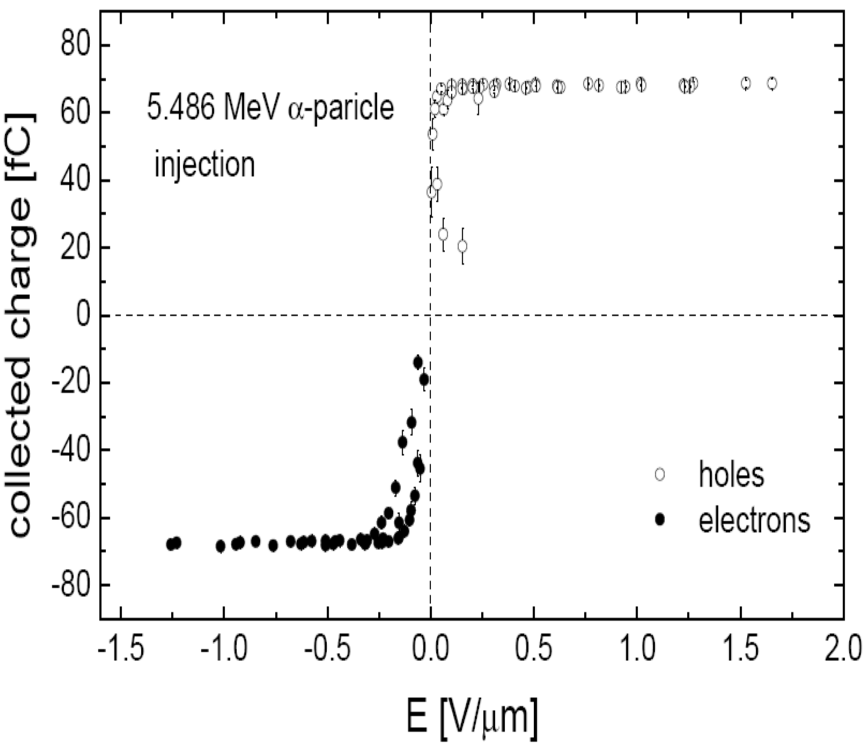
FAST DETECTOR :

~1 ns/100µm at high E

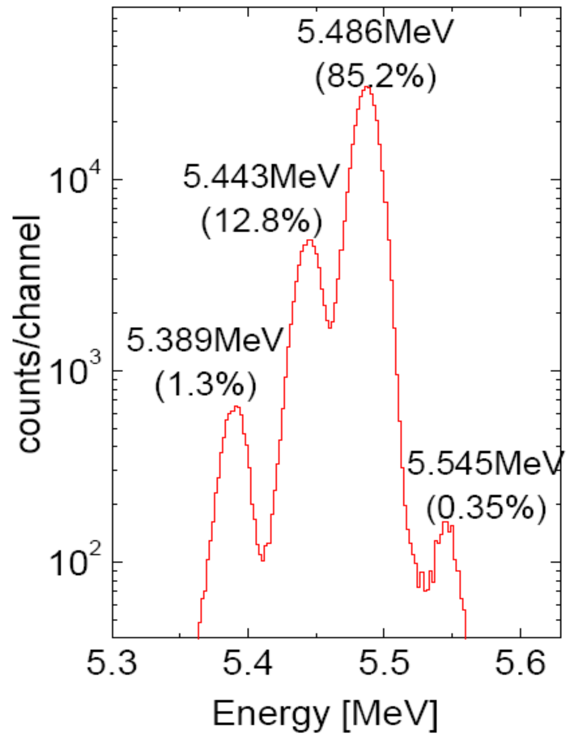
RISE TIME:

t_{rs}< 150 ps (electronics)

Charge collection – ΔE Spectroscopy



CCE ~100% at low E
for both e and h

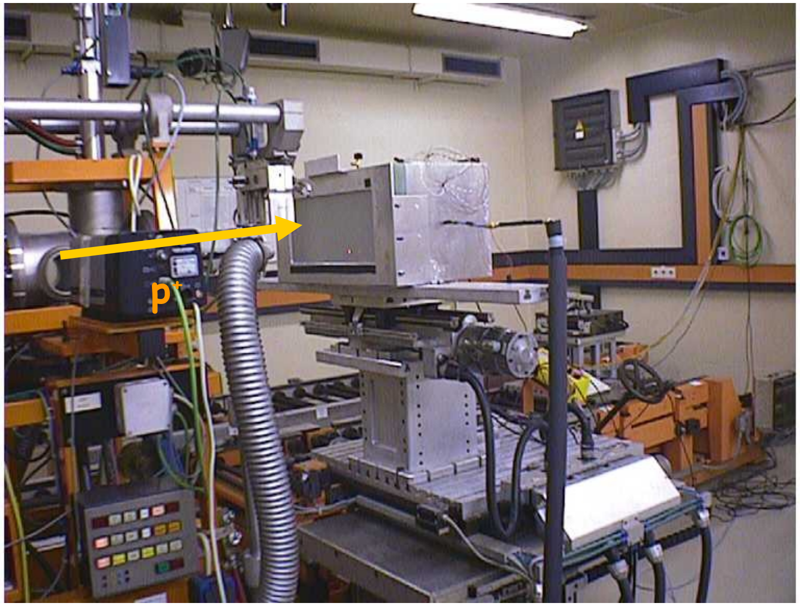


„spectroscopic" grade

17keV at FWHM

$$\Delta E = 2.355\sqrt{FE_0\varepsilon_i + (\Delta e/2.355) + a_1E_0^{a_2}}$$

Irradiation 26 MeV protons



Cyclotron facility in Karlsruhe

Continuous scanning of selected areas:
Beam currents used: 0.6μA, 6μA and 12μA

Homogeneous depth profile of irradiation for 300-500microns diamonds.

Off-line fluency verification- activation of Ni57 foils. Error ~2%

Three samples of different history used previously in heavy ion experiments at GSI:

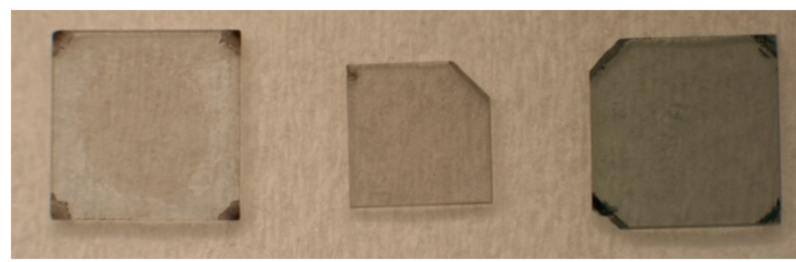
BDS14 – 4x4x0.49 mm3 – Cr(50nm);Au(100nm)

EBS3 – 3.5x3.5x0.39 mm3 – Cr(50nm);Au(100nm)

BDS13 – 4x4x0.48 mm3 – Cr(50nm);Au(100nm)

Total dose absorbed before irradiation is not known

BDS14	EBS3	BDS13



$6.39e10^{13}$	$6.11e10^{14}$	$1.18e10^{16}$

[p/cm^2]

Radiation related defects

Primary damage from impinging particle:

Vacancies (immobile at RT) + interstitials (mobile at RT)

damage due to knock-on carbon atom → clusters

Self-annealing during irradiation

A „Zoo" of radiation induced defects:

Known

- ND1 – negative-monovacancy (V^-) — low production in IIa type
- GR1 – neutral mono-vacancy (V^0) (~2.3eV migration energy)

and almost known...

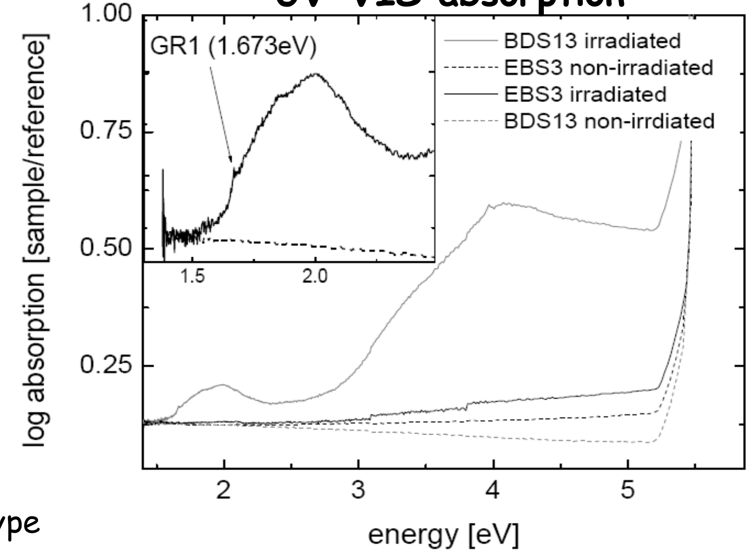
- 5RL with ZPL at 4.582 eV
- 594.4nm
- 1570.3 cm^{-1} - interstitials ....

→ trapped interstitials, clusters..and others

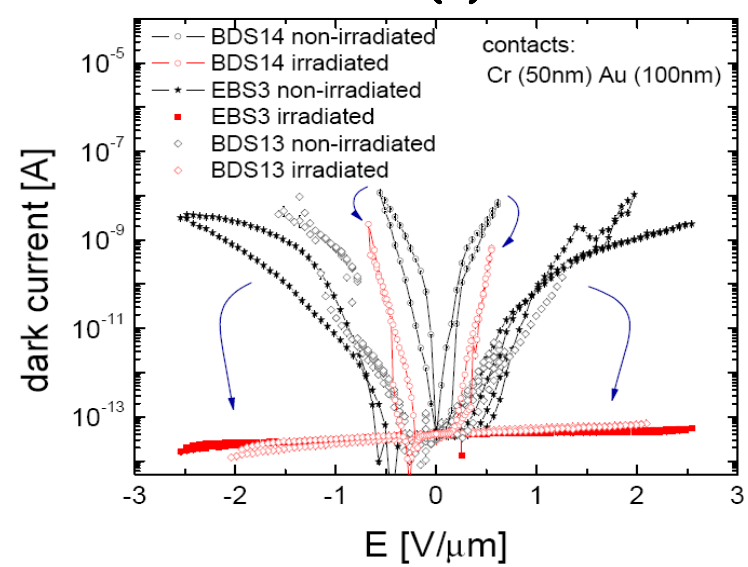
rather complicated .....

but how these affect charge carriers transport ?

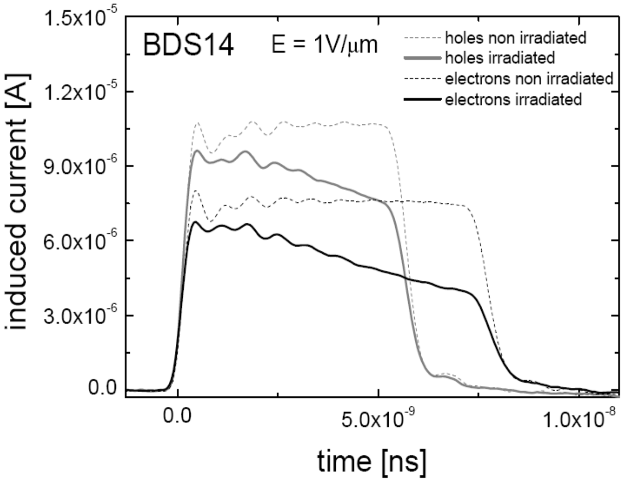
UV-VIS absorption

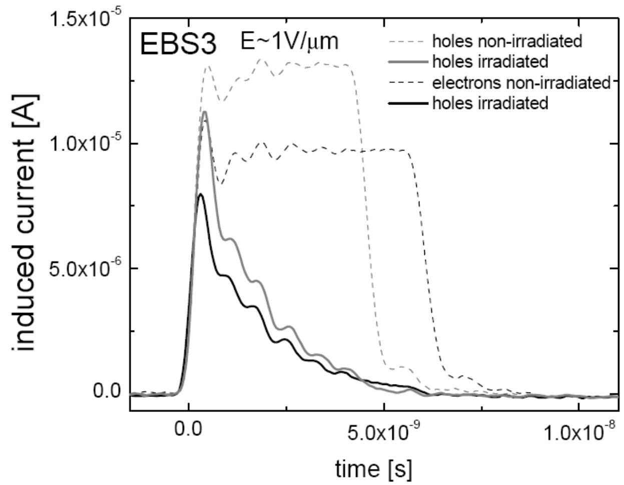


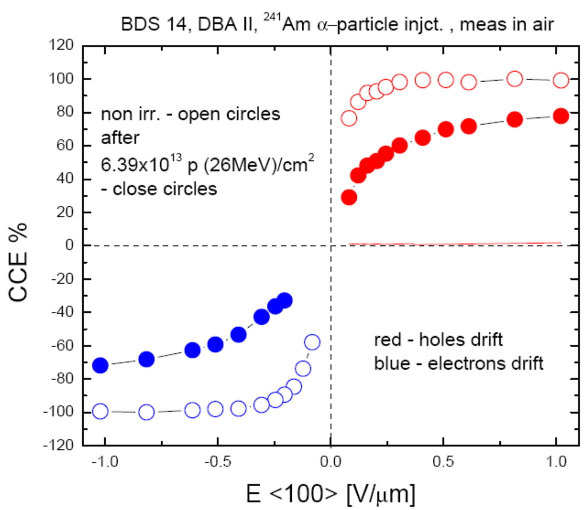
I-E(V)

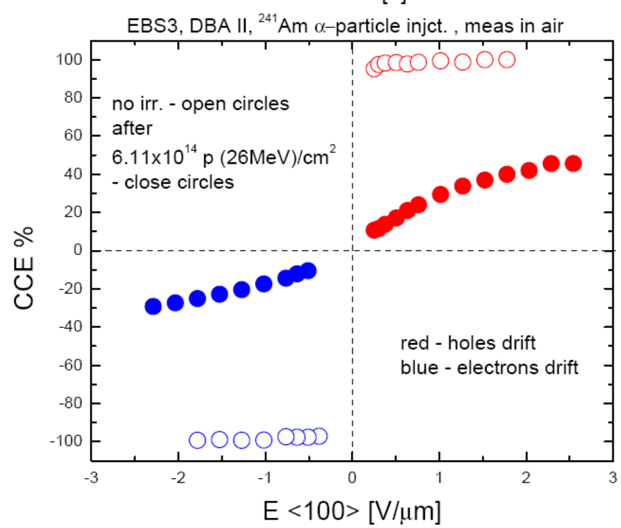


Transient signals after irradiation









Samples annealed at 400°C

only 100 events per step ~30s

exponential decay due to trapping

transient time does not change
→not visible space charge

creation of neutral defects (?)

BDS13 – gives no TC signals

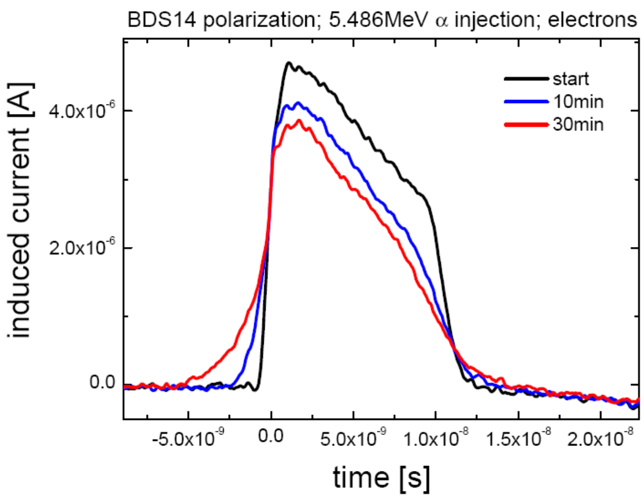
very short life time <100ps

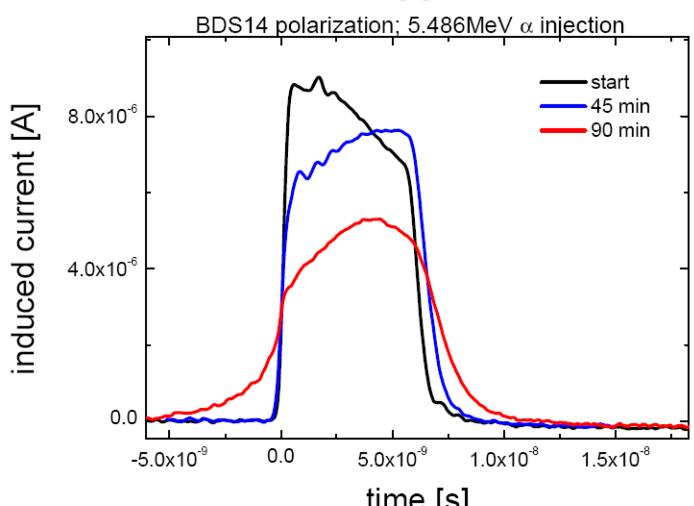
Bandwidth and noise limitation

CCE % is not a good parameter – thickness dependence

Traps passivation – priming effect

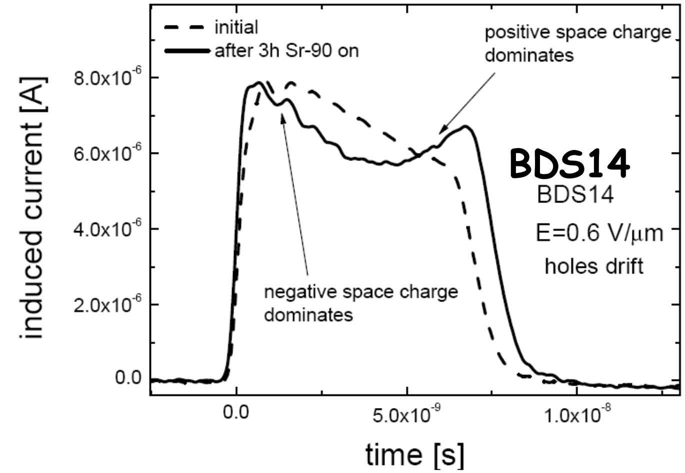
stopped particles → polarization

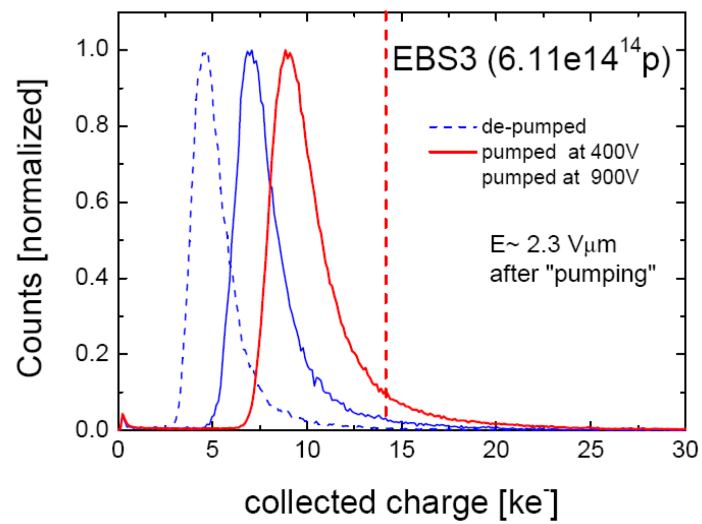




E(int) vanishes → no signals after a while

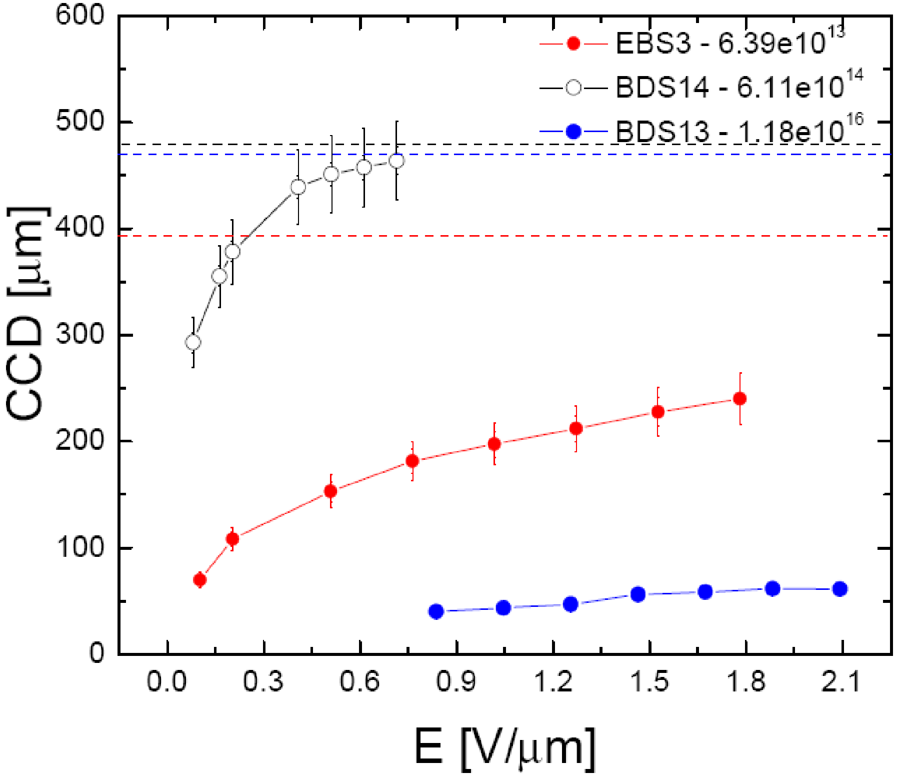
traversing particles → stable operation

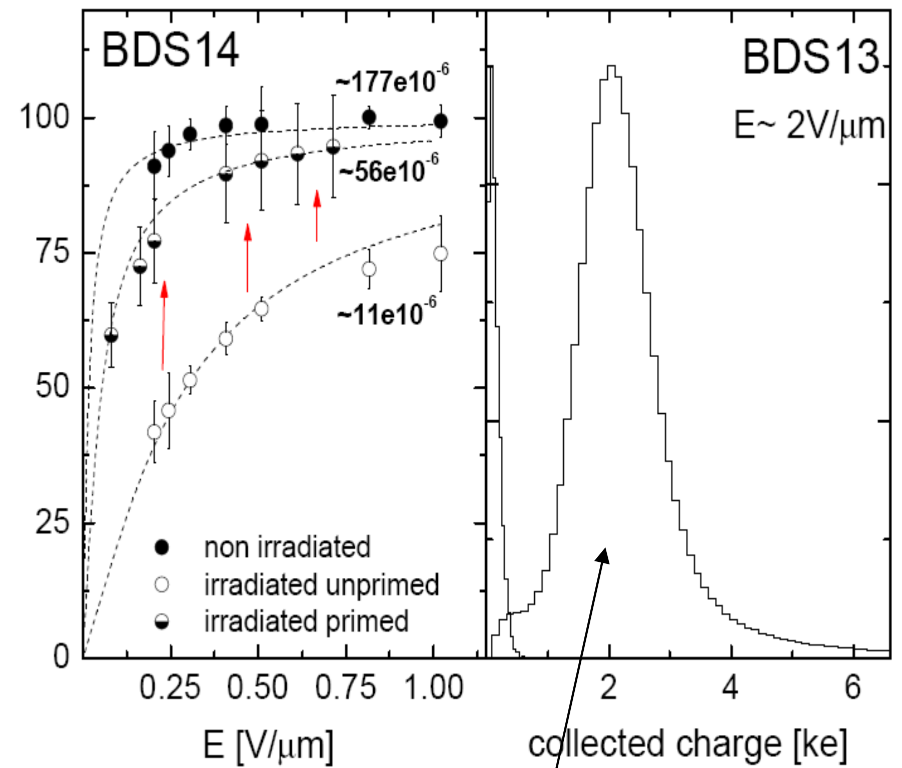




T_{eff} increases → better CCE

CCE after priming



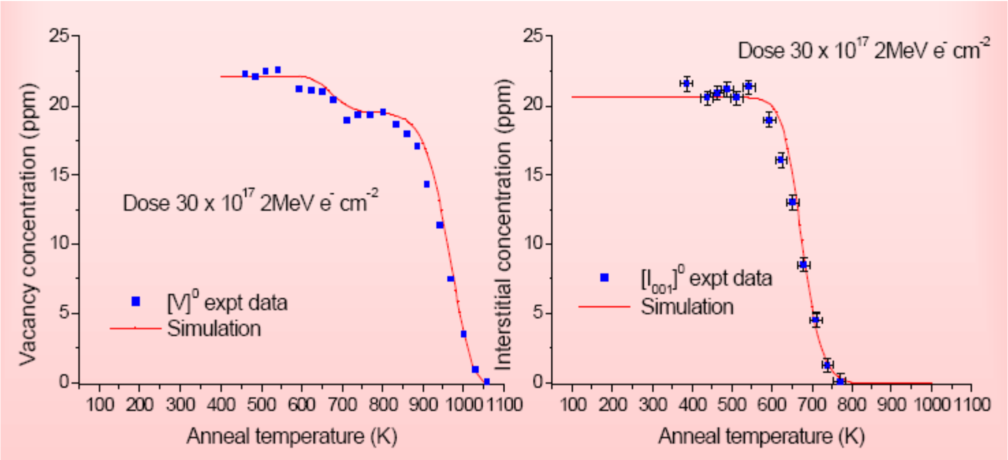


$CCD = Q_{coll}/Q_{gen}*d$

after 1.18e10^{16} 26MeV p/cm^2

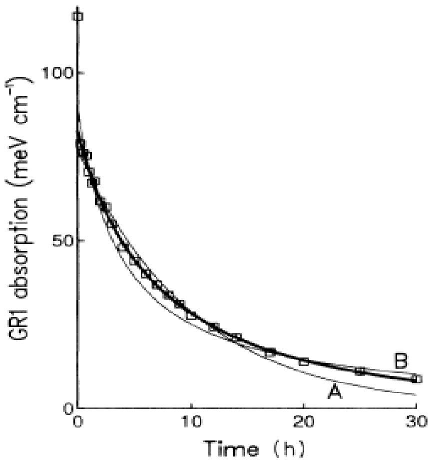
Defects annealing

A. Mainwood et al.



temperature dependence

C. Lawson et al.



dynamic at 700^{0}C

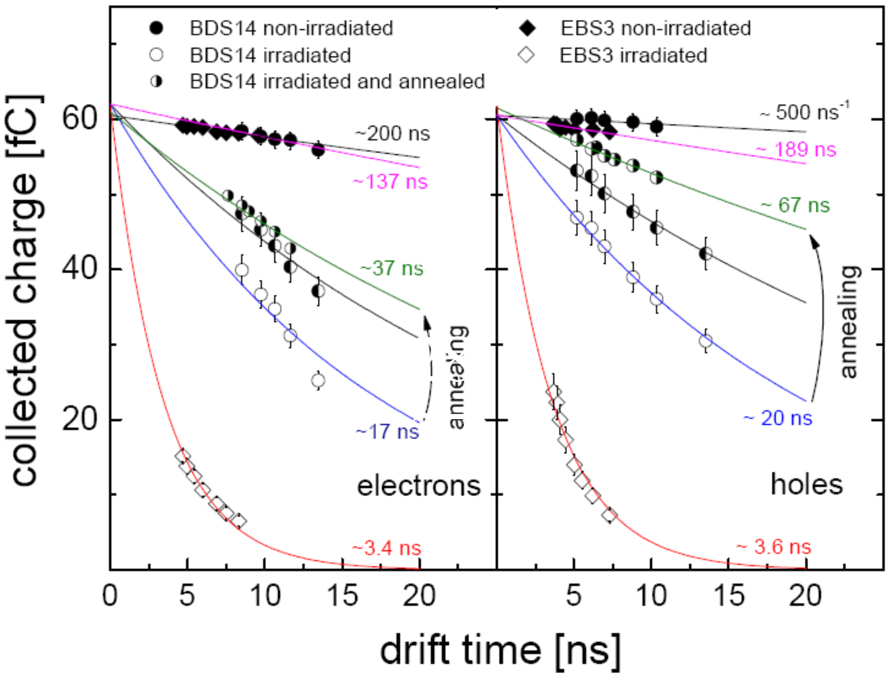
ND1 > 500^{0}C;
GR1 annealing > 650^{0}C

... but vacancies become mobile ... can form new centers

H3 A-aggregate bound to two vacancies > 1400^{0}C
NV and NV- nitrogen-vacancy pairs >1500^{0}C
and others...

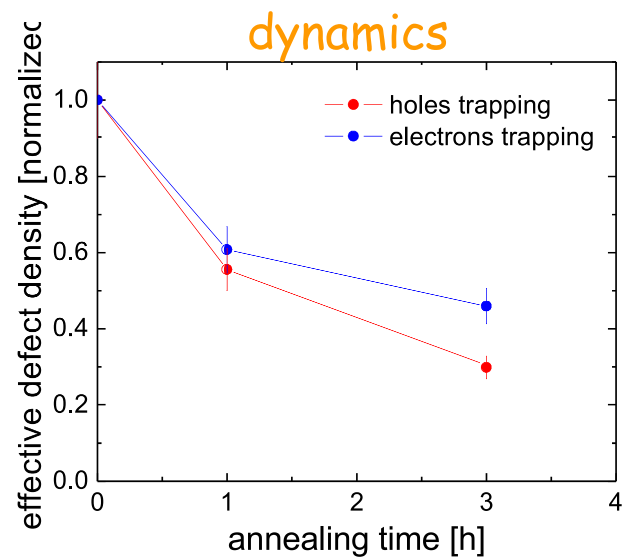
τ_{eff} – effective trapping time

$$Q_{coll} = Q_{gen} \cdot \exp\left(-\frac{t}{\tau_{eff-e,h}}\right)$$



a good parameter τ_{eff} ......
and even better ... t_{tr}/τ_{eff}

Annealing at 1000°C in Ar



$1/\tau eff \sim N_{A,D}$

~70% „holes active" defects annealed out
~50% for „electrons active"

Higher activation energy(?), different order kinetics(?)

SUMMARY

Non-irradiated SC CVD Diamond detectors:

- high purity intrinsic material → suitable for ΔE spectroscopy
- τ_{eff} >> transient time --> **CCE ~ 100%** at low E
- high and comparable charge carriers velocity
- operation close to drift velocity saturation range; transient signals **1ns/100µm**

Heavily irradiated SC CVD Diamond detectors:

- creation of deep donors and acceptors
- strong decrease of leakage current → no contribution to the noise
- symmetrically decrease of τ_{eff} for e and h after irradiation
- no space charge observed → mainly neutral defects(?)
- priming effect → polarization and increase of τ_{eff} for traversing particles
- created defects can be annealed but asymmetry in defects annealing for e and h

Thanks

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Target Laboratory crew of GSI:

Bettina Lommel,
Annett Huebner,
Willi Hartmann
Birgit Kindler
Jutta Steiner

... and thanks for your attention ...