Characterization of SC CVD diamond detectors for heavy ions spectroscopy and MIPs timing

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ABOUT SAMPLES

SC CVD diamonds → producer e6

SC-E6-4 → 3.5 x 3.5 x 0.48 mm³; Cr(50 nm) Au (100 nm)
BDS-5 → 5 x 5 x 0.325 mm³; Cr(50 nm) Au (100 nm)
BDS 7 → 5 x 5 x 0.318 mm³; Cr(50 nm) Au (100 nm)
BDS 9 → 5 x 5 x 0.32 mm³; Al(100 nm) guard ring
BDS 10 → 5 x 5 x 0.3 mm³; Al(100 nm) guard ring
BDS 14 → 5 x 5 x 0.49 mm³; Al(100 nm) guard ring

Cleaning and oxidation before metallisation:
If metallised before → Aqua Regia
H₂SO₄ + KNO₃ boiling ~30 min → rinse with ultra-pure water ultrasonic bath → dry with N₂

Metallisation sputtering or evaporation at Target Laboratory of GSI → Bettina Lommel talk
Cr(50 nm) Au(100 nm) ; Ti(30 nm) Pt(50 nm) Au(100 nm); Al(100 nm) → annealing 500°C for 10 min
Ar
• Current-Voltage characteristics and surfaces influence
• Charge collection properties and stability
• Energy resolution
• Timing properties
• Summary
CURRENT-VOLTAGE CHARACTERISTICS

 bulk + surface current

 screened box, no light + N₂ flow

 „Zoo“ of I-V characteristics

 - not reproducible I-V for various samples
 - asymmetry

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CURRENT-VOLTAGE CHARACTERISTICS

bulk current

screened box, no light + N\textsubscript{2} flow

top electrode

guarded electrode

ring electrode

guard

6517
V-source

6517
Picoammeter

no difference in I-V for:

- various metallisation (Al, Cr, Ti)
  (2 samples tested)

- guarded electrode \rightarrow
  mainly bulk leakage current
  (3 samples tested)

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AFM pictures of both diamond (BDS14) surfaces

substrate side (?)

roughness
rms ≈ 5.6 [nm]

growth side (?)

roughness
rms ≈ 1.4 [nm]
Asymmetry in I-V characteristic is present due to surface damage (polishing?) ... scratches „pop up” after samples annealing...

Annealed in 600°C, 30 min

\[ I_a \gg I_b \]

**CURRENT-VOLTAGE CHARACTERISTICS**

- Damaged surface
- Substrate side (unknown)
- Leakage current
- Growth side (unknown)
Long term stability

SC-E6-4
Cr;Au

Dark current [A]

Bias [V]

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- Use of an \( \alpha \)-source \( ^{241}\text{Am} \) (5.486 MeV) for charge injection

- \( \alpha \)-particle range in diamond \( \sim 12 \mu \text{m} \)

- detector thickness \( > 320 \mu \text{m} \), induced charge \( \rightarrow \) mainly motion of one type of carriers

- Choosing the HV +/- \( \rightarrow \) drift of holes or electrons

- presented geometry \( +HV \) – holes drift, \( -HV \) - electrons drift

- detector coupled to classical spectroscopy front-end electronic
Saturation to ~ 68.6 [fC] for both electrons and holes drift.

CCE=100% at low electric field < 0.3 V/mm

68.6 [fC] \rightarrow 429 372 e-h

Average energy for e-h pair creation \rightarrow 12.8 eV/e-h
DETECTION STABILITY

Time of spectrum collecting > 12h

SC\textsubscript{6}E6-4

BDS 9

BDS 14

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\end{figure}
DETECTION STABILITY

BDS 10

Indication of presence for electrons:
- regions with 100% efficiency → main peak
- region with lower efficiency 93%, quite uniform density of trapping centres → shifted peak

BDS 10 E~0.8 V/µm
5000 events

release of previously trapped electrons
Diamond resolution close to silicon detectors:

**FWHM = 17 keV** (5.486 MeV) (sc-e6-4 holes) measured with not dedicated CS electronics

silicon $\rightarrow$ e$\sim$3.6 eV/e-h; diamond $\rightarrow$e$\sim$12.8 eV/e-h

We are close to statistical limits (Fano factor?)

![Energy Resolution Diagram](image)
Time of Flight Technique

Low impedance of 50 Ω voltage amplifier
DBA – II, bandwidth 2.3 GHz (3dB), gain 44dB

Digital Scope
bandwidth 3GHz, 20GS/s
TIMING PROPERTIES

Average signals from 500 single shots

BDS9 holes drift

E = 1.23 V/µm

E = 0.03 V/µm

output signal [V] vs. time [s]

0.10
0.05
0.00
-0.05
-0.10

0.0
1.0 x 10^6
2.0 x 10^6
3.0 x 10^6

electronics oscillation 2GHz due to 50ohm mismatching

BDS10 holes drift

E = 1.25 V/µm

output signal [V] vs. time [s]

0.00
0.05
0.10
0.0
1.0 x 10^6
2.0 x 10^6
3.0 x 10^6

SCB4 sample thick. = 393 µm holes drift

BDS9 electrons drift

E = 1.23 V/µm

output signal [V] vs. time [s]

0.12
0.08
0.04
0.00

0.0
1.0 x 10^6
2.0 x 10^6

SCB4 electrons drift sample thickness 393 µm

BDS10 electrons drift

E = 1.25 V/µm

output signal [V] vs. time [s]

0.12
0.08
0.04
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0.0
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Assuming uniform internal electric field (flat top of BB signals) and CCE=100%

\[ v_{dr}(E) = \frac{d}{t_{tr}} \]

d – detector thickness
\( t_{tr} \) – transition time \( \rightarrow \) FWHM of BB signals

error \( \rightarrow \) standard deviation of signals at FWHM
Drift velocities for electrons and holes
TIMING PROPERTIES

$$V_{dr} = \frac{\mu_0 \cdot E}{1 + \left(\frac{v_{sat} \cdot E}{\mu_0}\right)^\beta}$$

holes

$$\beta \approx 1$$

electrons

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

2 fits:

0.3 – 1 V/μm → $\mu_0$

1 – 3 V/μm → $v_{sat}$

Holes

$\mu_0 \approx 2332$ [cm$^2$/Vs]

$V_{sat} \approx 140$ [μm/ns]

electrons

$\mu_0 \approx 1400 - 3100$[cm$^2$/Vs]

$V_{sat} \approx 190$ [μm/ns]
Current voltage characteristics

• huge difference in leakage current for various samples

• no difference for guarded samples → mainly bulk leakage

• Asymmetry in I-V probably due to damaged surface as a result of samples polishing → requires overgrowth after polishing

• No difference for various metallisation → proposal to use light elements e.g. Al
charge collection, stability, and \( \Delta E \)

- CCE \( \sim 100\% \) at low \( E < 0.3\, \text{V}/\mu \) for holes and electrons – most of tested samples
- all samples \( \rightarrow \) “spectroscopic grade” some of them resolution close to silicon detectors
- perfect behavior for holes drift – no trapping (or negligible)
- most of them stable as well for electrons drift
Timing properties

- flat top of BB signals for all tested samples – uniform internal electric field – no internal space charge
- common behavior -->
  holes drift velocity > electrons drift velocity in <100>
- intrinsic limit for timing application with CSA electronic drift of electrons 1ns / 100 µm (optimistic E=2.8V/µm)
- uniform rise time of ~160 ps (limited by electronics) jitter - 26 ps for BB electronic