Single Crystal CVD Diamond Position-Sensitive Detectors using DLC resistive electrodes

M Pomorski\textsuperscript{1}, K Desjardins\textsuperscript{2}, S Hustache\textsuperscript{2}, C Mer\textsuperscript{1}, J Morse\textsuperscript{3}, M Rebis\textsuperscript{1}, D Tromson\textsuperscript{1} and P Bergonzo\textsuperscript{1}

\textsuperscript{1}Diamond Sensors Lab, CEA, LIST, Saclay France
\textsuperscript{2}The SOLEIL Synchrotron, Saclay, France
\textsuperscript{3}ESRF, Grenoble, France
Motivations

Probing the beam characteristics (position, intensity, profile) at low energies and with a semitransparent material

- in front end (white light, high fluences – $10^{17}$ ph./s)
- in beam lines (monochromatic light, $10^8$ – $10^{13}$ ph/s)
Motivations

- Synchrotron beam monitoring

  Z=6 → low specific X-ray absorption / beam scattering

  Wide bandgap energy (~5.5 eV), excellent thermal/mechanical properties

Si PSD permanently damaged after 1 month in the beam

- Damaged area photo
- XBIC of the Si PSD
Semitransparent BPMs
- high transparency (low Z)
- fluence hardness
- temperature hardness
- mechanically resilient

Realisations have included
- Intensity monitors
- Beam position monitors \( \rightarrow 2\mu m \)
- Beam Profile monitors

Detector Fabrication

Diamond growth

- ASTEX 5400
- p-CVD diamond
- 4 inches and 2 inches
- Flame type deposition plasma
- sc-CVD diamond

Si, Ir, quartz, SiC
Detector Fabrication

Diamond growth

As introduced substrates →
- Reproducible polishing
- Analysis on 50 x 50 µm²
- Space between lines: 20 nm
- RMS: 3 nm
- Maximum peak to Valley: 8 nm

AFM measurements

Plasma pre-treatment →
- remove polishing traces (stress + stripes)
- reduce surface defects
- be up to make reproducible growth

Growth
Detector Fabrication

**Diamond bulk**

Laser cut + polishing

**DLC deposition on diamond surfaces**

DLC Surface morphology influence

<table>
<thead>
<tr>
<th>resistance [ohm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10M</td>
</tr>
<tr>
<td>1M</td>
</tr>
<tr>
<td>100k</td>
</tr>
<tr>
<td>10k</td>
</tr>
<tr>
<td>1k</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>120</td>
</tr>
<tr>
<td>180</td>
</tr>
<tr>
<td>240</td>
</tr>
</tbody>
</table>

Target region

- side B
- side A

**Free standing plates**

- 4 mm
- 5 mm

- 2 nm rms

- 20 nm rms
Detector Fabrication

Metal collecting electrodes (Cr/Au)

- shadow masks
  - easy
  - clean surfaces
  - any metal
  - fuzzy edges
  - relatively large motives
  - problems with positioning

- negative photo-lithography
  - sharp edges
  - clean surfaces (no resin processing prior metal dep.)
  - small motives
  - quite tricky for double side processing

4 mm
- detector bulk consists of scCVD electronic grade diamond
- prototypes active area up to 4 x 4 mm possible - thickness 40-500 µm
- resistive electrodes made of robust thin DLC layer (entire active area made of C)
- charge sensitive readout ... but current readout possible (pulsed and continuous)
- position sensitive single particle detection and energy spectroscopy possible
Principles of the Duo-lateral scCVD-PSD

Position coordinates from signal division:

\[ X = \frac{A(x_1) - A(x_2)}{A(x_1) + A(x_2)} \cdot \frac{L}{2} \]
\[ Y = \frac{A(y_1) - A(y_2)}{A(y_1) + A(y_2)} \cdot \frac{L}{2} \]
Detector characterization: pulsed mode

20kBq $^{241}$Am source
4.8 MeV α-particles
measurement in air

Electronics:

4 fast TCSA (M. Ciobanu of GSI, Darmstadt) with ~100ns rise time
3GHz DSO LeCroy (limited BW) for signal processing and 'histogramming'

not the best set-up possible regarding the s/n ratio (current s/n ~100)
Irradiation through Calibration Masks

Full Area Irradiation and the Cushion Distortion Correction (Pulsed Mode)

Irradiation through Calibration Masks

Calibration mask - squared pcCVD diamond with laser drilled micro-holes

diam. ~30 µm, dist. ~200 µm

Energy resolution for ~4.8 MeV α-particles

\[ \Delta E/E = 2.4\% \]

PHD ~ 7%

Energy res. limited by electronics used
**Linearity and Position Resolution**

- **Detector cartography**
  - 3D Gaussian fits

- **Detector active area as seen with OM**
  - Diffused edges of metal electrodes
  - Some defects in the DLC layer

**Position resolution (FWHM)** ≤ 1% of L

**Global linearity** ≤ 2%

!! Easy to improve in future devices !!
In-beam Performance: DC mode

ESRF, Grenoble, ID06
Beam energy: 10.5 keV
Beam size: 100 x 100 μm (slits)
Beam flux: 1.6 x 10^{11} ph/sec
Flux absorbed = 1.56 x 10^8 ph/sec/μm

Soleil, Gif-sur-Yvette, Proxima1

4 x Keithley 485’s electrometers
10Hz bandwidth - a ‘DC’ mode

Integral absorbed dose ~0.3 Giga Gy
no radiation damage signs
In-beam Performance: I-V, XBIC, intensity monitoring

**X-ray beam induced current**

![Graph showing X-ray beam induced current](image)

- **XBIC - normalized to beam decay Si diode (a.u.)**
- **leakage current**
- **breakdown**
- **Signal region**

- **bias voltage [V]**
- **0.05 V/µm**

- **bias voltage [V]**
In-beam Performance: I-V, XBIC, intensity monitoring

Beam intensity monitoring $X_1+X_2$ or/and $Y_1+Y_2$

![Graph showing beam intensity monitoring](image.png)
In-beam Performance: I-V, XBIC, intensity monitoring

Beam intensity monitoring $X_1 + X_2$ or/and $Y_1 + Y_2$

S/N > 3 decades
In-beam Performance: I-V, XBIC, intensity monitoring

Beam intensity monitoring $X_1 + X_2$ or/and $Y_1 + Y_2$
Beam drift

In-beam Performance: I-V, XBIC, intensity monitoring

Beam drift

X beam position [µm]

Y beam position [µm]

Time [min]
In-beam Performance: linearity, position resolution

Detector cartography

Fine raster scan with 25µm step (80x80 points)

Calculated vertical distance from centre (mm)

Calculated horizontal distance from centre (mm)

No pincushion, barrel distortion for 10 Hz

Step motors crash

Integral absorbed dose ~0.3 Giga Gy

No radiation damage signs
In-beam Performance: linearity, position resolution

**Detector cartography**

Fine raster scan with 25µm step (80x80 points)

**Local linearity**

FWHM 0.51 µm 0.10%

FWHM 1.15 µm 0.25%

Calculated vertical distance from centre (mm)

Calculated horizontal distance from centre (mm)

Counts

residuals [µm]
In-beam Performance: linearity, position resolution

Position resolution capability

FWHM_x = 247 nm
FWHM_y = 259 nm
Summary

Today scCVD-PSD prototypes

- Duo-lateral configuration & Pulse mode
- Cushion distortion compensation
- Stable and reliable
- Position: resolution in the 250 nm range
- Intensity: S/N > 3 decades

Future developments

- Radiation hardness tests
- Performance with high thermal load - ‘white beam’ applications
Acknowldgments

Dr. Mircea Ciobanu, GSI, Darmstadt, for development and providing of FCSAs used for the PSDs characterization

The authors wish to thank Hugo Riemis of WTOCD (Lier, Belgium) for laser processing of the diamond calibration masks

Thank you for your attention