Analysis of CVD Diamond Pad Detectors

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Michael Reichmann

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Section 1

Introduction
• diamond used as beam condition monitors at LHC
• diamond as future material for tracking detectors in high radiation areas
Introduction

- diamond used as beam condition monitors at LHC
- diamond as future material for tracking detectors in high radiation areas

Properties

- radiation tolerant
- isolating material
- high charge carrier mobility
• diamond used as beam condition monitors at LHC

• diamond as future material for tracking detectors in high radiation areas

Properties

• radiation tolerant

• isolating material

• high charge carrier mobility

Investigation of Rate Effects:

• Pad Detectors $\rightarrow$ whole diamond as single cell readout

• Pixel Detectors $\rightarrow$ diamond sensor on pixel readout chip

• 3D Pixel Detectors $\rightarrow$ 3D diamond detector on pixel readout chip
Introduction

- diamond used as beam condition monitors at LHC
- diamond as future material for tracking detectors in high radiation areas

Properties

- radiation tolerant
- isolating material
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Investigation of Rate Effects:

- Pad Detectors → this talk
- Pixel Detectors
- 3D Pixel Detectors
• several beam test starting from May 2015

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Irradiation [n/cm²]</th>
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</thead>
<tbody>
<tr>
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<td>0</td>
</tr>
<tr>
<td>poly A</td>
<td>pCVD</td>
<td>0</td>
</tr>
<tr>
<td>poly B</td>
<td>pCVD</td>
<td>0</td>
</tr>
<tr>
<td>poly C</td>
<td>pCVD</td>
<td>(1 \cdot 10^{14})</td>
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<tr>
<td>poly D</td>
<td>pCVD</td>
<td>0</td>
</tr>
<tr>
<td>poly E</td>
<td>pCVD</td>
<td>(5 \cdot 10^{14})</td>
</tr>
<tr>
<td>poly F</td>
<td>pCVD</td>
<td>(0 \sim 3.5 \cdot 10^{15})</td>
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<td>poly G</td>
<td>pCVD</td>
<td>(0 \sim 8 \cdot 10^{15})</td>
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<tr>
<td>poly H</td>
<td>pCVD</td>
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</table>

Table: Measured diamonds and irradiations.

• irradiation with thermal neutrons at Ljubljana
• irradiations in steps and always remeasured
Section 2

Test Site
- High Intensity Proton Accelerator (HIPA) at PSI (Cyclotron) → beam line PiM1

- clean positive pion beam ($\sim 98 \% \pi^+$) with momentum of $260 \text{ MeV/c}$
  - $\frac{3}{4}$ smaller signals than at CERN! ($120 \text{ GeV/c}$)

- tunable particle fluxes from $\mathcal{O}(1 \text{ kHz/cm}^2)$ to $\mathcal{O}(10 \text{ MHz/cm}^2)$

- significant multiple scattering → worsens resolution
Section 3

Setup
Figure: Modular Beam Telescope

- 4 tracking planes → trigger (fast-OR) with adjustable effective area
- diamond pad detectors in between tracking planes
- low time precision of fast-OR trigger (25 ns)
- fast scintillator for precise trigger timing → $\mathcal{O}(1 \text{ ns})$
- PSI DRS4 Evaluation Board as digitiser for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger: using coincidence of FOR 2 and FOR 3 + scintillator signal
- using custom built Trigger Unit (TU) to handle all the trigger logic
Pad Detectors

- building the detector: cleaning, photo-lithography and Cr-Au metallisation
- gluing to PCBs in custom built amplifier boxes
- connecting to low gain, fast amplifier with $O(5\text{ ns})$ rise time
Section 4

Measured Currents
• typical rate scans for up to \(\sim 30\) h with rates up to \(\sim 20\) MHz/cm\(^2\)

• beam induced current clearly visible

• low leakage currents \((<10\) nA) at 2 V/\(\mu\)m
beam induced current increases linearly with increasing flux

interpolated leakage current: 2.63 nA
• also observe slowly changing base lines (2/10 scans)
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- high spikes and erratic currents (mainly at high fluxes, 1/10 scans → excluded from further analysis)
Section 5

Analysis
Waveforms

- most frequent peak (@ $\sim 35$ ns) $\rightarrow$ signal from triggered particle
- other peaks from other bunches $\rightarrow$ resolve bunch spacing of PSI beam: $\sim 19.8$ ns
- signals in pre-signal bunch forbidden $\rightarrow$ noise extraction

**Figure:** Peak timings.
- perform DRS4 timing correction (circular buffer with varying cell size: $(0.5 \pm 0.3)$ ns)
- define signal region: $\sim \pm 10$ ns around peak of the triggered signal $\rightarrow [60$ ns, $80$ ns]
- signal: finding the peak in the signal region and integrate around it $[-4$ ns, $6$ ns]
- pedestal: same integral in the centre of the pre-trigger bunch $\rightarrow [40$ ns, $60$ ns]
• left length = integration width to the left of the peak position

• optimise SNR by scanning the integral width in both directions

• maximum values around the FWHM of the peak

• wide plateau around the maximum
Event Cuts

- separate pedestal and signal

**Exclude Events:**
- saturated
- pulser
- incomplete tracks
- wrong peak timing
- outside fiducial region
- during beam interruption

**Also cuts on:**
- track $\chi^2$ in x- and y-direction
- track slope
- pedestal sigma

- after all cuts usually $\sim 25\%$ event left
(a) Track angle in $X$

(b) Track angle in $Y$

- only take events with $\pm 1^\circ$ around the most probable slope
- slope has direct influence on the track length inside the sensor
- slope distribution slightly changes in every setup
noise distribution agrees well with Gaussian even at high rates

extract noise by taking the sigma of the Gaussian fit

noise very similar for scCVD and pCVD diamond
**Signal Distributions high rate**

(a) scCVD (6 dB attenuation)

- correction by the mean of the noise (baseline offset)
- pCVD signal smaller and wider (less uniform)

- FWHM/MPV:
  - sCVD: $\sim 0.3$
  - pCVD: $\sim 1.0$
Signal Maps

(a) scCVD (6 dB attenuation)

- uniform signal distribution in scCVD

(b) pCVD

- signal corresponding to wide Landau in pCVD
rate scaled to the mean

- scCVD diamond shows now rate dependence within the measurement precision
- noise stays constant
- Rate scaled to the mean
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- Noise stays constant
rate scaled to the mean

most non-irradiated pCVD diamonds have slight rate dependence (<5 %)

behaviour very similar for both positive and negative bias voltage
rate scaled to the mean
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A Special Case

(a) First measurement.

(b) After reprocessing.

- very large rate dependence at the first measurement (>90%)
- after reprocessing and surface cleaning with RIE very stable behaviour (∼2%)
- possible to “fix” bad diamonds
- largest increase of pulse height found so far
- all measurements very continuous and reproducible
- only very weak theories for this behaviour → try to model it
- try to fix by reprocessing
Rate Studies in Irradiated pCVD

- rate scaled to the mean
- pulse height very stable after irradiation
- noise stays the same
Conclusion

- built beam test setup to characterise the rate behaviour of diamond pad detectors
- most leakage currents $< 10\,\text{nA}$ and beam induced currents linear with flux
- pCVD diamond show non-uniformity according to wide landau of the signal depending on the position in the diamond
- nonirradiated scCVD show no rate dependence (large in irradiated)
- rate dependence for most non-irradiated pCVD $< 5\%$
  - unknown origin, maybe surface contamination during production
  - possible to fix it for one sample $\rightarrow$ try to repeat it
- detectors with irradiated pCVD diamond sensors have a rate dependence below $\sim 2\%$ up to a flux of $20\,\text{MHz/cm}^2$
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