3D Diamond Detectors

Alexander Oh
3D Diamond Research

• **2009: Small Collaboration (Manchester/Saclay/CERN)**
  – **Manchester:** Alexander Oh, Stephen Watts, Mahfuza Ahmed, Cinzia Da Via
  – **CEA Saclay:** Benoit Caylar, Michal Pomorski
  – **CERN:** Thorsten Wengler

• **Started activity in 2009**
  – Cubic samples to study influence of grain boundaries (‘09)
  – Lasered graphitic structures in pCVD (‘10)
  – Single crystal with column structure (‘11)
  – Femto second laser for improved graphitic electrodes (‘12)
  – Several Prototypes tested at **Diamond Light Source** and at **CERN test beam.**
3D Diamond Research

• **Growing in 2011**
  – Iain Haughton (Manchester)
  – Vladyslav Tychynevyi (Manchester)
  – David Whitehead (Manchester)
  – Lin Li (Manchester)
  – Lars Baeni (Zuerich)
  – Felix Bachmann (Zuerich)
  – Rainer Wallny (Zuerich)
  – Dmitry Hits (Zuerich)
  – Harris Kagan (Ohio)

• **2012:**
  Tested 3D sample with CERN test beam with the help of RD42. Zagreb RBI testbeam with proton IBIC.
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Graphitic structures

2011
• Work with CEA Saclay to fabricate graphitic bulk electrodes.
• Samples:
  – single crystal samples for normalisation.
  – Polycrystalline samples with structures
    • Ridge structures of varying width.
    • Graphite electrodes -> 3D

Michal Pomorski
Samples

• Set-up to measure four samples.
Results: pCVD diamond

• Three types of electrical contact patterns were tested:
  – Matrix of cones
  – Single graphitic cones
  – Trench structures
Results: pCVD diamond

• Matrix of cones
  – Area scan of matrix of columns
  – Embedded in a planar contacts
  – Allows to compare the signal response at the same bias voltage
  – Response of the matrix (red) is clearly visible and higher then the planar contact response (yellow).
Results: pCVD diamond

- Scan on **single columns** show strong non-uniform signal.
- Response pattern is dependent on polarity, different contribution from electrons and holes.
- Pattern likely related to grain-structure.
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Femto second laser for improved graphitic electrodes ('12)

See Benoit’s talk
3D Diamond Research

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femto second laser set-up (2012)

University of Manchester, Laser Processing Research Center.

- Wavelength = 800 nm
- Repetition rate = 1kHz
- Pulse duration = 100 fs
- Spot size = 10μm
- Pulse Energy:
  - $E = 700 \text{ nJ/pulse for scCVD diamond (absorber 5-4)}$
  - $E = 1.3 \text{ μJ/pulse for pcCVD diamond (absorber 5-1)}$
femto second laser set-up

- Some first results on single crystal diamond.
  - Find good parameters for continuous thin graphitic wirers.
  - Achieved ~3-5 μm diameter
  - R ~ 1 Ωcm (AF tip measurement)
Prototypes

**Batch 1 Samples**
- First 3D prototypes (SC, PC)
  - Good yield for PC, not so good for SC.
- 4 patterns
  - FE-I4, 2E readout
  - Cubic, 50um pitch
  - Cubic, 100um pitch
  - Cubic, 150um pitch
- First Beam test in July 2012.
  - Took several million events
  - First indication of signal collection.
  - Problems with metallization (Al).
  - Re-metallization procedure failed for second beam test.
Final detectors - 45° tilted

» First batch 70% success rate
$^{90}$Sr experiment to approximate MIP in lab
Charge collection efficiency measurement (Single Crystal – Batch 1)

HV = -200V

~65% CCE at maximum

Most probably due to bad metallization and photolithography process
Prototypes

• **Batch 2 samples**
  – Again SC and PC.
  – Larger active area.
  – Including strip detector and “no-hole” detector for calibration.
  – 2 patterns
    • cubic 100 um
    • cubic 150 um
  – Tested in August test-beam
    • only 150 um pattern was read-out.
    • took O(10^6) events at different bias voltages
    • clear signal in SC, PC had problems ! (see Lukas talk).
  – Radiated SC in Los Alamos to
    \( \sim 4 \times 10^{14} \text{ncm}^{-2} \)
  – Re-tested in October test-beam
    • Both SC and PC gave good signals.
    • Analysis ongoing
    • Some very preliminary results ->
CERN test beam (Aug/Oct/Nov)

- SPS H6 line
  - 120 GeV protons
  - spill every 40 sec
  - ~60-100k triggers per spill
- Strasbourg telescope
  - 2 x and 2 y planes in front of DUT
  - 2 x and 2 y planes in back of DUT
  - ~3.6k events recorded per spill
  - Scintillator trigger
- DUT pumped before the start of the first measurement and after changing the sign of the voltage
CERN test beam

- Fiducial Cuts defined by requiring hits in
  - a) Exactly one cluster in each silicon plane
  - b) + exactly one cluster in DUT
  - c) cuts used for analysis

Analysis Team:
- Lars Baeni (Zuerich)
- Felix Bachmann (Zuerich)
- Rainer Wallny (Zuerich)
- Dmitry Hits (Zuerich)
CERN test beam

- 3D single crystal CVD (batch 2)
  - Strip detector (16 strips, 50 μm spacing)
  - 3D no holes (9 strips, 150 μm readout,
  - 3D with holes (9 strips, 150 μm
CERN test beam

- 3D collects charge above w/o holes structure -> works!
- 3D area collects roughly the same charge as the strip detector, although smaller field
  - Strip ~ 10 kV/cm, 3D ~ 1.6 kV/cm
- Wider signal distribution -> Analysis in progress...

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Dmitry Hits (Zuerich)
IBIC @ RBI

- 4.5 MeV protons
- Single proton counting / irradiation possible
- Tested batch 1 SC and batch 2 pCVD 3D prototypes.
- Objective:
  - Map response with 4.5 and 4 MeV protons (~100 / 80 um penetration).
  - Lateral charge collection in 3D-> no polarisation!
IBIC @RBI

• Sample Holder and pcCVD batch 2 device
• Setup:
  – one strip A -> channel 1
  – two strips adjacent to A -> channel 2
• Response to 4.5 MeV protons.
• Areal response (~500x500 um):

  +5V  +10V  +20V
  -5V  -10V  -20V  -40V

• Response contained in basic cell.
• Electrodes / grains are visible.
• Pos and neg polarity different response, one carrier type dominates at low fields?
Spectra

- MP efficiency $\sim 50\% \sim 250\text{um}$ collection distance @-40V.
- Ub limited by noise, need to improve metalisation.
- Spectra extends up to 100% efficiency.
• Irradiate to $\sim 1e13$ and $1e14$ protons/cm$^2$, 4.5MeV.
• Probe beam 4.5 MeV.
• Analysis ongoing...
Conclusion

• Good progress made in the last three years towards 3D diamond detectors.

• CVD diamond samples with graphitic bulk electrodes were investigated with a micro-focused 15 keV photon beam and CERN test beam.

• 3D diamond configuration works for pCVD and single crystal diamond.

• Studies demonstrate the feasibility of 3D electrode structures in diamond.

• Last year’s progress has been very impressive, and a lot of work is ahead toward a real 3DD vertex detector.