Development of CVD Diamond Detectors for the LHC

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Outline of the Talk

✦ Introduction
✦ 2001/2002 Milestones
✦ Diamond Properties
✦ Tracking Studies
✦ Diamond Pixel Detectors
✦ Radiation Hardness Studies
✦ Summary and RD42 Plans

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♦ Spokespersons

Institutes from HEP, Heavy Ion Physics, and Solid State Physics
Introduction

Motivation: Tracking Devices Close to Interaction Region of Experiments

LHC + SLHC Issues:

→ Inner tracking layers must survive!
→ Inner tracking layers must provide high precision tracking to tag b, t, Higgs, ...
→ Annual replacement of inner layers perhaps?

Diamond Properties:

✦ Radiation hardness
✦ Low dielectric constant → low capacitance
✦ Low leakage current → low readout noise
✦ Room temperature operation, Fast signal collection time

Tracking Detector Implementation:

✦ Based on Chemical Vapor Deposition (CVD) Diamond
✦ Material goes Beyond Silicon in Radiation Hardness
✦ Signal Size and Uniformity? → Fred Hartjes, Andrew Whitehead
✦ Performance of Trackers? → Sung Han
✦ Pixel Detector Performance? → Bob Stone
✦ Radiation Hardness? → Fred Hartjes

Reference → http://rd42.web.cern.ch/RD42
Priorities of Research in 2001/2002

- Increase charge collection distance in a dedicated program with industry to $>250 \, \mu m$
- Test the tracking and radiation tolerance properties of the newest diamonds
- Establish the performance of pixel detectors with radiation hard front-end chips from ATLAS and CMS
- Establish the performance of large detectors
- Test diamond trackers with LHC specific electronics (SCTA128 chip). Irradiate modules, sensors and front-end chips together
- Finalize the geometry and metalisation of diamond LHC pixel detectors
**Characterization of Diamond:**

- **Signal formation**
- **Signal versus applied electric field**

- Metalization was typically Cr/Au or Ti/Au or Ti/W → new
- Typically operate at 1V/µm
- Drift velocity saturated
- Test Procedure: dot → strip → pixel
Diamond Properties

Growth side of a recent diamond.
In 2000 RD42 entered into a Research Program with DeBeers Industrial Diamond to increase the charge collected from diamond (→ talks by Fred Hartjes, Andrew Whitehead).

Latest Diamonds Measured with a $^{90}$Sr Source:

- System Gain = 124 e/mV
- $Q_{MP} = 62$mV $= 7600e$
- Mean Charge = 79mV $= 9800e$
- Source data well separated from 0
- Collection Distance now 275$\mu$m
- Most Probable Charge now $\approx 8000e$
- 99% of PH distribution now above 3000e
- FWHM/MP $\approx 0.95$ — Si has $\approx 0.5$
- This diamond available in large sizes

The Research program worked!
History of Diamond Progress

Charge Collection in DeBeers CVD Diamond

Collection Distance (microns)

Time (year)

RD42 Goal
The Linear Model

- Use 2 samples from the same wafer
- Mark the substrate side on one, the growth side on the other
- Remove material from the unmarked side
Could we make a diamond detector with improved characteristics?

Imagine… → Andrew Whitehead’s talk
CERN Testbeam Setup for Diamond Telescope:

- 100 GeV/c pion/muon beam
- 7 planes of CVD diamond strip sensors each 2cm × 2cm
- 50µm pitch, no intermediate strips → new metalisation procedure
- 2 additional diamond strip sensors for test
- Several silicon sensors for cross checks
- Strip Electronics (2 µsec) → ENC ≈ 100e + 14e/pF
Recent Tracking Studies

Photograph of Two Planes of the Telescope:
PH Distribution on each Strip

Residual versus Track Position

- Uniform signals on all strips → new metalisation
- Pedestal separated from “0” on all strips
- 99% of entries above 2000 e
- Mean signal charge ~ 8640 e → new metalisation
- MP signal charge ~ 6500 e
Recent Tracking Studies

Next advance → take advantage of charge sharing:
Radiation Hard Diamond Tracking Modules:

- Large (2cm × 4cm) Module constructed with new metalisation
- Fully radiation hard SCTA128 electronics → 25ns peaking time
- Tested in a $^{90}$Sr → ready for beam test and irradiation
- Charge distribution cleanly separated from the noise tail → S/N > 8/1
- Efficiency will be measured in test beams at 40 MHz clock rate
Diamond Pixel Detectors

Sided View of a Pixel Detector

CVD diamond

Bump Bonds

Read Out Chip
ATLAS FE/1 Pixels (Al)

- Atlas pixel pitch $50\mu m \times 400\mu m$
- Over Metalisation: Al
- Lead-tin solder bumping at IZM in Berlin

CMS Pixels (Ti-W)

- CMS pixel pitch $125\mu m \times 125\mu m$
- Metalization: Ti/W
- Indium bumping at UC Davis

→ Bump bonding yield $\approx 100\%$ for both ATLAS and CMS devices
→ Excellent track and pixel hit correlation

New radiation hard chips produced this year.
Radiation Hardness Studies with Trackers

Irradiation Studies:

Signal to Noise

- Dark current decreases with fluence
- S/N decreases at $2 \times 10^{15}/\text{cm}^2$
- Resolution improves at $2 \times 10^{15}/\text{cm}^2$

Resolution

- Diamond CDS-69 at 0.9 V/µm
  - before irradiation
    - mean 57, most prob. 41
    - FWHM 54
  - after 1 E15 protons/cm$^2$
    - mean 49, most prob. 35
    - FWHM 41
  - after 2.2 E15 protons/cm$^2$
    - and re-metalization
    - mean 47, most prob. 35
    - FWHM 36

- Residual Distributions, Proton Irradiated Diamond
  - before irradiation
    - 2-strip center of gravity method
    - $\sigma = 11.5$ µm
  - after 1E15 p/cm$^2$
    - $\sigma = 9.1$ µm
  - after 2.2 E15 p/cm$^2$
    - and re-metalization
    - $\sigma = 7.4$ µm
Summary

✦ Charge Collection
  270 $\mu$m collection distance diamond attained in research contract
  MP signal $\approx 8000$ $e$
  99% of charge distribution above 3000 $e$
  FWHM/MP $\sim 0.95$ – Working with manufacturers to increase uniformity
  This diamond process will be moved to production reactors this year

✦ Tracking Results
  Operated a 7 plane telescope with 50 $\mu$m pitch detectors
  Attained high efficiency and tracking precision of 10-20 $\mu$m
  A rad-hard module with SCTA128 electronics (DM\|LL) was constructed
  Source tests indicate high efficiency at 40 MHz
  Beam test and irradiation $\rightarrow$ this year!
  Constructed first diamond detector with intermediate strips $\rightarrow$ test this year!

Significant progress in the last year
Summary

- **Radiation Hardness of Diamond Trackers**
  - Using trackers allows a correlation between S/N and Resolution
    - Dark current decreases with fluence
    - Some loss of S/N with fluence
    - Resolution improves with fluence
  - All tests will be repeated with more trackers and the latest diamonds

- **Diamond Pixel Detectors**
  - Successfully tested ATLAS and CMS pixel patterns
    - Bump bonding yield ≈ 100%
    - Excellent correlation between telescope and pixel data
    - Reasonable spatial resolution attained
  - Radiation hard chips have just arrived

  More progress in the next year
Future Plans for RD42

✦ Charge Collection
  Continue research program to improve material in progress:
    collection distance → 300 µm (Q = 10, 800e)
  → improved uniformity
  → identification of trapping centers

✦ Radiation Hardness of Diamond Trackers and Pixel Detectors
  Continue tracker irradiations this year, add pixel irradiations
  With Protons:
    → 5 × 10^{15}/cm^2
  With Pions:
    → 5 × 10^{15}/cm^2
  With Neutrons:
    → 5 × 10^{15}/cm^2

✦ Beam Tests with Diamond Trackers and Pixel Detectors
  → trackers with intermediate strips, SCTA128 electronics
  → pixel detectors with ATLAS and CMS radhard electronics now available!
  → construct the first full ATLAS diamond pixel module

✦ Material Research
  → Florence, OSU, Paris, Rome