Fabrication and characterisation of 3D diamond detectors

S. Murphy - The University of Manchester

- Introduction to 3D diamond detectors
  - Why diamond?
  - Why 3D?
- Fabrication of graphitic electrodes
  - Improvement to this technique
- Characterisation of detectors using both fabrication techniques
  - Resistivity measurements - electrical properties
  - Raman spectroscopy measurements - material content
  - Cross polarised images - stress measurements

Introduction to 3D diamond detectors

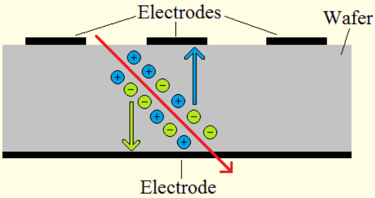
When compared to silicon, diamond has:

- Higher displacement energy
  - More radiation tolerant
- Higher thermal conductivity
  - Less cooling required
- Larger band gap
  - Lower leakage current

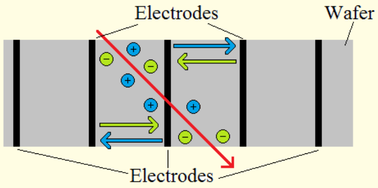
- Trapping
  - Loss of charge
- Larger band gap
  - Fewer electron-hole pairs produced
- Higher cost

Radiation tolerance is key for tracking detectors in the HL-LHC

Planar



3D

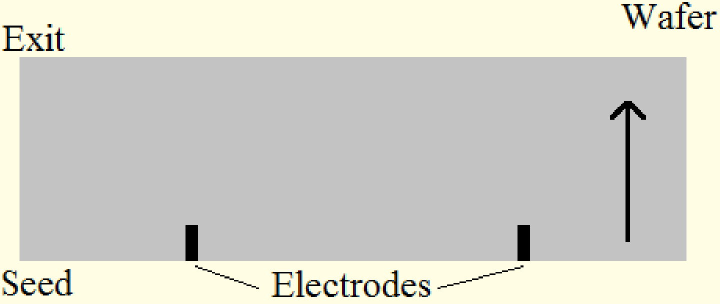


- Planar detectors have electrodes on both sides of wafer
- 3D detectors have electrodes through the wafer bulk
- Shorter charge collection distance in 3D geometry
  - Lower trapping probability
  - Higher detection efficiency
- Higher electric field in 3D

Electrode fabrication technique

Electrode Fabrication

- Use a Ti:Sapphire 100 fs pulse length laser
- Phase transition from diamond to graphite occurs at focal point
- Moving diamond wafer relative to focal point forms continuous electrode



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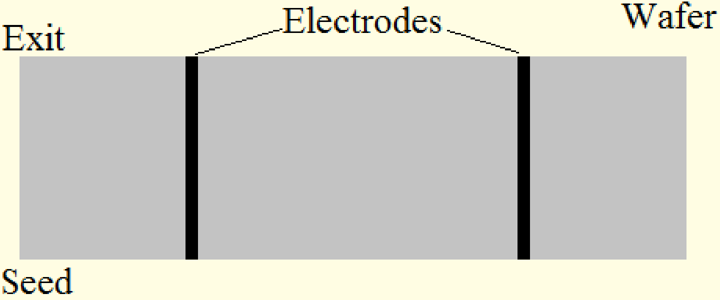
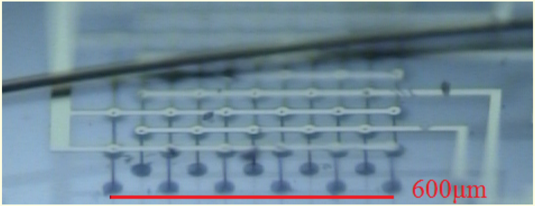
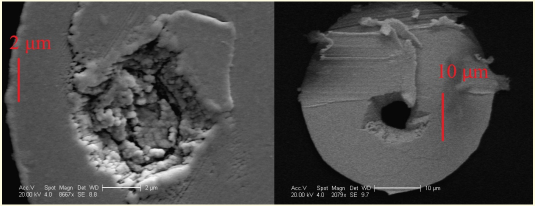


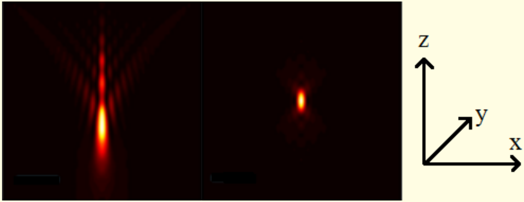




- Pulp formed on seed side
- Crater formed on exit side due to lower density of electrode material

- Current fabrication technique limits electrode diameter to 6 µm.
  - Limits active area of detector
- Resistivity limited to 2 Ωcm
  - Highly conductive channels desirable (resistivity $<<$ 1 Ωcm)
- Both effects are due to aberrations and distortions of the laser pulses
  - Distortion by refraction at the diamond surface
  - Depth-dependent aberrations within the diamond
- These are rectified using a dynamic adaptive wavefront

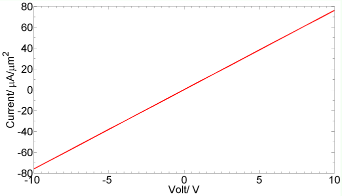
- Use a spatial light modulator (SLM) to alter focal spot[1]
- A phase pattern is calculated to adjust for the aberrations at a particular depth
- The patterns are calculated every 10 μm
- Results in a smaller focal spot (1 μm, right)

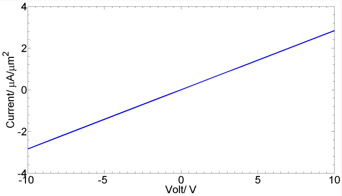


[1]. B. Sun, P. Salter, M. Booth, doi:10.1063/1.4902998

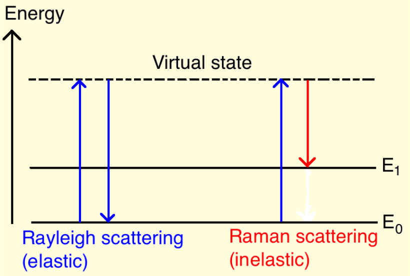
Characterisation of 3D diamond detectors

- Graphitic electrodes fabricated with and without an SLM
- Electrical properties measured from current-voltage curves
- Both techniques produce ohmic electrodes
- Lower resistance observed when using an adaptive wavefront (left, green) than without (right, red).
- Resistivities of 0.2 Ωcm and 2 Ωcm with and without an adaptive wavefront, respectively
  - Much closer to ideal electrodes





- Photons from a laser are incident on the surface of a sample
- Photons are scattered by molecules within the sample
  - Results in energy loss from vibrational levels
- Spectrometer analyses energy of scattered photons
  - Spectrum is characteristic of the molecule
- Helps to probe the material content of fabricated electrodes



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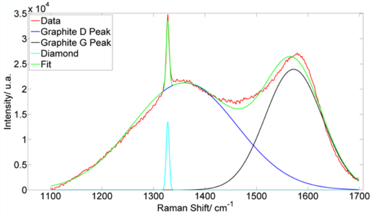
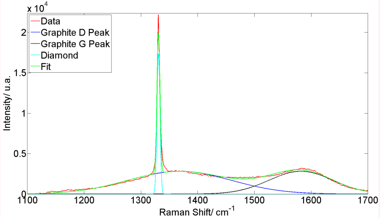
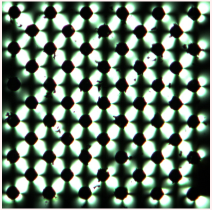
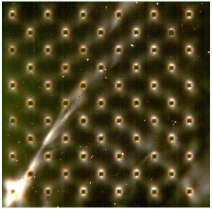
- Three peaks: One narrow diamond peak (1330 cm^{-1}) and two broad graphite peaks (1350 cm^{-1} and 1583 cm^{-1} for graphite D and G peaks, respectively)
- Apply fits to extract heights of diamond and graphite G peaks
  - Ratio gives an estimate of graphite content inside electrode
- Lower ratio observed when using an adaptive wavefront (left, 0.2–0.4) than without (right, 2–4)



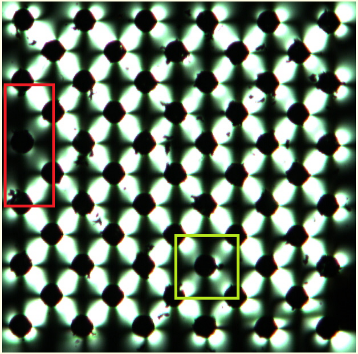


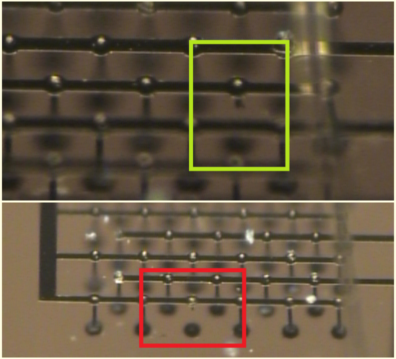
- Level of stress within diamond observed using two crossed polarisers at 90°
  - Bright areas indicate high stress
- Dominant source of stress without using an adaptive wavefront (left) is from electrodes on diamond bulk.
- Dominant source of stress using an adaptive wavefront (right) is the wafer purity
- Can reduce the electrode separation when using an SLM
  - More cells within detector, so better particle tracking





- Technique can also be used to determine electrode yield
- Partially formed electrodes have lower surrounding stress
- Electrode yield higher when using an adaptive wavefront (100%) than without (90%)





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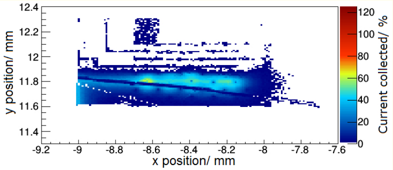
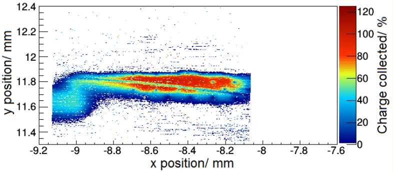
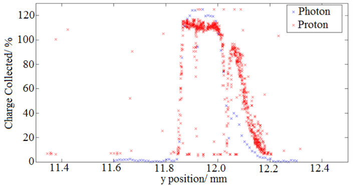
- Photon (left, top) and proton (left, bottom) data taken for a detector produced without an adaptive wavefront[2]
- Full charge collection observed, and no significant charge sharing seen
- Proton data compared to simulations, with reasonable agreement (see talk by G. Forcolin)







[2] G.T. Forcolin, V. Grilj, B. Hamilton, L. Li, M. McGowan, S.A. Murphy, A. Oh, N. Skukan, D. Whitehead, A. Zadoroshnyj, doi:10.1016/j.diamond.2016.02.005

- Graphitic electrodes have been fabricated with and without an adaptive wavefront
- Comparing the techniques shows a reduction in the resistivity and induced stress in the diamond when using an SLM, while increasing the graphitic content
- A detector will be fabricated using an SLM, and the performance will be investigated with particle beams
- The results will be compared to a detector fabricated without an SLM[2]

Special Thanks

- G. Forcolin (see next talk), A. Oh [1]
- M. Booth, P. Salter, B. Sun [2]
- L. Li, D. Whitehead [3]
- A. Zadoroshnyj [4]
- V. Grilj, N. Skukan [5]
- Diamond Light Source, Oxford
- STFC

[1] School of Physics and Astronomy, University of Manchester
[2] Department of Engineering Science, University of Oxford
[3] School of Mechanical, Aerospace, and Civil Engineering, University of Manchester
[4] School of Materials, University of Manchester
[5] Ruđer Bošković Institute, Zagreb, Croatia