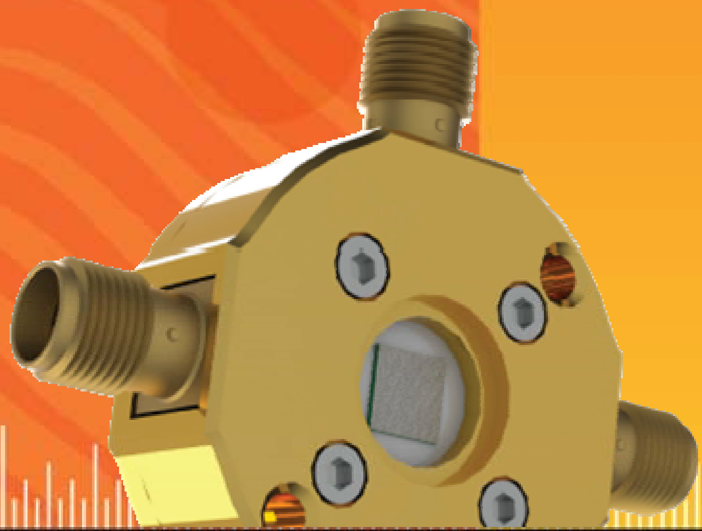
Diamond Detectors Ltd

Diamond Detectors

CVD Diamond History
Introduction to DDL
Properties of Diamond
DDL Proprietary Contact Technology
Detector Applications
BDD Sensors

Kevin Oliver CEO
Alex Brown Sales & Marketing



CVD Diamond History

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Diamond as a detector is not a new technology and as early as 1920's highly selected natural diamonds were being used for UV detectors. The recent commercial available of high purity single crystal diamond with excellent bulk uniformity is however a new development.

1920 Diamond demonstrates UV response
1940 Diamond used to detect ionising nuclear radiation
1950 – 60 Interactions of Alpha and high energy fast electrons with diamond studied
1962 Photoconductivity of Natural Diamond investigated
1970 Advances made in forming electrical contacts to diamond
1980 Commercial x-ray dosimeters for medical applications

Early 90's Advances made in quality of polycrystalline CVD diamond (pCVD)
pCVD recommended for use in Super Conducting Super Collider
Employed as commercial solar blind UV detector.
Late 90's Beam position monitors for synchrotrons
Charge Collection distance > 200 μ appropriate
Many high energy physics detector applications.

2000 DeBeers Industrial Diamond patents manufacturing procedure for High purity single crystal diamond with superior electronic characteristics
2002 DeBeers Industrial Diamond forms Element Six
2006 E6 perfects volume manufacturing process for electronic grade" materials
2007 DDL formed by Element Six
2008 DDL patents metallisation development
DDL achieves surface polishing improvements <1nm roughness
DDL 50% acquired by BAE Systems

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elementsix

Press release Thursday 3rd May 2007

"Element Six Spins Out New Company to Develop Diamond Detectors…….

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June 2007, DDL Moves into new office, Poole, Dorset

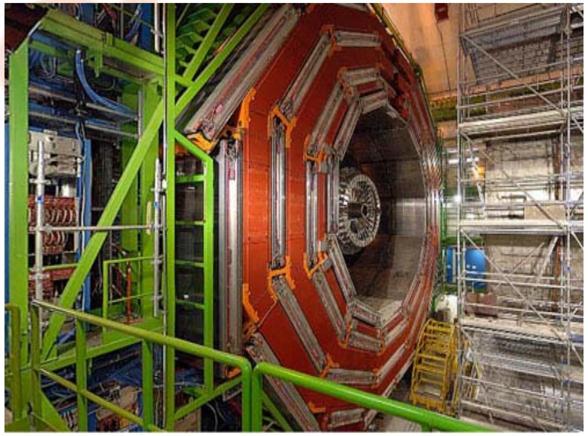
BAE SYSTEMS

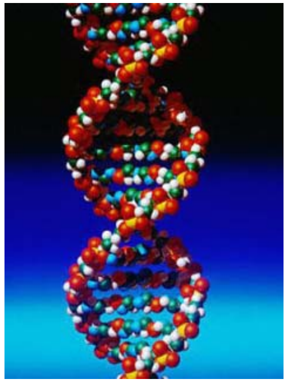
2008, BAE systems acquires 50% share in DDL

High Tech Application of Diamond

Diamond Detectors focus includes…

- Diamond Wide Band Gap Detectors. (solid state ionizing chamber)
- Diamond Sensors (Electro-chemical and Bio applications).





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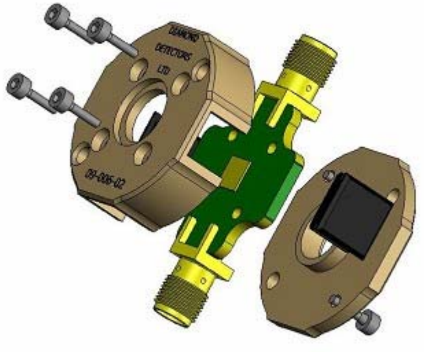
"From Concept through Design & Prototype to Manufacture"

Concept - Design



Manufactured Devices

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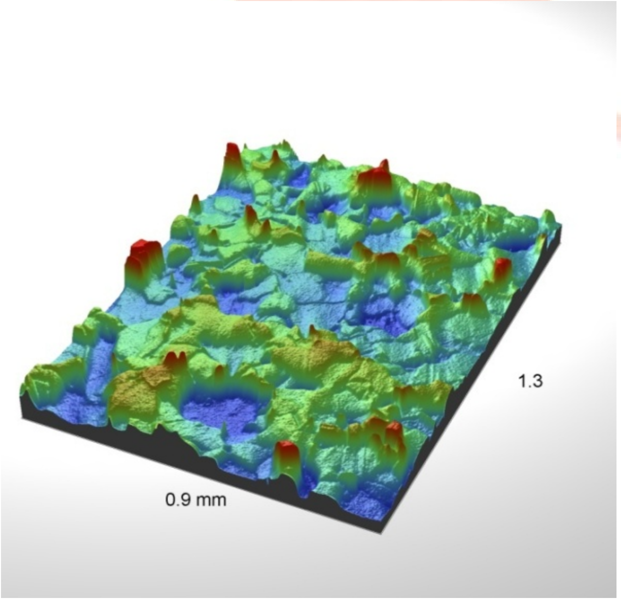
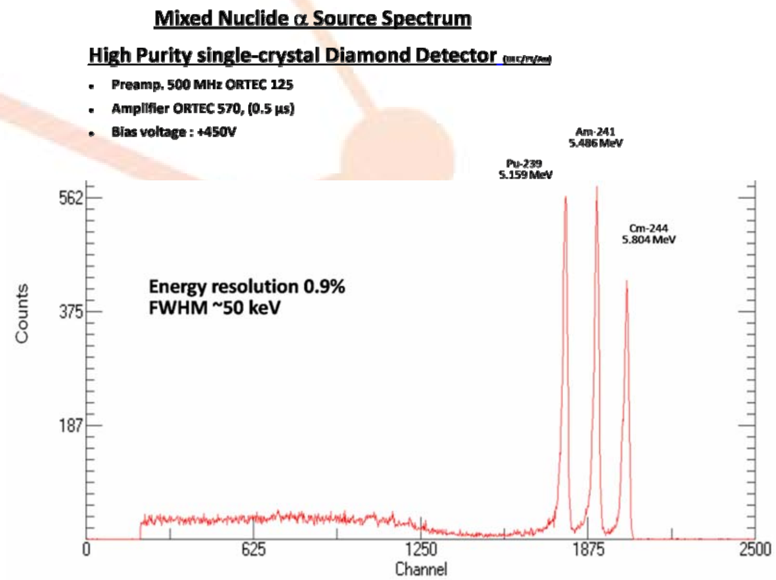
Characterisation



Typical process specifications :-

Polycrystalline standard polish	Ra < 20nm
Polycrystalline detector polish	Ra < 12nm
Polycrystalline Super polish	Ra < 5nm
Single crystal detector polish	Ra < 1nm

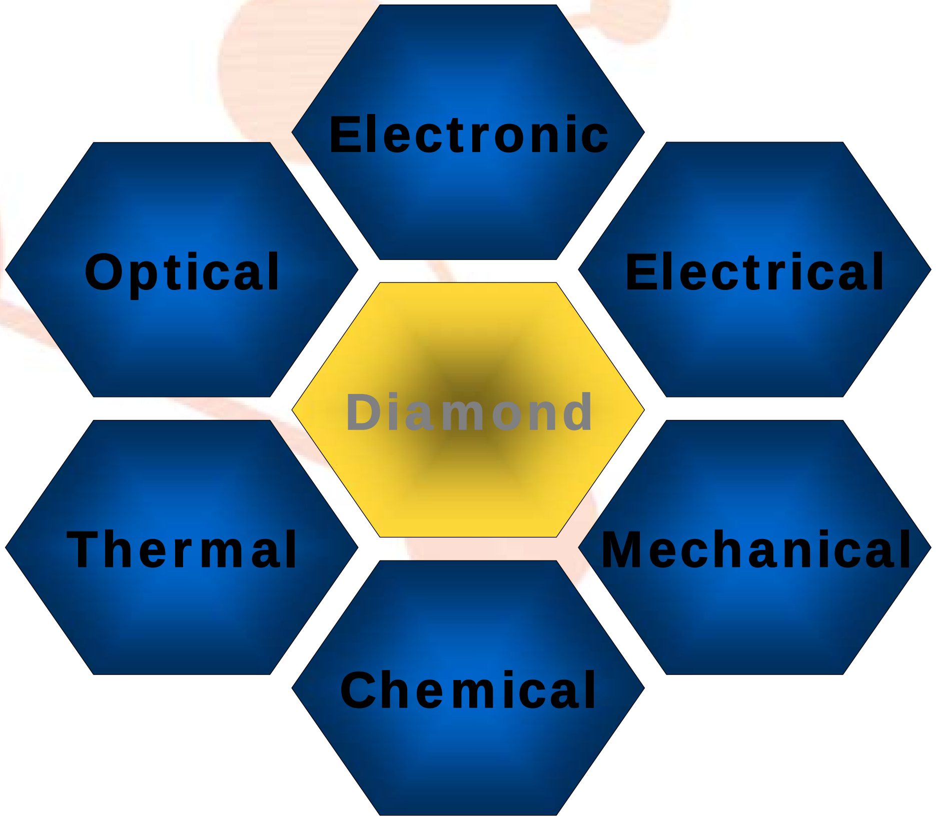


J. Dueñas et al., Department of Applied Physics GEM, University of Huelva, Spain

Electronic / Device Characterisation

Properties of Diamond

Broad transmission spectrum
Highest thermal conductivity
Highest resistance to thermal shock
Low thermal expansion coefficient
High chemical (bio) inertness
Highest Young's modulus
Highest Knoop hardness
High tensile strength
Good electrical insulator
Good electrical conductor (doped)
Low dielectric constant
Low dielectric loss
Wide electronic band gap
High electronic mobility



Properties of Diamond

Diamond radiation detectors are able to detect deep UV photons, X-rays, gamma rays, electrons, alpha particles, charged ions and neutrons, with a dynamic range in energies spanning from 5.5 eV up to GeV of cosmic rays.

Since the bandgap of diamond is 5.5 eV this leads into a negligible dark current noise at room temperature with no need for cooling.

Metal diamond interfaces play a key role in the performance of the detectors as different metallization techniques lead to either "ohmic" or Schottky electrical contacts.

Intrinsic Properties

Radiation Hardness
Wide band gap 5.5eV (no thermally generated noise)
Low Z (tissue equivalent)
Low energy absorption
High thermal conductivity
High Hole and Electron Mobility

Detector Properties

High sensitivity
Good spatial and temporal resolution achievable
Low leakage currents and stable *(< 0.01pA / pixel)*
Low capacitance

Device Advantages

Intrinsically simple device (no pn junction required)
can fabricate robust, compact devices
High temperature operation (no need for cooling)

Applications Include:

High Energy Physics
Civil Nuclear
Medical Therapy / Dosimetry (X-ray & Particle Therapies)
Synchrotrons and Cyclotrons
Radiation Monitoring (nuclear, medical and oil & gas)
Deep UV (< 240nm)

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Properties of Diamond

Intrinsic Material Properties

	Si	4H-SiC	GaN	Natural Diamond	CVD Diamond	Potential device application benefit
Bandgap (eV)	1.1	3.2	3.44	5.47	5.47	High temperature
Breakdown field ($MVcm^{-1}$)	0.3	3	5	10	10	High voltage
Electron saturation velocity ($x10^{7}$ cm s^{-1})	0.86	3	2.5	2	2	High frequency
Hole saturation velocity ($x10^{7}$ cm s^{-1})	n/a	n/a	n/a	0.8	0.8	
Electron mobility ($cm^{2}\ V^{-1}\ s^{-1}$)	1450	900	440	200–2800	4500	
Hole mobility ($cm^{2}\ V^{-1}\ s^{-1}$)	480	120	200	1800–2100	3800	
Thermal conductivity ($Wcm^{-1}\ K^{-1}$)	1.5	5	1.3	22	24	High power
Johnson's figure of merit	1	410	280	8200	8200	Power-frequency product
Keyes' figure of merit	1	5.1	1.8	32	32	Transistor behavior thermal limit
Baliga's figure of merit	1	290	910	882	17200	Unipolar HF device performance

Isberg, J., *et al.*, *Science* (2002) 297, 1670

Chris J. H. Wort* and Richard S. Balmer

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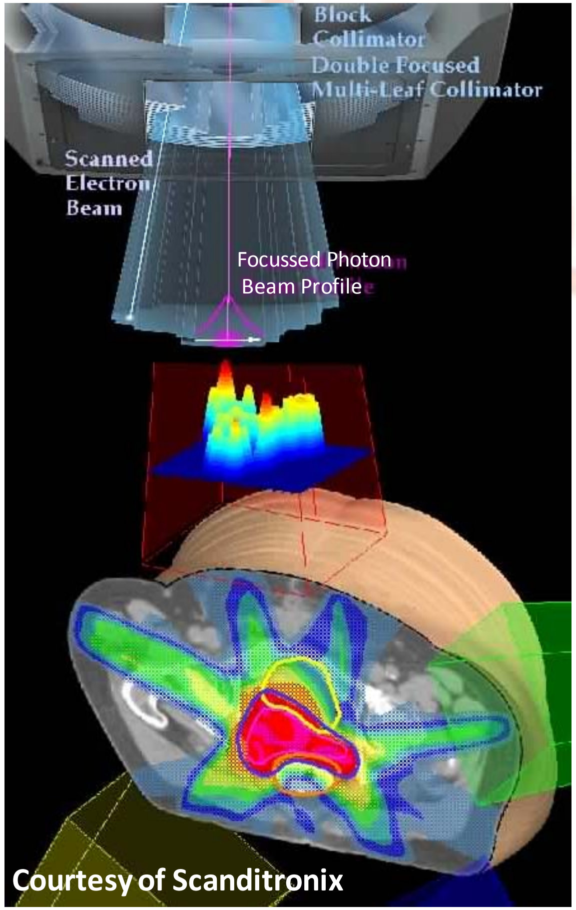
Example Application of EL SC CVD Diamond:



Intensity Modulated Radiation Therapy

Before treatment of patient:

- Dummy run with detector
- Detector placed in tissue equivalent material to assess beam profile
- Detector must be moved several times to collect enough information
  - an array of detectors would be ideal

Treatment:

- Patient typically receives 3 treatments, each from a different angle of entry

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X-ray Sensitivity Comparison for Different Dosimeter Types

Higher sensitivity of High Purity SC CVDD

Smaller devices

Improved spatial resolution

	E6 HP SC CVD diamond	Commercial Silicon dosimeter	Air-filled Ionisation chamber
Sensitivity (nC/Gy)	240	74	7.5
Active Detector Volume (mm^3)	0.3	0.2	120

Data for samples irradiated in a 6MV photon beam with a 10cm x 10cm field at a source-to-detector distance of 100cm, courtesy of Scanditronix

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X-ray Sensitivity for Different Diamond Types

Sample Type	Dose Rate (Gy/min)	Signal ($nC/Gy/mm^3$)	Priming (Gy)
E6 High Purity SC CVDD	0.5	308	0
E6 Standard purity SC CVDD	2	26	3
Commercially available natural diamond dosimeter	2	48	8

Data for samples irradiated with 5MV X-ray beam courtesy of Scanditronix

High Purity SC CVD diamond gave ~6x signal of commercially available natural diamond dosimeter

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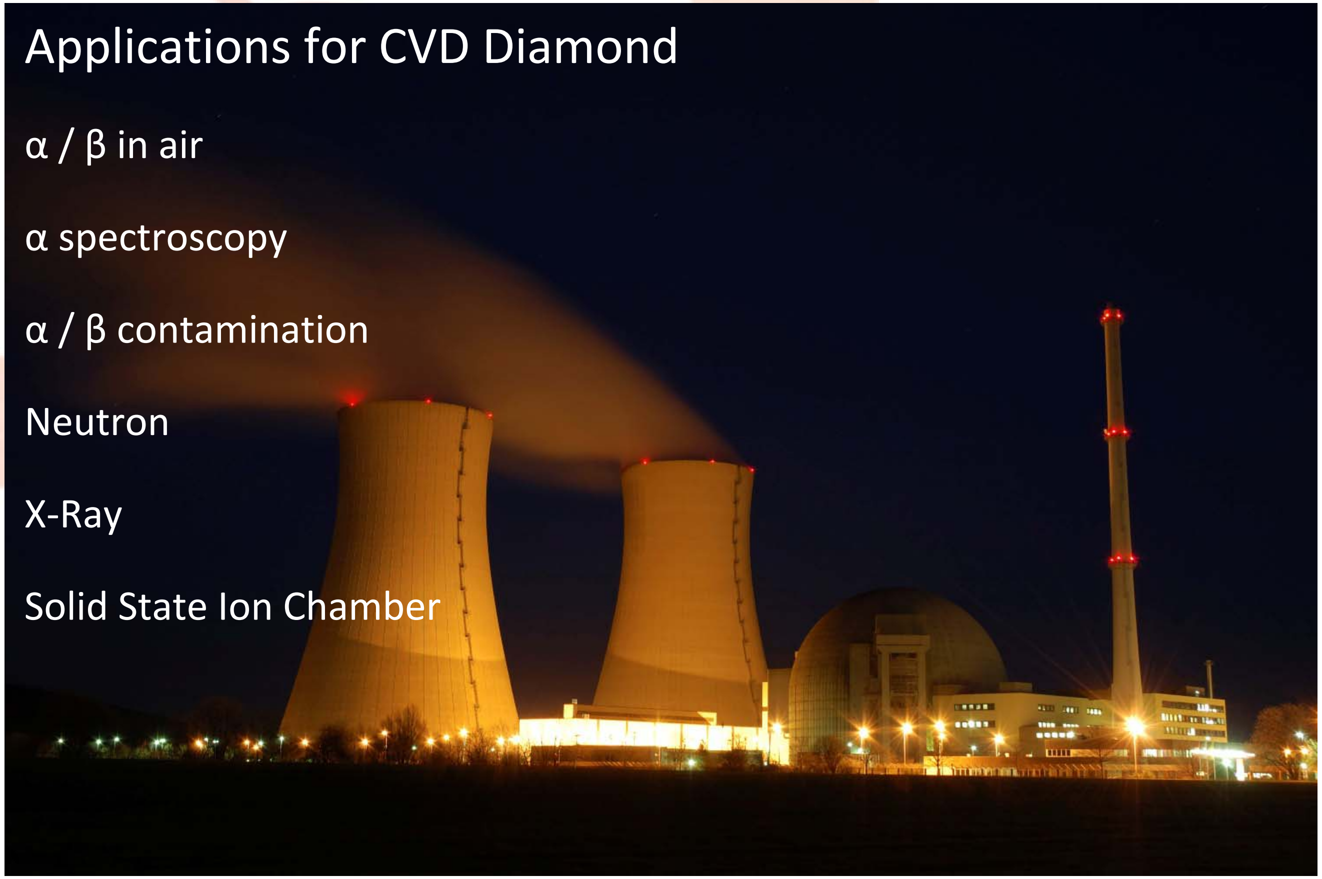
Nuclear Applications

X-ray, Alpha, Beta, Gamma and Neutron radiation detectors for dose / spectroscopy applications in nuclear power and reprocessing plants



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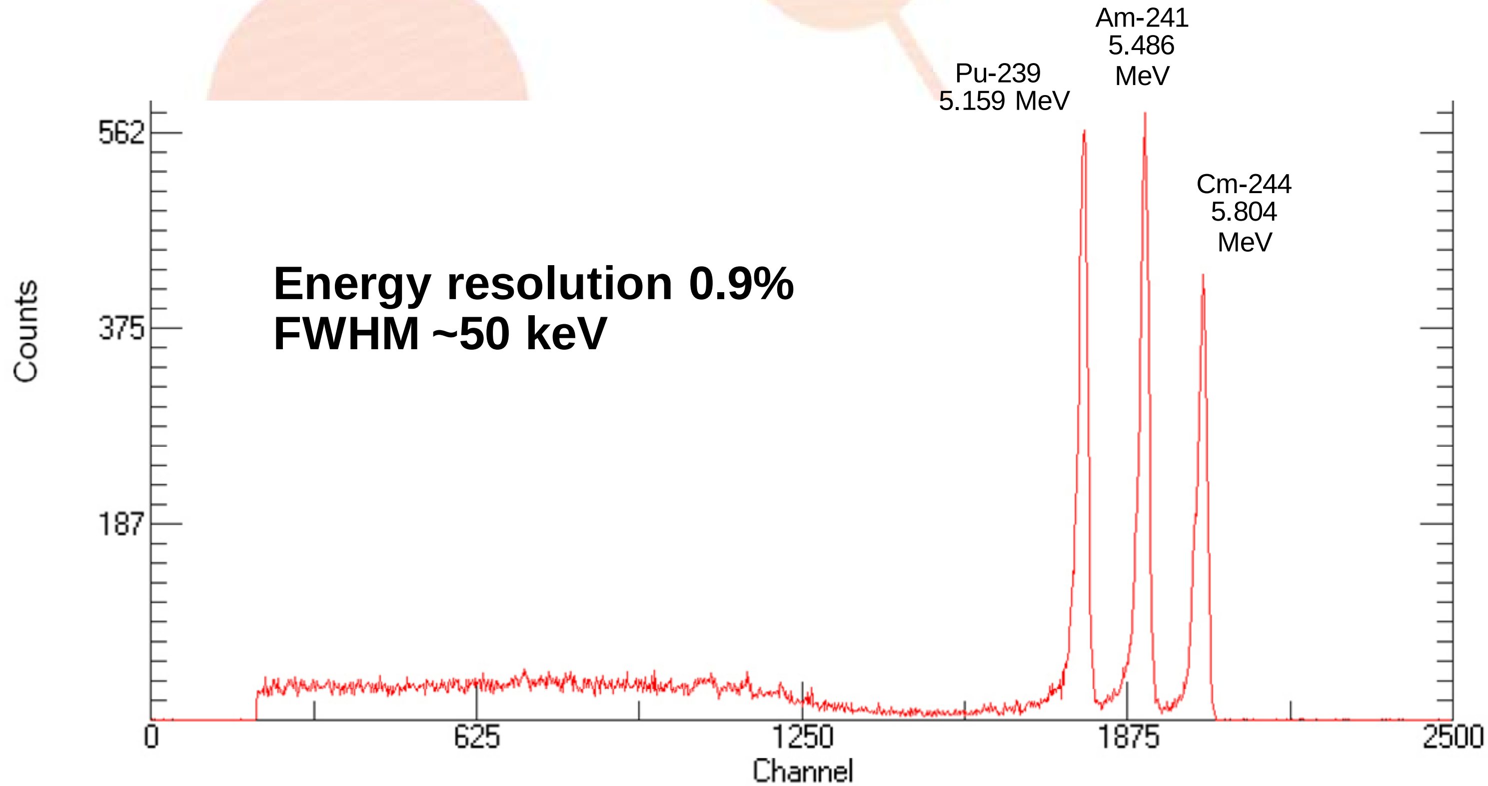
Application Alpha-Spectroscopy

Mixed Nuclide alpha Source Spectrum

High Purity single-crystal Diamond Detector



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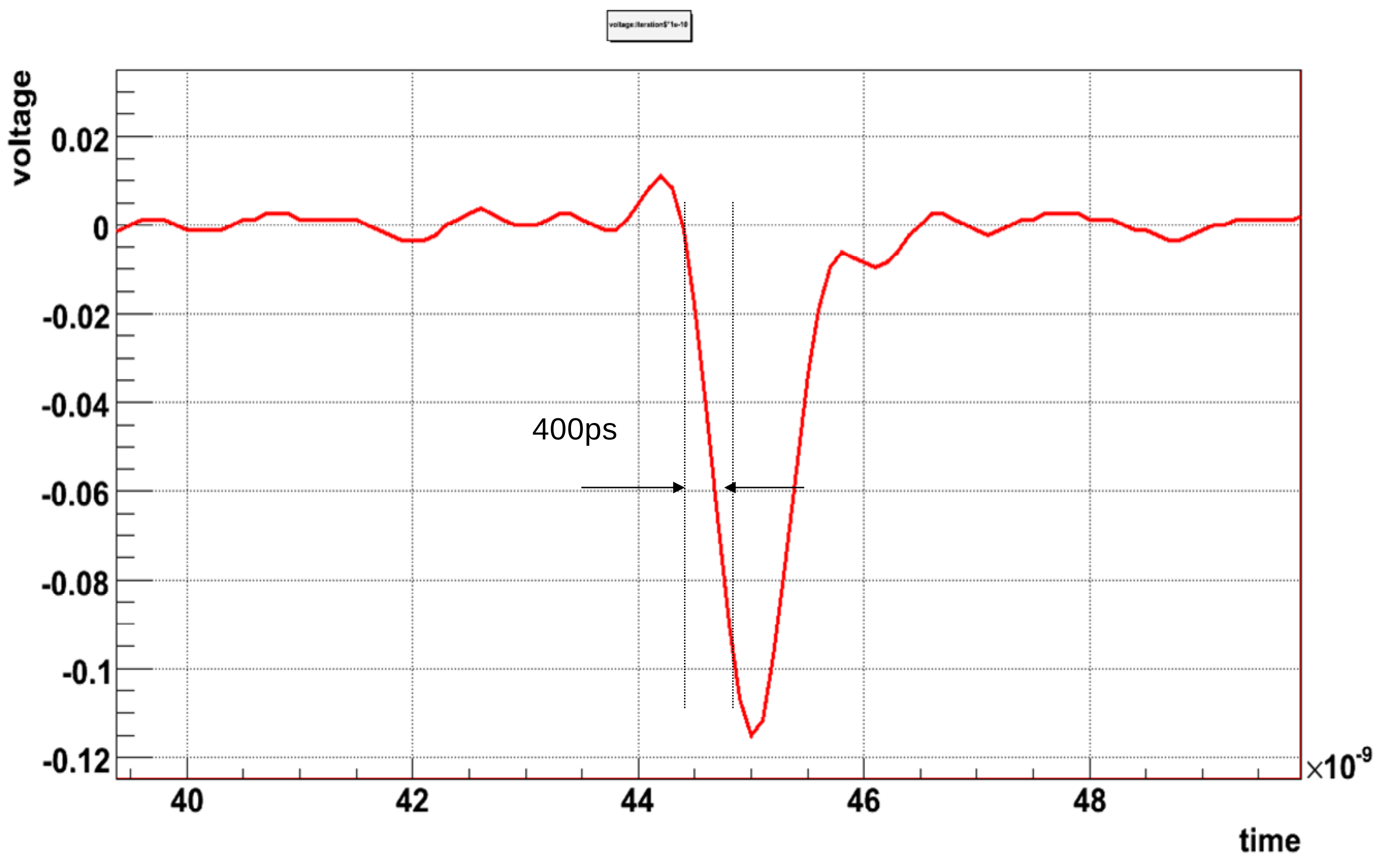
Alpha Particle Pulse



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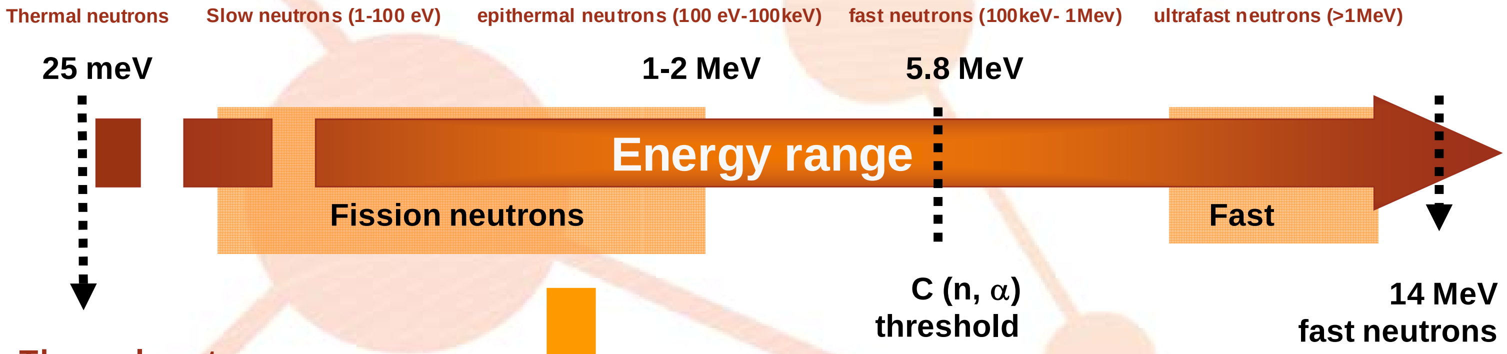
Application Neutron detection using diamond …



Thermal neutrons

Precise fluency
Monitoring
High n/γ selecivity

Nuclear reactors
Fluency monitoring
Profile Monitoring etc

Elastic scattering
OK at high neutron fluencies
Typ. 1nA/cm @ 10 n.cm s
in a 100µm thick diamond layer

Nuclear reactors
Essentially when small size devices are required
e.g. propulsion reactors

Fusion neutrons
or confinment plasmas

temporal metrology (TOF),
Spectroscopy,

Tokamaks,
Rochester,
Laser Mega-Joule (LMJ)

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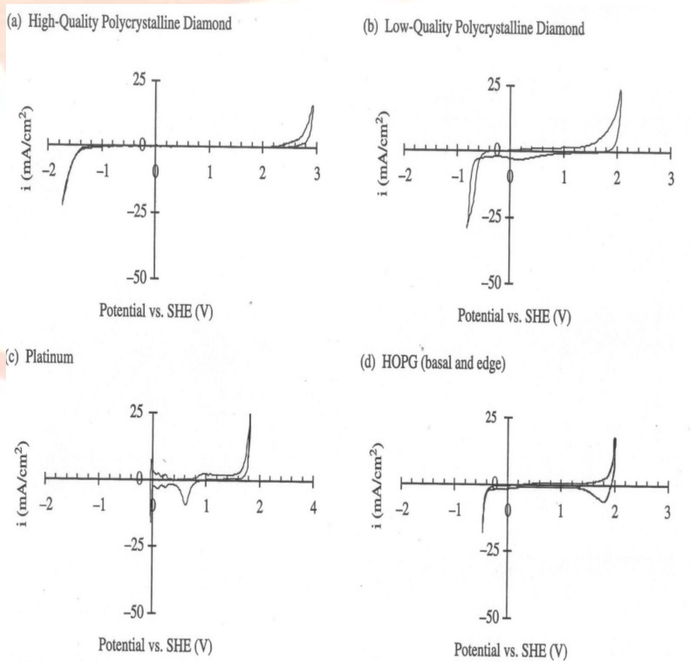
Application Diamond Sensors
Bio-and Chemical Sensing

- Wide electrochemical window
- Extremely low background current.
- Bio-Compatible (non-fouling)
- Very stable surface (Chemically inert)
- Varied surface terminations possible
- Mechanically robust



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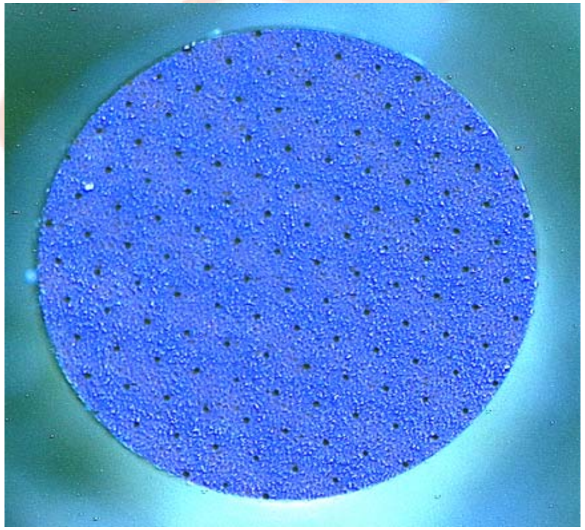
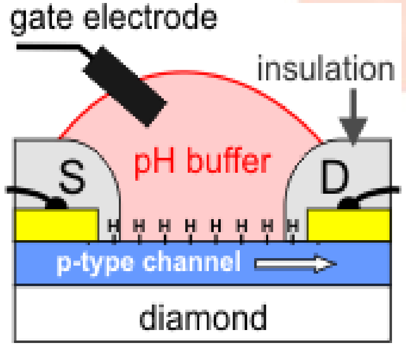
Application Diamond Sensors

- Electro-chemical sensors (MEA, trace element analysis) (Mining, Automotive, Medical, Food, Water, Environmental, Emissions …..)
- PH-Sensors
- Temperature-Sensors
- Conductivity
- Replacement of Mercury Electrodes (Mercury ban widens)



Next Generation (addressable MEA) under consideration



Conclusion

- High quality electronic grade and electro-chemical grade single and polycrystalline materials are now readily available.
- DDL has made significant investment to ensure we have the ability and tools to manufacture diamond prototypes leading to standard products for a range of applications including high energy physics, medical, civil nuclear and oil and gas.
- DDL will continue to provide design, development and manufacturing expertise to our customers.
- DDL will continue to support the development of diamond applications with the aim to provide a range of standard products with datasheets.

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Thank you