Characterization of large-size diamond sensors for medical and nuclear applications

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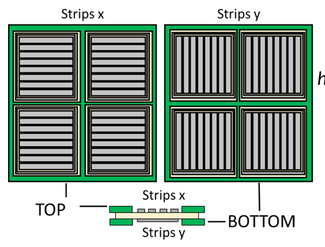
Context

For several years, this collaboration has been studying the particle detection performance of large-size diamond sensors with the prospect of using them in medical or nuclear applications. CVD single & poly crystals as long as hetero-epitaxial sensors have been exposed to β and α particles, to 8.5 keV x-ray bunches at ESRF, to fission products at ILL, to protons at ARRONAX and carbon ions at GANIL. They were also scanned with an EBIC setup at Institut Néel to obtain a 2D map of their response. The charge collection, time and energy performance has been measured.

Targeted applications

- **Beam tagging hodoscope for fast online ion range verification in hadrontherapy**

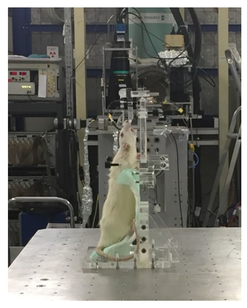
In vivo online ion range measurement could reduce security margins currently set during treatment planning. A diamond-based beam hodoscope is currently developed at LPSC Grenoble. It aims to provide time and 2D position tagging of ion beams in the context of Prompt-Gamma Imaging (CLaRyS collaboration).



Diamond-based hodoscope made with 4 large area (1 cm²) stripped sensors

- **In vivo active dosimetry for synchrotron radiation therapy**

ESRF is one the very few sites in the world that have already carried out clinical tests of intense synchrotron radiation therapy. Due to ultra-high dose rates, the question of in vivo dosimetry arises. A diamond-based portal active dosimeter is currently developed at LPSC Grenoble. It aims to provide a real-time measurement of the dose delivered to the patient.



Diamond sensors

Crystal structure

Single-crystal CVD diamond (sCVD) ← **Crystal quality – Charge collection** → **Polycrystalline CVD Diamond (pCVD)**

Size – Price -Availability →

Alternative : **Diamond hetero-epitaxy on iridium substrate (DOI)**

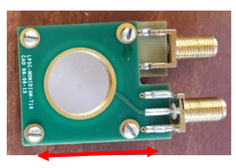
Large crystals (> 1cm²) with good charge collection properties still at R&D stage

diamond intrinsic properties

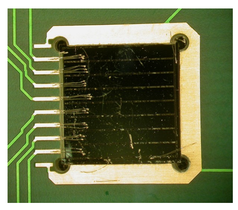
Resistivity	> 10^{13} Ω.m
e/h pair creation energy	13.1 eV
Displacement Energy	43 eV
Charge carrier mobilities	≥ 2000 cm²/V/s
Atomic number	6

→ Low leakage currents
→ Good Signal-to-Noise Ratio (SNR)
→ Radiation hardness
→ Fast time response
→ Tissue-equivalent

Types of tested sensors



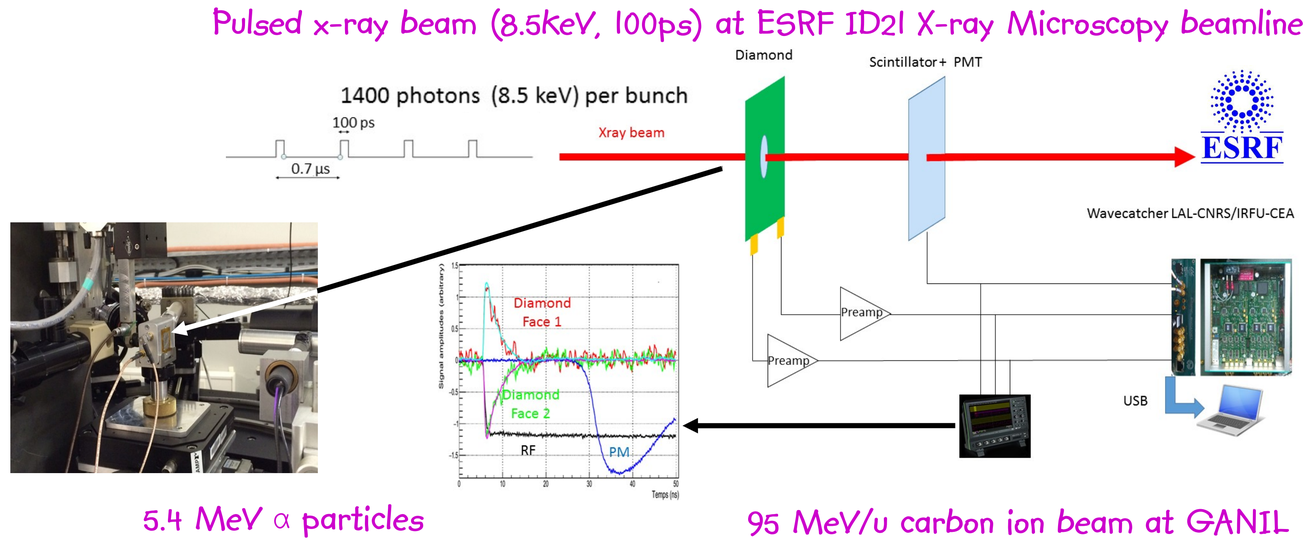
Single-pad aluminum-metalized diamond sensor



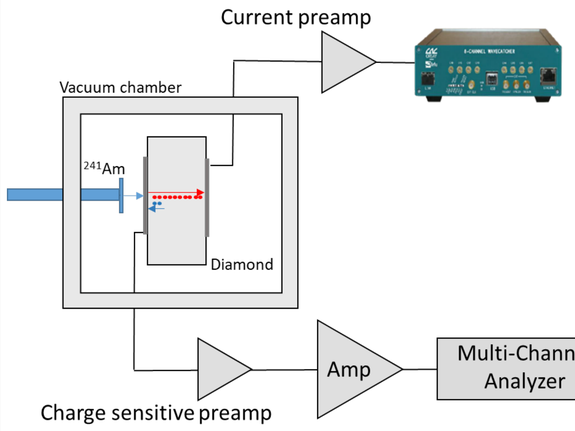
Double-sided stripped diamond sensor

Characterization of diamond sensors

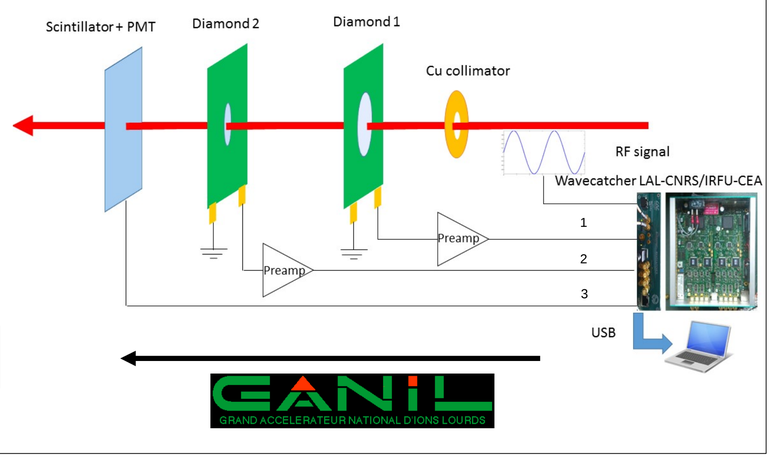
Pulsed x-ray beam (8.5keV, 100ps) at ESRF ID21 X-ray Microscopy beamline



5.4 MeV α particles



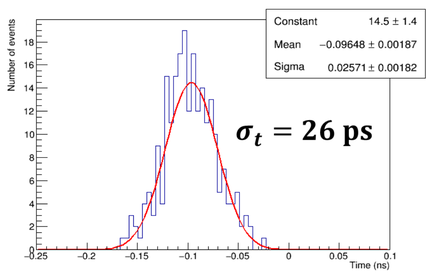
95 MeV/u carbon ion beam at GANIL



Results

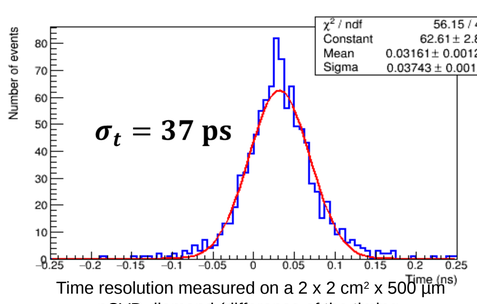
Time resolution

Pulsed photon beam (8.5 keV)



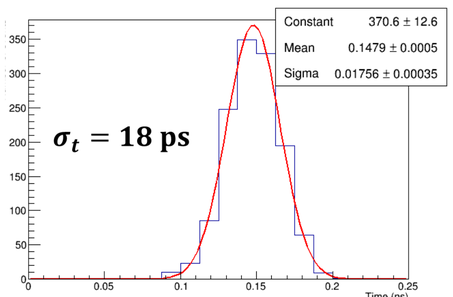
Time resolution measured on a 0.45 x 0.45 cm² x 518 µm sCVD diamond (difference of the timing of both surface signals)

5.4 MeV α particle



Time resolution measured on a 2 x 2 cm² x 500 µm pCVD diamond (difference of the timing of both surface signals)

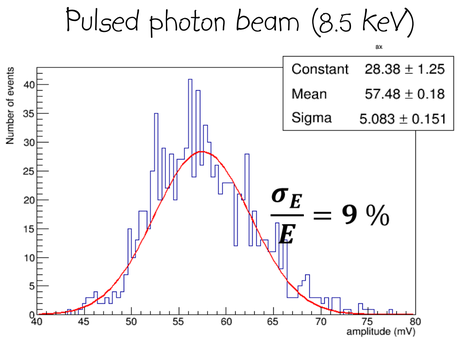
95 MeV/u Carbon ion beam



Time resolution measured between a 0.45 x 0.45 cm² x 518 µm sCVD diamond and a 0.5 x 0.5 cm² x 300 µm pCVD diamond

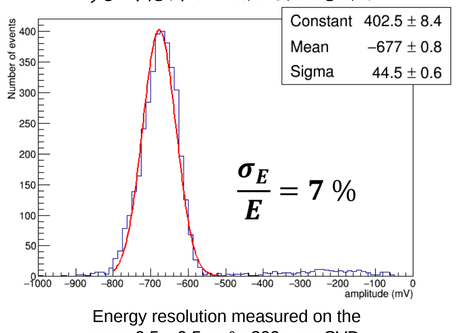
Energy resolution

Pulsed photon beam (8.5 keV)



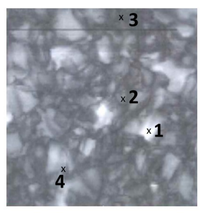
Energy resolution measured on a 0.5 x 0.5 cm² x 300 µm pCVD diamond

95 MeV/u Carbon beam

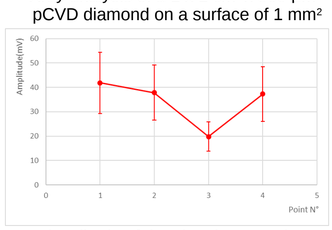


Energy resolution measured on the same 0.5 x 0.5 cm² x 300 µm pCVD diamond

Structure of pCVD diamond



Xray analysis of a 1 x 1 cm² x 500 µm pCVD diamond on a surface of 1 mm²



Amplitude of the signal versus the pencil beam localization from point 1 up to 4

Conclusion and Prospects

Radiation hardness, fast response and good signal-to-noise ratio make diamond sensors good candidates for medical and nuclear applications :

- a time resolution better than 40 ps
- an energy resolution better than 10 %

Synthetic pCVD diamond sensors are foreseen for online hadrontherapy beam tagging and dosimetry applications.

Large area (> 1 cm²) diamond sensors with good and homogeneous charge collection properties are still at the R&D level. Much more intense coordinated efforts should address this point in the future.

References : ML Gallin-Martel et al, ANIMMA 2017, EPJ Web of Conferences **170**, 09005 (2018) https://doi.org/10.1051/epjconf/201817009005
J Collot et al, PoS - Proceedings of Science EPS-HEP2017, pp.781 (2017) https://pos.sissa.it/314/781/

This work partly takes place within the CERN RD 42 collaboration. http://rd42.web.cern.ch/rd42