Diamond-based thin detectors for radiobiological applications of charged-particle microbeams

P. Barberet\textsuperscript{1}, M. Pomorski\textsuperscript{2}

1. Centre d’Études Nucléaires de Bordeaux-Gradignan, France
2. CEA-LIST, Diamond Sensors Laboratory, France
AIFIRA facility

- 3.5 MV Singletron accelerator (HVEE)
- Ions: p, d and helium
- 2 microbeam lines → 1 dedicated to targeted irradiation of cells
Micro-irradiation and dose control

For MeV light ions (p, He), medium to thick detector upstream the sample.
Micro-irradiation and dose control

For MeV light ions (p, He), medium too thick ⇒ detector upstream the sample
Detecting (efficiently) MeV light ions

We have to use **thin transmission detectors**

Several approaches:

- Thin plastic scintillators (e.g. Gray Lab, PTB ...)
- Gas detectors
- Secondary electrons from vacuum window
- Thin semi-conductors (Si or diamond)
Detecting (efficiently) MeV light ions

We have to use **thin transmission detectors**

Several approaches:

- Thin plastic scintillators (e.g. Gray Lab, PTB ...)
- Gas detectors
- Secondary electrons from vacuum window
- Thin semi-conductors (Si or diamond)

**3 MeV Helium ions:**
140 keV·μm⁻¹ in water, range ≈ 15 μm
⇒ secondary electrons

**3 MeV protons:**
12 keV·μm⁻¹ in water, range ≈ 150 μm
⇒ thin active scCVD membrane
Secondary electrons detectors

Up to now, mainly used for detecting heavy ions (GSI Darmstadt)

B. Fischer et al. (2003), NIMB 210, 285–291
Secondary electrons detectors

We revisited the idea of using Boron-doped NanoCrystalline Diamond (BNCD) coatings

⇒ coating of commercial Si$_3$N$_4$ vacuum windows with nm thick BNCD

![Diagram of secondary electron detection system]

Dr. Sjuts
Optotechnik GmbH
BNCD membranes fabrication

1. Substrate seeding with 5 nm diamond nano-particles on Si$_3$N$_4$ windows
2. MWCVD p+ diamond growth (MicroWave assisted Chemical Vapour Deposition)

Fabrication: Diamond materials and sensors lab, CEA (Michal Pomorski)
BNCD membranes fabrication

BNCD growth on 150 nm thick Si₃N₄ windows
Thickineess measurements

STIM measurements:

- 3 MeV He
- Energy loss $\approx 200$ keV

$\Rightarrow$ BNCD thickness $\approx 500$ nm (SRIM)
Thickness homogeneity

Median map of the energy transferred through the BNCD membrane
⇒ very good homogeneity on mm scale (scale bar = 100 µm)
Channeltron pulse height analysis

- Pulse height well separated from the background
- Very low dark counts ($< 10 \text{ s}^{-1}$)
- Good reproducibility and homogeneity over the membrane surface

SE map (Scale bar: 100 $\mu$m)
Efficiency measurements

Counting the transmitted particles with a silicon detector

- BNCD 1: Sum = 273387
- BNCD 2: Sum = 273371
- PIPS 1: Sum = 273770
- PIPS 2: Sum = 273227
Efficiency measurements

Counting the transmitted particles with a silicon detector

⇒ 100% efficiency
Radiation hardness: BNCD
Radiation hardness: CsI
Validation using track detectors

Use of BNCD membrane as a vacuum window.

CR39 Track detectors irradiated in air through the BNCD membrane
a. Single He ions delivered in air (Scale bar = 10 µm)
b. 10 He per spot (Scale bar = 10 µm)
Validation for cell irradiation

Irradiation of U2OS cells expressing RNF8-GFP
RNF8 Ubiquitylates Histones at DNA Double-Strand Breaks

Figure: 1 He ion delivered every 5 \( \mu \text{m} \). Online image acquisition 30 min. after irradiation (Scale bar = 10 \( \mu \text{m} \))
scCVD active membrane

Secondary electron yield is not sufficient for proton detection
⇒ active membrane
Preliminary measurements (1)

Microscope view of the membrane

Pulses:
blue = Si detector
yellow = membrane
S/N ration not very high
but enough to achieve
99.6 % efficiency
Preliminary measurements (3)

Energy loss measurements under vacuum with a 3 MeV proton microbeam

Thickness assuming 37 keV \cdot \mu m^{-1} for 3 MeV protons in diamond
Conclusion

BNCD based thin detector:

- Thin enough for MeV Helium ions
- 100% efficient
- Compared to CsI:
  - Radiation hard ($2 \times$ CsI)
  - Can be stored in air

This detector is now installed on the AlFIRA facility in Bordeaux for routine irradiations
Work submitted to *Scientific Reports*, under review ...
Acknowledgement

Gérard Claverie, Laurent Daudin, Hervé Seznec, Giovanna Muggiolu, Marina Simon, Guillaume Devès, Philippe Alfaut

Funding: