# Wide Bandgap Semiconductors For Novel Radiation Monitoring System Applications

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## Introduction

Diamond has an exceptional radiation and temperature resistance due to its wide band gap. University of Hokkaido has recently published spectroscopy results at an operating T° of 500 °C [1] and TIDs of 2 MGy [2]

One of the applications foreseen is the monitoring of small accident conditions such as steam losses where the maximal T° of use can be extended from 120 °C to 200 °C (GIM 204K upgrade)

Another application envisioned is the monitoring of neutron flux rates in fusion reactors where spectroscopy allows the study of the plasma regime

Silicon carbide is radiation and T° hard materials that also shows potentials for these applications. The first alpha spectroscopy results are presented for this material

## The Challenges of T° Upgrading for RMS Gamma Dose Rate Applications

Upgrading the max T° range of an ionization chamber from 120 °C to 250 °C can enable a more secure use of RMS systems in small accidents conditions. The RMS 250 has a maximal rating of 205 °C for 3 hours.

A first diamond detector-based demonstrator will be demonstrated in the field of application of the GIM204K for small accidents. The aim is to upgrade the current max T° and TID.

| Parameter | Value |
|---|---|
| T° of use: | -30 to 120 °C → min 150 °C, challenging 250 °C |
| Detector TID | 2.5.10$^{5}$ Gy → 3 MGy |
| Energy range | 80 keV to 1.5 MeV according to IEC60532 |
| Energy range capability | up to 7 MeV (± 60%) |
| Typical measurement range | 10$^{-7}$ to 10$^{+2}$ Gy/h or Sv/h |

The placing of a diamond sensor in an RMS system around the reactor vessel for an ex-core use.

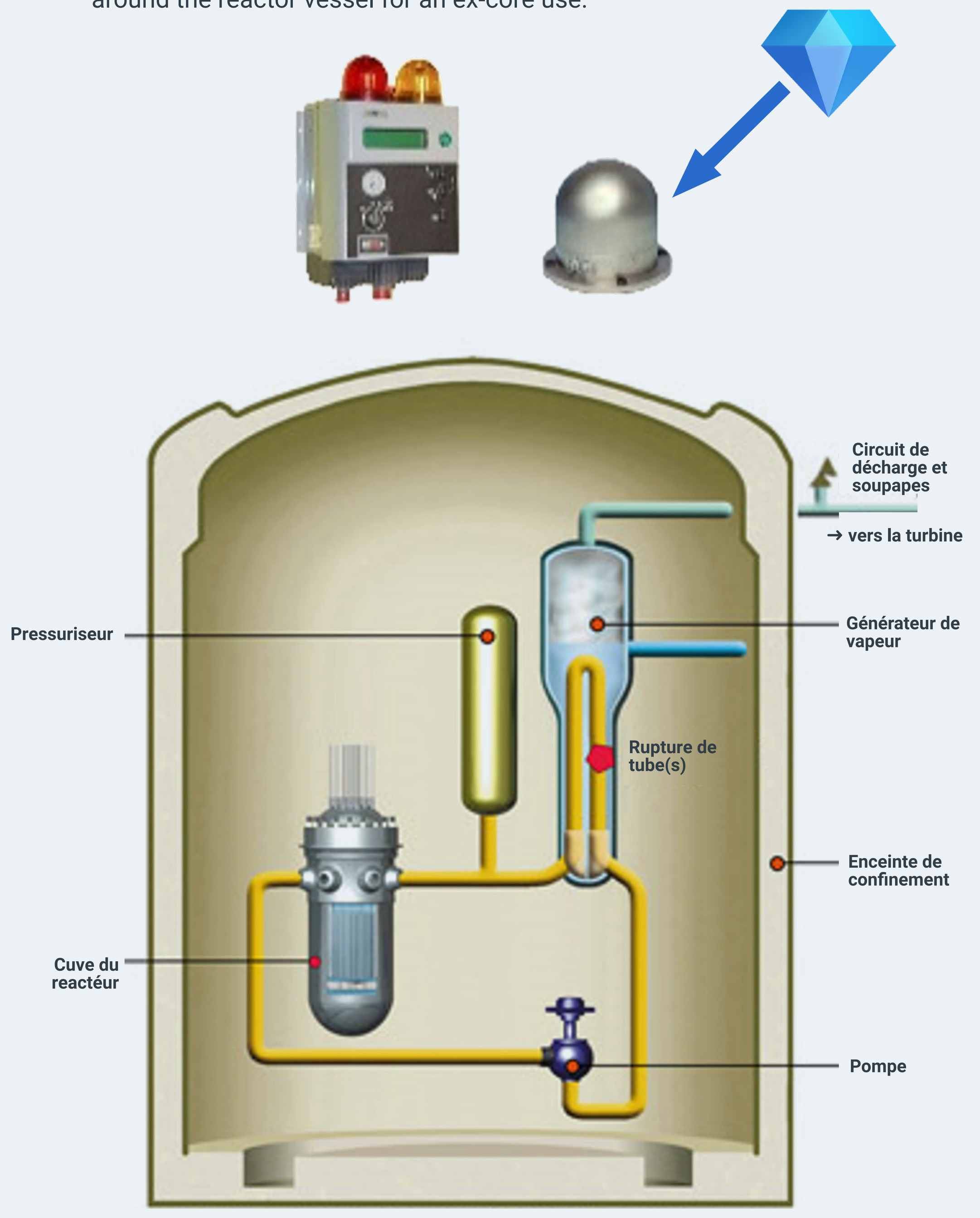



*Figure 1 Gim 202k γ dose rate operating in nuclear facilities under mild operating or post-accident conditions outside the containment vessel: small steam losses are an example*

## The Challenges Of Neutron Flux Measurements

The neutron flux rates seen by diamond detectors in the vicinity of Tokamak fusion reactors will be extreme. Today 500 µm thick detectors are experimented. The use of 50 µm thick detectors will increase the maximal fluence by a factor of 20

If a section of the front end of the electronics connected to the detector is in close vicinity to the detector, its radiation resistance will have to be guaranteed as well.

| Description | Value |
|---|---|
| Range of neutron fluxes from experimentation to commercial use | 10$^{16}$→10$^{19}$ n/sec. |
| 1 MeV equivalent flux | 1.90.10$^{12}$ n/cm$^{2}$/sec. |
| 1 MeV equivalent max fluence | 9.50.10$^{16}$ n/cm$^{2}$. |
| 14 MeV max fluence 500 µm thick detector | 0.5.10$^{14}$ n/cm$^{2}$. |
| 14 MeV max fluence 50 µm thick detector | 1.0.10$^{15}$ n/cm$^{2}$. |

## Principle Of Neutron Detection

The neutrons produced by the fusion reaction have an energy of 14 MeV

$$d+t \rightarrow {}^{4}He_{[3.5\ MeV]} + n_{[14.1\ MeV]}$$

In the diamond detector, the following reaction can occur between a 14 MeV neutron and a carbon, atom of the detector

$$n_{[14.1\ MeV]} + {}^{12}C \rightarrow {}^{9}Be + \alpha$$

The resulting energy of these alphas will be around 8.3 MeV

## The spectra and their importance for the assessment of plasma regimes

The following spectra are taken from ITER publications; the 8.3 MeV peak resulting from the n+C reaction is highlighted in the spectrum below

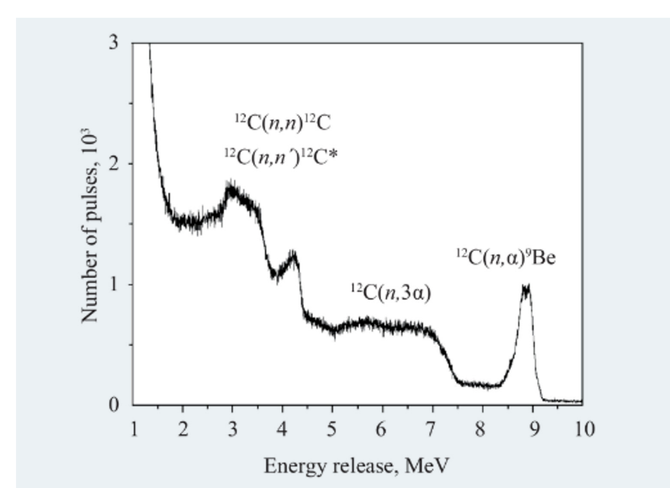



*Figure 2 A typical Alpha spectrum resulting from a 14 MeV neutron beam interacting with a diamond detector*

Montecarlo modelling of the neutron emission spectrum in a reactor show that the tail of the 14 Mev peak can give precious information about the plasma regime (injection of neutral beam). Having leading edge resolutions will thus allow fusion reactor operators to have a diagnosis on the regime of the plasma

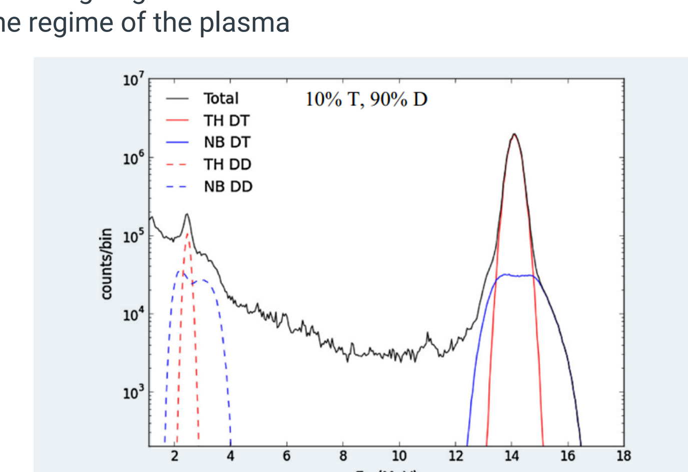



*Figure 3 Modelled neutron spectra in fusion applications and the influence of the neutral beam (NB) on the alpha tail*

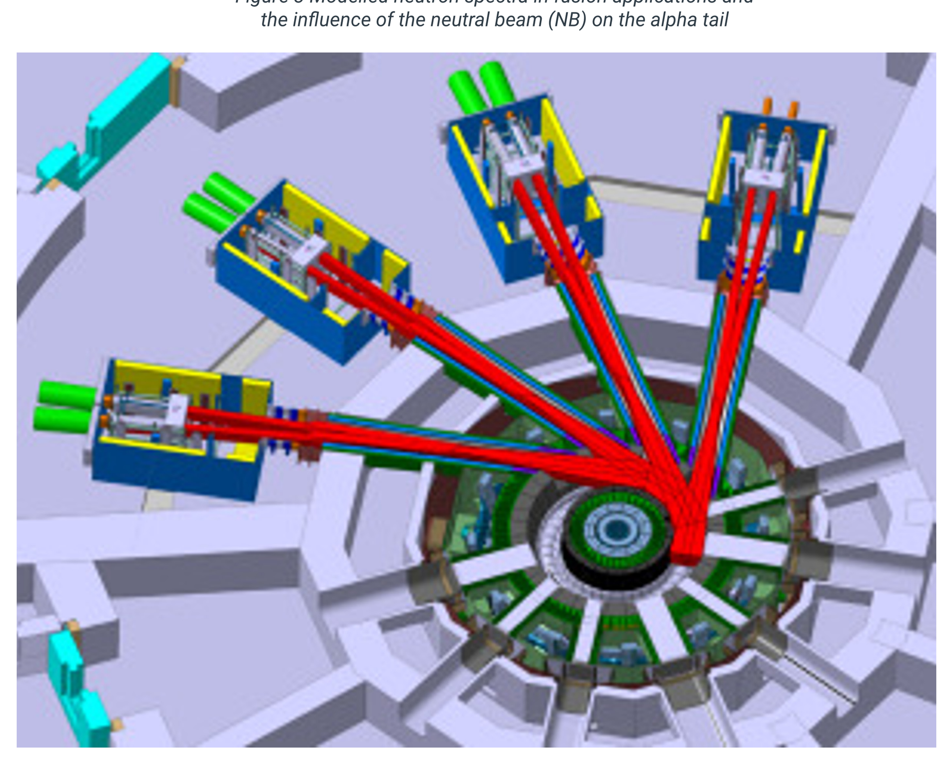


*Figure 4 Neutral beam injectors in a tokamak*

## Spectroscopy Characterization of a Diamond Detector

### Campaign 1: γ spectroscopy with a Canberra™ charge sensitive amplifier and MCA

A 4 mm by 4 mm by 500 µm electronic grade diamond detectors of Elements 6 was connected to a Canberra CSA and MCA for spectroscopy measurements

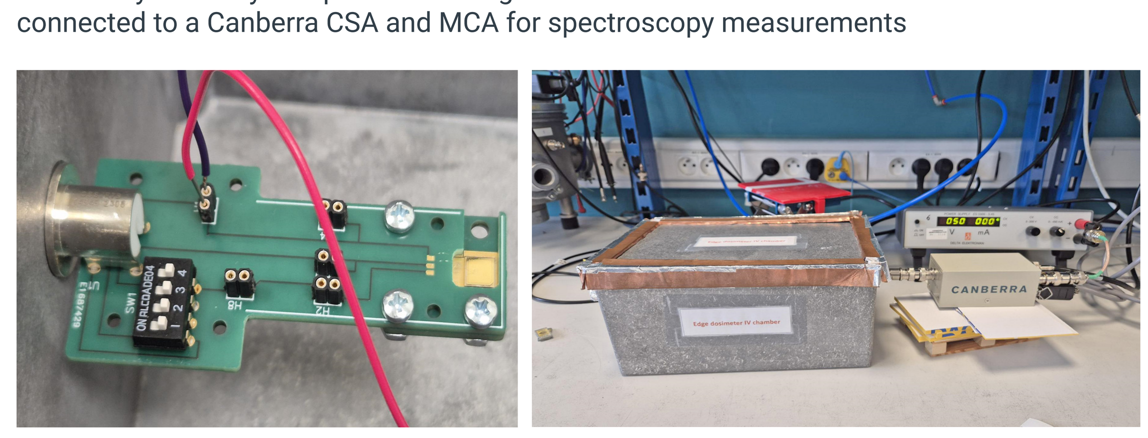


*Figure 5 The 4 mm by 4 mm diamond detector mounted on a FR4 (right photo) pcb and its connection to a 2018 EB CSA (left photo)*

### The setup

**Electronics:**

- The diamond detector was connected to a 2018 EB charge sensitive amplifier of Canberra by AC coupling.
- A DSA-Lx MCA was used for the spectroscopy acquisition

**Operating conditions:**

- A rise time of 1 µsec was used.
- A voltage of 200 Volts was applied to the detector
- A source of 10 µCi of Cs-137 was placed at a distance of 5 mm from the detector surface

### Gamma spectroscopy results

Several features can be witnessed on a Cs-137 spectrum

- The Compton edge at 480 keV
- An escape peak at 580 keV related to the metal contacts used for making the junction
- The photo peak at 662 keV

There is a good match between the MCNP modelling and the experimental spectra.

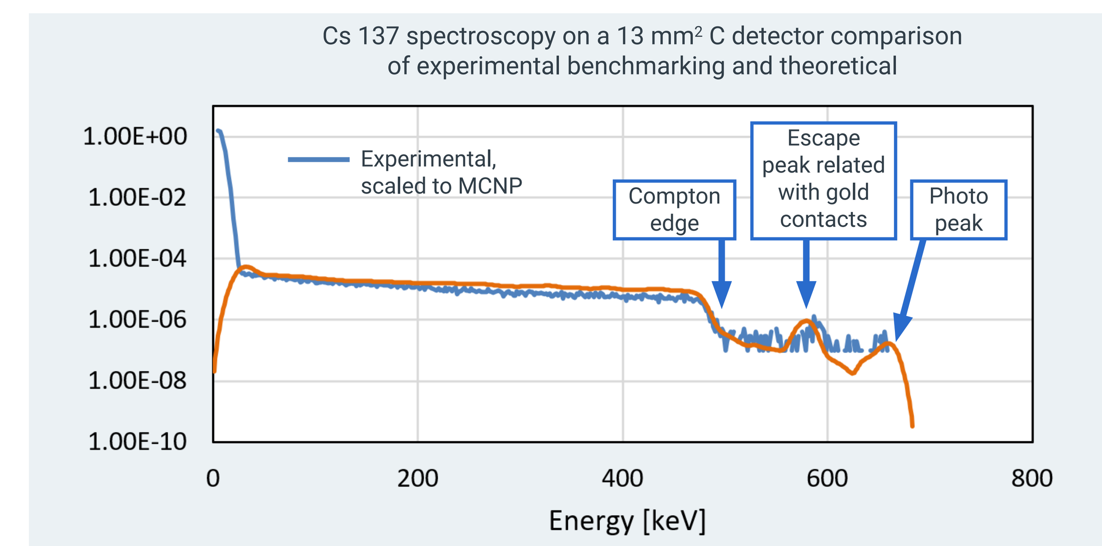



*Figure 6 A gamma spectrum taken with an Cs 137 source*

### Campaign 2: neutron spectroscopy

Our detector was set at a distance from 20 mm from a 1.04.1010 Bq AmBe source. The same CSA and MCA was used as in our gamma spectroscopy characterization.

An alpha peak centered around 4 MeV is typically observed. An overlay of measurements with Mirion detector and detector from other producers is shown below us shown below:

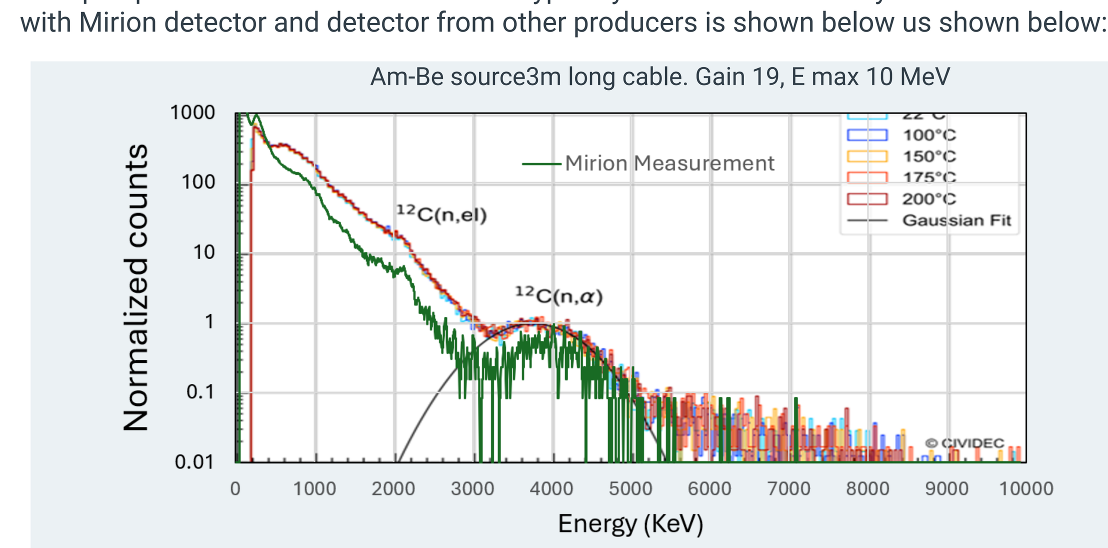



*Figure 7 An alpha spectrum taken with an Am Be source*

### Campaign 3: validation of a platform for rad hard electronics

In order to match the TID of the electronics to the TID of the detector, an electronic planform was devised whare the front-end section would be limited to a rad , T° hard 1st stage amplifying transistor (in SiC or C) and an integrating capacitor and the rest of the electronics would be deported on a second board

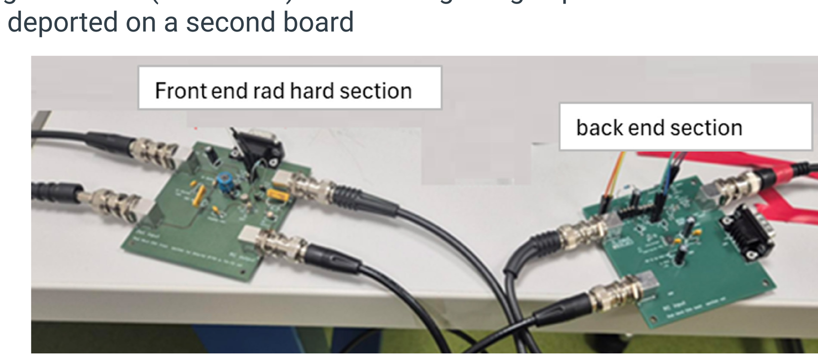



*Figure 8 An electronics section with a front panel for hosting hard , T° hard 1st stage transistors*

An alpha spectrum of a silicon PD50 detector was taken with distances between the front end and back-end board of 0.5 m and 5 m at and is shown on the figure below. Currently silicon based JFETs have been used. Rad hard SiC RadFETS will be evaluated soon and will be connected to diamond detectors

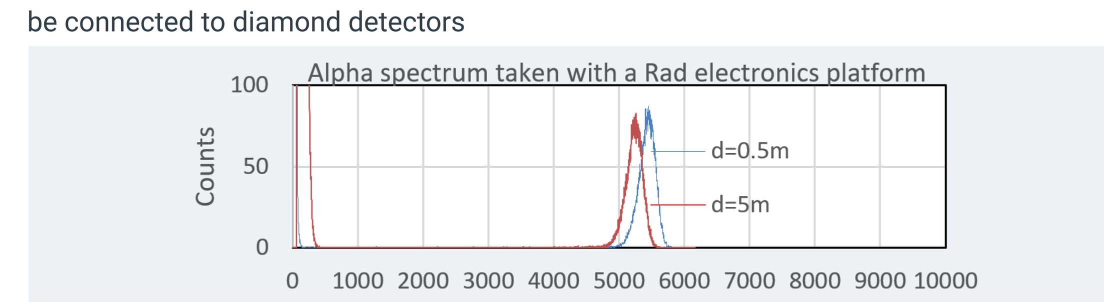
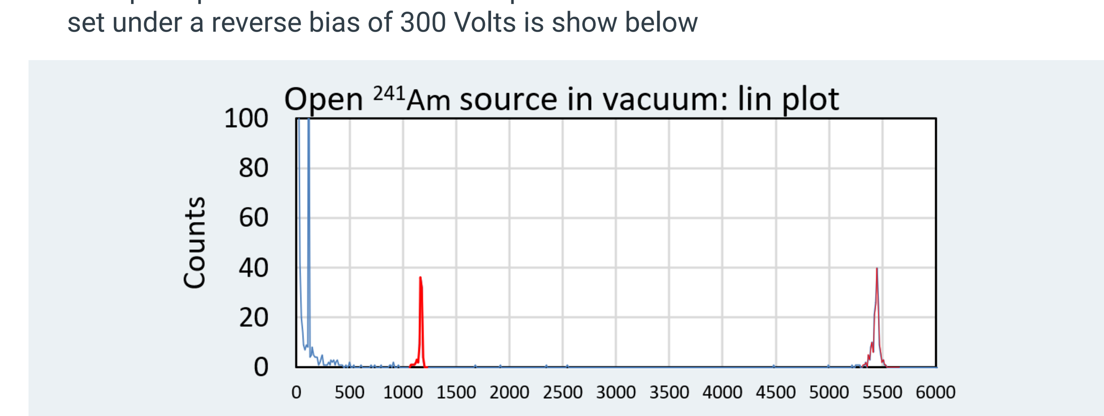



*Figure 9 An alpha spectrum taken with a back panel at 0.5 m and 5 m from the rad hard front panel*

### Campaign 4: alpha spectroscopy on a SiC detector

- An alpha spectrum of a 0.7 mm$^{2}$ 50 µm thick SiC detector taken with an Am241 source set under a reverse bias of 300 Volts is show below




## Conclusions

Diamond detectors assembled at Mirion have proven to conform to state of the arts spectroscopy standards in terms of gamma and neutron spectroscopy.

The first alpha spectroscopy results of 50 µm thick siC detectors grown by CSIC are very promising as well

The ground stones for a rad and T° hard electronics platform have been devised for evaluating RadFETS in SiC and C from several suppliers

## References

1. High-temperature Operation Characteristics of Diamond Radiation Detectors Masakatsu Tsubota Sensors and Materials, Vol. 37, No. 5 (2025) 1959–1967
2. Heat and radiation resistances of diamond semiconductor in gamma-ray detection Katsunori Ueno Japanese Journal of Applied Physics 58, 106509 (2019)

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