Diamond and silicon as possible candidates for LHC cryogenic beam loss monitors

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Plan of the presentation

• Introduction
  – Beam Loss Monitoring system at CERN
  – Cryogenic BLM for new LHC

• Cryogenic irradiation test
  – Setup
  – Results
    • Leakage current
    • Degradation curves (Kurfuerst parameter)
    • Voltage scan

• Cryogenic BLM in LHC ring
Beam Loss Monitoring system at CERN

Damage and quench protection of the sensitive superconductive elements by measurement of secondary shower particles from beam losses by Ionisation chambers, secondary emissions monitors and diamond detectors.
Cryogenic BLM for new LHC

Overview of LHC ring with four main experiments

LHC triplet magnets left of LHC-b experiment at CERN
Cryogenic BLM for new LHC

- Deposited dose in the coils from losses inside magnet (red),
- Deposited dose in the coils from the debris (blue),
+ BLM signal from debris (one blue cross for each BLM),
× BLM signal from dangerous losses (one red cross for each BLM) inside magnet and
— proposed BLM beam abort threshold to protect from dangerous losses.
Cryogenic BLM for new LHC

Cross section of the new triplet magnet for the HL-LHC [courtesy of Paolo Ferracin].
Cryogenic BLM for new LHC

The main challenges for CryoBLM are:

- the superfluid helium environment (1.9 K),
- the integrated dose of about 2 MGy in 20 years,
- the reliable operation in a magnetic field of 2 T,
- the mechanical resistance to a fast pressure rise up from 1.1 to about 20 bar, in the case of the quench of a magnet,
- the time response faster than 1 ms.

Cross section of the new triplet magnet for the HL-LHC [courtesy of Paolo Ferracin].
First radiation-hardness test of scCVD diamond and Si detectors performed in liquid helium environment.

CRYOGENIC IRRADIATION TEST
Cryogenic irradiation test - setup

- Beam coming from the CERN PS (24 GeV/c momentum protons),
- Beam spread with a FWHM of 1.2 cm at the cryostat and
- Average beam intensity per spill of $1.3 \cdot 10^{11}$ protons/cm², corresponding to $1 \cdot 10^{10}$ protons/s on the detectors.
Cryogenic irradiation test - setup

6 $p^+\text{-}n\text{-}n^+$ silicon detectors of 4.5, 200, 500 and 10k $\Omega\text{cm}$ resistivity with Al metallisation (The thickness of the samples was of 300 $\mu$m.)

2 scCVD diamond detectors with a double layer metallisation of gold and titanium and a thickness of 500 $\mu$m.

DC current generated by the beam was measured.
Cryo-test - Leakage current

At the end of the irradiation a total integrated fluence of $1.22 \cdot 10^{16}$ protons/cm$^2$ was reached, corresponding to an integrated dose of 3.26 MGy for silicon.
Cryo-test - Leakage current

Diamond leakage curve (after irradiation) in room temperature.

At the end of the irradiation a total integrated fluence of $1.22 \cdot 10^{16}$ protons/cm$^2$ was reached, corresponding to 3.42 MGy for the diamond.
Cryo-test - Degradation curves

Degradation curves of the scCVD diamond detector (with 500 Ωcm silicon as an reference).
Cryo-test - Degradation curves

The reduction of collected charge per MIP of fluence (based on Hecht equation).

\[
Q_{MIP}(\varphi) = Q_{MIP}(0) \sum_{i=e^-, h} \frac{\mu_i E \tau_i(\varphi)}{d} \left(1 - \left(\frac{\mu_i E \tau_i(\varphi)}{d}\right) \left(1 - e^{-\frac{d}{\mu_i E \tau_i(\varphi)}}\right)\right)
\]

\[
\tau_i(\varphi) = \frac{\tau_i(0)}{1 + \tau_i(0) \cdot k \varphi^s}
\]

Degradation curves of the scCVD diamond detector (with 500 Ωcm silicon as an reference).
Cryo-test - Degradation curves

10kΩcm silicon degradation curves under reverse bias (with 500 Ωcm silicon as reference).
Cryo-test - Degradation curves

10kΩcm silicon degradation curves under forward bias (with 500 Ωcm silicon as reference).
Cryo-test - Silicon and diamond detector comparison

scCVD diamond degradation curves (with 10 kΩcm and 500 Ωcm silicon detectors as reference).
Cryo-test - Silicon and diamond detector comparison

- At low irradiation dose, silicon detectors operated at 300 V reverse bias had a larger signal than the diamond detector with 400 V bias.
- The crossing point was at a fluence of $3.8 \cdot 10^{14}$ protons/cm$^2$ (0.1 MGy), from where on sCVD started to have higher signal.
- The crossing point between sCVD with 400 V and the silicon detector with 300 V forward bias was at $3.35 \cdot 10^{15}$ protons/cm$^2$ (0.9 MGy),
- showing that for very high radiations diamond sensors should be the material of choice.

scCVD diamond degradation curves (with 10 kΩcm and 500 Ωcm silicon detectors as reference).
Cryo-test - Voltage scan

Charge/MIP of bias voltage for scCVD diamond detector at different irradiation stages.
Cryo-test - Voltage scan

Charge/MIP of bias voltage for the 10 kΩcm silicon detector at different irradiation stages.
Frist cryogenic beam loss monitor on cold mass of a superconducting magnet in Large Hadron Collider ring

CRYO-BLM IN LHC RING
Cryo-BLM in LHC ring

Intersection between LHC bending magnets (left) and view on a cold mass of bending magnet with places, marked in red, for Cryo-BLM installation (right).
Cryo-BLM in LHC ring

On the cold mass of a LHC magnet was installed:

A 500μm scCVD diamond detector (In collaboration with Erich Griesmayer, CEO of CIVIDEC instrumentation GMBH, Vienna).

A module with four 300μm Si detectors and modules with one 100μm Si and four 300μm Si (not on the picture) in collaboration with Vladimir Eremin, IOFFE, St. Petersburg.
Cryo-BLM in LHC ring

Single photons of $\gamma$-radiation recorded by scCVD diamond detector during test in the tunnel.
These first LHC CryoBLM detectors will allow testing of:

- the detectors performance,
- their long term stability and
- their radiation hardness for actual LHC particle showers and particle rates.
Thank you!