RD39 Status Report 2011-2012

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Outline

- Review Charge Injected Detector (CID) development
- Cryogenic Beam Loss Monitoring (BLM) for LHC
- BLM experimental results
  - Test beams
  - Transient Current Technique (TCT) measurements with laser
- Near term plans of BLM project
- Summary
Expected CCE of CID at -50°C

Strips  Pixels & Cryogenic Beam Loss Monitor

- Simulation takes into account linear trapping
- $\beta=0.01$ cm$^{-1}$
  $\sqrt{x}$ E-field distribution is assumed

$$W_{pin} \propto \left(1 - \frac{x}{d}\right)$$

$$W_{CID} \propto \sqrt{x}$$

$$CCE = CCE_{Geometrical} \times CCE_{trapping} = \frac{w}{d} \times e^{-t_{dr}/\tau_{trapping}} \times \begin{cases} 1 \times 10^{14} \text{n$_{eq}$/cm$^2$} & \tau_{trap}=10\text{ns} \\ 1 \times 10^{15} \text{n$_{eq}$/cm$^2$} & \tau_{trap}=1\text{ns} \\ 1 \times 10^{16} \text{n$_{eq}$/cm$^2$} & \tau_{trap}=0.1\text{ns} \end{cases}$$

12.06.12  J.Härkönen, 110th LHCC Open Session, 13.06.2012, CERN
Charge Injected Detector (CID) –Operational Principle

The electric field is controlled by charge injection, i.e. charge is trapped but not detrapped at “low” temperature

\[ \tau_{\text{trapping}} = \frac{1}{\sigma_{e,h} v_{th} N_t} \]

\[ \tau_{\text{detrapping}} = \frac{1}{\sigma_{e,h} v_{th} e^{\frac{-E_t}{kT}}} \]

Electric field is extended through entire bulk regardless of irradiation fluence.

Electric field is proportional to square of distance \( E(x) \sim \sqrt{x} \)

Detector is “fully depleted” at any bias or irradiation fluence.
At given voltage, ensuring sufficient electric field $E(x)$ strength, forward current decreases when irradiation fluence increases.

IV data recorded at -50°C.
Test Beam experiment on CID detectors

- Sensors investigated
  - $2 \times 10^{15} \text{ n}_{\text{eq}} / \text{cm}^2 \text{ n}^+/\text{p}/\text{p}^+ \text{ MCz-Si}$
  - $5 \times 10^{15} \text{ n}_{\text{eq}} / \text{cm}^2 \text{ p}^+/\text{n}/\text{n}^+ \text{ MCz-Si}$ (in 2008 $3 \times 10^{15} \text{ n}_{\text{eq}} / \text{cm}^2 \text{ p}^+/\text{n}/\text{n}^+ \text{ MCz-Si}$)

$\mu^-$ 230 GeV
$5 \times 10^{15} \text{n}_{\text{eq}} / \text{cm}^2$ results - Collected charge vs V

- Average 13.4 ADC @ 600V
- Full charge measured by 12 reference planes is 40 ADC
- One data point is MPV of typically >20 000 events seen by telescope
- Relative Charge Collection Efficiency is about 33% while the noise $\approx 1000e^-$
$5 \times 10^{15} \, n_{eq} / \text{cm}^2$ results - Collected charge vs non-irrad
Beam Loss Monitoring (BLM) for LHC

- There are currently about 4000 BLMs in LHC.
- BLM is needed in order to give warning signal of a beam loss that might result in magnet quenching.
- In current BLM devices, it is possible that signal of a dangerous beam loss is hidden behind of background induced by normal beam debris.

Fluka Simulations for Assessing Thresholds of BLMs Around the LHC Triplet Magnets, A. Mereghetti and M. Sapinski, http://indico.cern.ch/conferenceDisplay.py?confId=156472
Proposed solution

- Place the BLM inside of cold mass, close to interaction point
- CERN workgroup: B. Dehning, M. Sapinski, T. Eisel, C. Kurfuerst
- Challenge: Si detector should operate at LHe temperature <2K and should simultaneously be radiation hard up to 1 MGy.
- At LHe temperature there is no annealing of radiation defects + shallow donor/acceptor impurities are not ionized
- For more information about BLM project see “Cryogenic Beam Loss Monitors workshop”
  http://indico.cern.ch/conferenceDisplay.py?confId=156472
Experimental work this far

- Test beam measurements at CERN, 9 GeV particles from PS
- Transient Current Technique (TCT) measurements at CERN Cryolab
Test Beam at CERN PS

MPV ≈ 4fC i.e. 1 MIP charge

Counts

Collected charge [C]

x 10^{-13}
TCT setup @ Cryolab

- RD39 Cryo-TCT
- LHe cryosystem made by Thomas Eisel

Cryogenic system is presented at:
Cryogenic Beam Loss Monitors workshop
Cryogenics for East Hall experiments 5'
Speaker: Thomas Eisel (Technische Universitaet Dresden)
Detector arrangement

- Detector delivered by PTI
- Degenerately doped $p^+/n^-/n^+$ sensor
- Thickness 300µm
- Optical illumination both sides
- Sample holder etc designed by Vladimir Eremin
TCT measurement in CID mode

- Detector **non-irradiated**
- CID operation up to 200V
- Forward current \( \sim 100\mu A \)
- Drift time \( \approx 6-7\) ns for holes
- Very long \( \sim 50\) ns tail in signal

Back side illumination, i.e. hole current transient
CID Electron current transient vs Temperature

- In principle, CID concept should not work unless detector is heavily irradiated, i.e. lot of deep levels.
- Nice signal $T<15K$
- $T>15K$ signal polarity inverts and amplitude decreases
CID Hole current transient vs T

- Nice signal T<15K
- T>15K signal polarity inverts and amplitude decreases
Ohmic behaviour with forward bias

- \( T \approx 7K \)
- The resistance is 2M \( \Omega \)
- Sensor 0.5cm x 0.5cm x 0.03cm
- Resistivity \( \approx 17M \, \Omega \text{cm} \)
- About 50 times more than Si intrinsic resistivity at RT

\[
y = 0.5x - 1.7
\]

\[\text{Current [\mu A]}\]
\[\text{Voltage IVI}\]
Reverse bias operation

Si electron pulses at 3330 V/cm

Measurement by C. Kurfürst
Near term plans

- August 2012 “warm” test in a beam

- November 2012 high intensity (irradiation) test beam with cryogenics at CERN PS T7 area.

- Production of BLM dedicated silicon detectors ongoing. Activity coordinated by Vladimir Eremin, Ioffe PTI
Summary

- Si detectors produced by RD39 are successfully tested in particle beams and by laser TCT setups.
- Non-irradiated detector provides signal T<15K, i.e. below shallow level freeze-out T in Si.
- Polarization due to radiation defects at deep cryogenic temperature is likely to be a major challenge > CID operation might be mandatory.
- At very low temperatures and CID mode, symmetrical behaviour, i.e. electron and hole current transients apparent, both.
- IV is ohmic with forward bias.
- Current is ≈ 0 reverse bias.
- When dopant freeze-out, Si bulk turns into insulator.
- Forward current establishes $E(x)$ over 2MΩ resistor.
- Reverse bias operation of a non-irradiated detector rather “normal” T<15K.