High Level Gamma Radiation Effects on Cernox™ Cryogenic Temperature Sensors

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Background

- High Energy Physics applications are driving radiation hardness requirements in cryogenics.
- It’s not the goal to irradiate the supporting infrastructure, but it invariably happens.
- Applications such as ITER and the FCC require SC magnets to steer particles and they require cryogenic systems for use to below 4.2 K, including thermometry.

This work examines the effects of high level gamma radiation on Cernox™ Resistance Temperature Sensors.
Cernox Resistance Temperature Sensors

CxRT Properties:

• Adjustable temperature sensitivity to optimize response
• High sensitivity and resolution at lower temperatures
• High stability over thermal cycling and time
• Excellent in magnetic fields

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<thead>
<tr>
<th>Temperature (K)</th>
<th>Sensitivity (ohms/K)</th>
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<tbody>
<tr>
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<td>40</td>
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<table>
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<tr>
<th>Temperature (K)</th>
<th>Resistance (ohms)</th>
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CX-1050
CX-1080
CxRTs and Radiation

- **CxRT Material:**
  - Sensing material is a ZrN / ZrO combination
  - Materials should be good in radiation
  - Confirmed by previous experiments in gamma, neutron, and proton radiation

- **CxRT Models:**
  - Chose models CX-1050 (1.4 K – 420 K) and CX-1080 (20 K – 420 K)

- **CxRT Package:**
  - Lake Shore’s standard SD package
  - All metal / ceramic construction (materials traditionally radiation hard)
  - Body approximately 2 mm wide × 3 mm long × 1 mm high
Experimental design

- **Sensors**
  - 2 wafers of each model, 20 sensors from each wafer
  - Divided into 10 Groups – 2 sensors from each wafer

- **9 irradiation levels + 1 control group**
  - 10 kGy, 25 kGy, 50 kGy, 100 kGy, 250 kGy, 500 kGy, 1 MGy, 2.5 MGy, 5 MGy

- **Performed at SNL Gamma Irradiation Facility**
  - Linear Array Co-60 source
  - Dose rate $\approx 10$ Gy/s
  - Room Temperature irradiation
Measurements

- **Calibrate → Irradiate → Calibrate**
  - Calibrations performed in Lake Shore’s Temperature Calibration Facility
  - CX-1050s: 84 points spanning 1.4 K – 325 K temperature range,
    CX-1050s: 52 points panning 20 K – 325 K temperature range

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<tr>
<th>Temperature (K)</th>
<th>Uncertainty (± mK)</th>
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<tr>
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- Results given as Calibration shifts calculated as $\Delta T = \Delta R / S_T$ where $\Delta R = (R_{final} - R_{initial})$ and $S_T =$ Temperature Sensitivity
CX-1050: Average ΔT after irradiation

ΔT ≈ 1,750 mK is
ΔR ≈ 0.25 Ω or
ΔR/R ≈ 0.5%
CX-1050: Average ΔT after irradiation

Less than 35 mK Offset at 4.2 K after 5 MGy
CX-1080: Average ΔT after irradiation
CX-1080: Average ($\Delta T/T$) (%) after irradiation
CX-1080: Average ($\Delta T/T$) (%) after irradiation
Discussion

- **CxRT Resistance decreased following irradiation**
  - Current results are consistent with previous measurements at 10 kGy
  - Main interaction with Co-60 gammas should be Compton Effect
  - Would expect creation of defects $\Rightarrow$ resistance increase!

- **Similar Types of Devices after gamma irradiation**
  - Germanium: Resistance increased in both bulk and Ge on GaAs films
  - Carbon glass resistors: Resistance increased in bulk devices
  - Carbon resistors: Resistance decreased in both bulk and thin film versions

- **Explanation?**
  - In carbon: suggested the result is due to creation of additional carriers
  - Additional carriers could also be forming in CxRT sensing films
  - Could also be due to interactions between sensing film and contact metals
CxRTs are a 2-lead device

Sapphire Substrate

Sensing Film

V+, I+ Contact

V-, I- Contact

Contact Pads

1.02 mm

0.81 mm
- Shared voltage / current contacts not the best design
- Measuring resistance in this 2-lead design can distinguish between changes in the sensing film and changes in the contact metallization
4-lead CxRT Pattern for future testing

Sapphire Substrate  Sensing Film

V+ Contact  I+ Contact

V- Contact  I- Contact

No current flow under Voltage contact metallization

This pattern will help separate out effects
Conclusions

- Tested: 80 samples of CxRTs, 2 models, 4 wafers
- Gamma radiation: Co-60, 10 Gy/s from 10 kGy to 5 MGy

Results

- No catastrophic failures
- Equivalent temperature shift increased with increasing temperature and dose
- Low temperature behavior very good
  - Average offset of 13 mK at 1.8 K after 5 MGy dose
  - Average offset of 33 mK at 4.2 K after 5 MGy dose

- Future work to examine metallization contacts