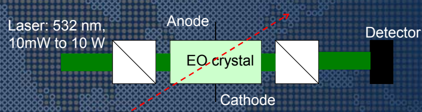

Electro-Optic Detector

Project number: SL09-ELOPDET-PD03, P.I. Nathalie Le Galloudec, Sandia National Laboratories, Livermore, CA, Ph: (925) 294-3453, Email: nlegall@sandia.gov

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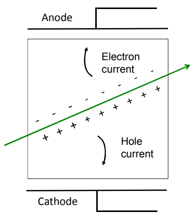
I. Goals and objectives: investigate a radically new type of radiation detector that supplies tracking information about the incoming particle and particle identification.

II. Introduction: an ionizing event generates free electrons and holes in the medium with which it interacts and leads to a change of the index of refraction

Advantages: The measured signal is independent of the scintillation light. The intensity of the detected signal is proportional to the intensity of the incident signal and the intensity of the effect (index change) in space and time, and can be time gated.

III. Method: Develop a step by step understanding of effects and detection limits (theoretical and experimental)

IV. Results: Given the magnitude of the change expected, we looked first at bulk effects. These have been seen and the community agrees. To understand single ionizing event we need to understand the detection limit experimentally in space and time.



When an energy E_0 is deposited it, it produces No = Eo/Epair carriers. The energy (Epair) to create an electron hole pair carrier is ~3.4 time the band gap
From C. A. Klein, J. Appl. Phys. 39,2029 (1968)

Gammas:
A. I. Gusarov and D. B. Doyle, Vol. 37, No. 4, Applied Optics, Feb 1, 1998, bulk effect of gamma radiation on commercial optical glass.
M. Fernandez-Rodrıguez et al., Thin Solid Films 455 –456 (2004) - gamma rays on coatings

Electrons:
D. Gardner, Journal of applied polymer science vol. 11, pp. 1065-1078 (1967) - 13 MeV electrons in plastic

X-rays:
Berzins and Graser, Appl. Phys. Lett., 34, 500 (1979)
Robert E. Green, Metallurgical and Materials Transactions A, Volume 20, Number 4, 595-604, 1989
Z. Marka et l., ieee transactions on nuclear science, vol. 47, no. 6, December 2000, effect of x-rays measured through second harmonic generation.
Previous internal reports for this project in LiTaO3, not in KDP

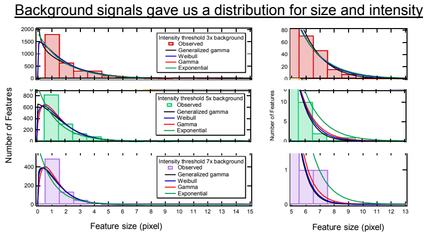
Neutrons:
K. Nelson et al., "Investigation of CdZnTe and $LiNbO_3$ as electro-optic neutron detectors", Vol 620, Issue 2-3, 11–21 August 2010, Pages 363–367 (2010)
Nelson, K.A., et al., Nuclear reactor pulse calibration using a CdZnTe electro-optic radiation detector. Appl. Radiat. Isotopes (2012), doi:10.1016/j.apradiso.2011.12.038
K. Nelson et al., NIM A 680 (2012) 97-102 – Electro-optic detector response to nuclear power pulses
Y. Eisen and A. Shor, IEEE transactions on nuclear science, vol. 56, no. 4, august 2009 - 1cm thick pixelated CZT detector, neutrons create bulk defects affecting spectral quality

Theoretical estimates for single ionizing events:
$\Delta n/n = n^2 rE/2$
Length: $SQRT(kT\varepsilon/e^2 n_o)$
$E = SQRT(n_o kT/\varepsilon)$

Index change estimates:
For a 1micron track: 0.06%
For a 10 micron track: 0.00004%

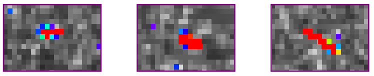
Investigated KDP, and LiTaO3 crystals
Used a 14 MeV neutron source and 500 µCi 152Er source

Background signals gave us a distribution for size and intensity



Typical statistically significant features

Greater maximum intensity: >50 × background
Larger sizes: up to 13 pixels
Wider features: 5 – 8 pixels

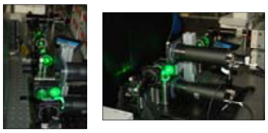


Direct imaging has limitation:
- Viewing region is ~1.7mm by 0.425mm with a 30 µm depth of focus, 25µm resolution
- Background cosmic ray interaction with CCD
- Direct radiation interaction with CCD
- Acquisition time 15µs

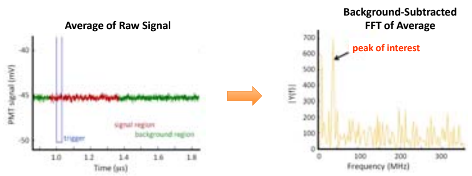
Background interactions in the CCD camera imitate charge particle interactions within the crystal

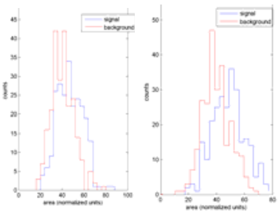
Several improvements to the muon setup have been identified to determine lifetime of the effect

- Setup in a stable environment: temperature/humidity
- Build a mechanical mount so alignment between xtal and muon paddles is optimized
- Use a stable laser
- Measure the laser output in parallel to compensate for fluctuations
- Align axis of laser and axis of Muon detection
- Apodize the beam to maximize the overlap between the beam and the crystal at a constant intensity
- ~0.5 % of the light on the tracks is rotated and passes through the cross polarizers



50,000 electron-hole pairs, linear pair density of 20 /µm.





Method: Compare an average of PMT traces from 47 triggers
- Identify signal and background regions of the recorded data
- Signal region: + 0.4 ms from the trigger
- Background region: Time prior to and > 0.4 ms from the trigger
- Perform an FFT on both signal and background regions, and background-subtract

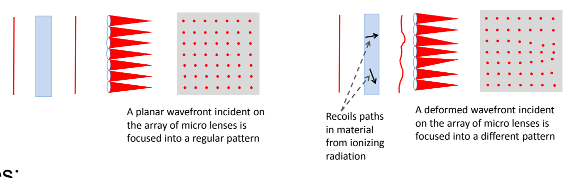
Result: region of interest identified at 39-45 MHz. Its amplitude varies with applied voltage.

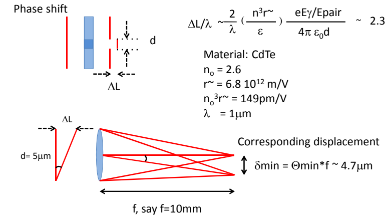
Suspected signal is a few count above background. Further statistical analysis in progress.

V. Future developments: Improved understanding is leading to proposed multi-parameter method with orders of magnitude increase in signal sensitivity

A change of the index of refraction modifies the wavefront. A pixelated array of micro lenses sense the wavefront deformation and quantifies it. This is a known technique in astrophysics and high-intensity lasers. The pattern observed is different than background interactions in the CCD and sensitive to x, y, z, time, wavelength, intensity.
An appropriate material and thickness as well as array of micro lenses and detector will optimize potential for detection.

A wavefront sensor and the appropriate material can optimize detection





VI. Conclusion and relevance to program objectives:

The development of the electro-optic detector would provide a radically new type of radiation detector that supplies tracking information about the incoming particle and particle identification. Development of this technology will provide progress toward achieving the high-level portfolio requirements detailed in the NA-22 SNM Detection Portfolio GOR document (NA22-PDP-03-2006) by addressing the high-tier areas identified in Table 9 of the SNM Movement Detection Portfolio: Technology Roadmap (NA22-PDP-02-2007)

Rad Sensing, 2012

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