SCINT 2017 - 14th Int. Conference on Scintillating Materials and their Applications

Contribution ID: **164** Type: **Oral presentation**

Light spread manipulation in scintillators using Laser Induced Optical Barriers

Wednesday 20 September 2017 12:00 (15 minutes)

As a diametric alternative to mechanical array fabrication, Laser Induced Optical Barriers (LIOB) is being explored for fabrication of high resolution and high sensitivity scintillator detectors for a number of imaging applications including Positron Emission Tomography (PET) [1], Single Photon Emission Tomography (SPECT) [2], and Computed Tomography (CT) [3].

With LIOB one can permanently change the crystal structure of a scintillator on a nano/micro scale using pulsed laser beam(s) tightly focused in a small focal volume. With this arrangement we can cause material optical breakdown which can be exploited to create crack(s), or lattice deformation and void formation in the focal point, depending on the crystal's thermo-mechanical properties and the nature of laser energy transfer to the crystal structure. The resulting so-called optical barriers will have a refractive index (RI) different from that of the crystal bulk, and their size, shape and RI can be engineered by carefully selecting laser parameters like pulse energy, pulse duration and repetition rate. Optical barriers incorporated inside the bulk of a monolithic detector block will redirect the scintillator light and can thus be used to manipulate and control the light spread in the detector.

We are exploring the capabilities of the LIOB technique for fabrication of thick LYSO:Ce detectors with depth of interaction (DOI) capability and single-side readout for PET. The behavior of these laser processed scintillators is between that of a monolithic block and a mechanically pixelated array. Given the flexibility in the optical barrier patterns that may be incorporated in the crystal, one important part of the detector development is the optical barrier pattern optimization. We are performing light transport simulations, using the Monte-Carlo code DETECT2000, to study the scintillation light spread in these laser processed crystals as a function of optical barrier pattern as well as characteristics of the barriers such as RI and roughness of the barrier-crystal interface.

Our results show that slab-shaped optical barriers, arranged in a 1 mm pitch pixel-like pattern all the way through a 20 mm thick crystal (resembling mechanically cut arrays) can provide up to 67% light confinement within individual pixels. The FWHM of the light response function (LRF) for a barrier RI of 1.0 and a smooth barrier-crystal interface was calculated at ˜2.3 mm. A rougher interface increases the inter-pixel crosstalk but results in a depth-dependent width of the LRF that becomes wider further from the photodetector plane. The latter can be used for DOI extraction. We further studied the expected detector performance when the crystal is only processed partially through its thickness. Such barrier pattern shows improved transversal as well as DOI resolution compared to a monolithic detector especially close to the crystal edge.

Our experimental results show that the barriers can be placed at any depth within the crystal with barrier width as narrow as 2 microns. Through our preliminary results, we further demonstrate that the roughness of the barrier-crystal interface can be controlled.

References:

[1] H. Sabet, L. Blackberg, D. U. Ozsahin, A. Sitek, and G. El-Fakhri, "A sub-mm spatial resolution LYSO:Ce detector for small animal PET,"in 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2015, 2016.

[2] H. Sabet, L. Bläckberg, D. Uzun-Ozsahin, and G. El-Fakhri, "Novel laser-processed CsI:Tl detector for SPECT,"Med. Phys., vol. 43, no. 5, 2016.

[3] L. Bläckberg et al., "Scintillator-based Photon Counting Detector: is it feasible?,"in 2016 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2016, 2016.

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Session Classification: Metamaterials

Track Classification: S10_Metamaterials / Light Output (Orals)