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Comparing BSO and BGO with different surface finishes as cost-effective, hybrid scintillation/Cherenkov detectors for TOF-PET

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Before the introduction of L(Y)SO:Ce, BGO was used in many PET systems. Compared to L(Y)SO:Ce, BGO offers a number of superior properties, such as a higher stopping power, higher photoelectric-fraction, no intrinsic radiation, and cost-effectiveness. On the other hand, BGO was not thought to be a good scintillator for time-of-flight detection, due to its relatively low light yield and long scintillation decay time.

In recent years, TOF-PET detectors exploiting the fast nature of the Cherenkov effect have been proposed. For example, CRTs down to 70 ps FWHM have been achieved using PbF_2 coupled to MCP-PMTs. One problem of this method is the low Cherenkov emission yield in the order of ~10-20 photons per 511 keV annihilation photon, which complicates energy discrimination–a severe disadvantage in clinical PET.

We have recently observed a radioluminescence response in the 100 ps domain upon excitation of BGO with 511 keV photons, using time correlated single photon counting (TCSPC). This fast emission is likely to be connected with the Cherenkov effect. We have furthermore shown that this fast luminescence component can be used for improving the timing properties of BGO, while still using the scintillation signal for energy discrimination. This hybrid scintillation / Cherenkov scheme allows TOF detection while maintaining the previously mentioned advantages of BGO. For example, with BGO cubes of 3 mm x 3 mm x 3 mm we obtained coincidence timing spectra with FWHM values down to 200 ps FWHM. However, the timing histograms have non-Gaussian shapes with relatively high FWTM values, ranging from 1.3 ns to 3 ns for 3 mm to 20 mm long crystals, respectively.

Here, we show how the timing kernel of BGO can be improved for TOF-PET by optimizing the crystal surface roughness. We present an improvement of the FWTM by almost 50%, ranging from 0.6 ns to 1.65 ns for 3 mm to 20 mm long crystals, respectively.

A potential disadvantage when applying BGO in TOF-PET is a reduced rate capability due to the scintillation decay time of about 300 ns. We therefore investigate BSO ($Bi_4Si_3O_{12}$) as a possible alternative for BGO. We show that with its 100 ns decay time and just 20% of the light yield, the FWHM can be improved by up to 20% compared to BGO. Moreover, while BGO can already be considered cost-effective compared to L(Y)SO:Ce, BSO allows substituting the relatively expensive GeO_2 by SiO_2 and, therefore, reducing the costs of material even further, while slightly improving the timing characteristics.

Coincidence timing results will be presented for BGO and BSO crystals with polished surfaces and with surfaces optimized for coincidence timing. Best results to date were achieved with BSO, viz. a FWHM of 192 ps and a FWTM of 725 ps (cubes with 3 mm edge-lengths). Moreover, temperature dependent TCSPC spectra will be presented for both materials. The results of this work show that the fast emission in BGO and BSO can be used to boost the timing performance of both materials.

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