TOFPET 검출기용 고광도 섬광 결정 및 고주파 전단 회로를 이용한 시간 분해능에 관한 종합적 연구

A Comprehensive Study on the Timing Limits Using High Light Yield Crystals and High-frequency Front-end Circuit for TOF PET Detectors

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Abstract

The coincidence time resolution (CTR) values can be improved by increasing photostatistics, which in the PET detector occurs with a high light yield (LY) of scintillation crystals. We report on a systematic study on achievable CTR performance with high light yield scintillation crystals, especially including Ce:Ca and Ce:Mg double-doped LYSO crystals, and state-of-the-art high-frequency (HF) electronics. The HF electronics utilizes a balun transformer to passively compensate the undesirable capacitance of silicon photomultipliers and wide bandwidth RF amplifiers were used to amplify the high frequency signal. The CTR value of 142 ps and 135 ps FWHM were achieved with LYSO:Ce:Ca and LYSO:Ce:Mg, respectively.

1. Purpose

Time-of-flight (TOF) information is now a standard for recent positron emission tomography (PET) systems [1]. The precise detection of coincidence gamma-ray timestamps improves the signal-to-noise ratio of PET images. Therefore, many research groups have developed and tested their own ultra-fast high-frequency benchtop experiment setups to achieve the timing limits. The state-of-the-art design utilizes a balun transformer and fast RF amplifiers to take full advantage of high frequency electronics in leading-edge timestamp discrimination.

The coincidence time resolution (CTR) values can be improved by increasing photostatistics, which in the PET detector occurs with a high light yield (LY) of scintillation crystals. The two main contributors to the LY are the intrinsic light yield of the scintillation crystal and the light transfer efficiency [2], which depend on crystal material, dimensions, and wrapping conditions. Photons generated from scintillation events go through a series of processes consisting of SiPM and high-speed electronics to pick off a precise arrival timestamp. We report on a systematic study on achievable CTR performance with high light yield scintillation crystals, especially including Ce:Ca and Ce:Mg double-doped LYSO crystals, and state-of-the-art high-frequency electronics. Especially, an investigation into the trade-off relationship between CTR performance and power consumption was included.

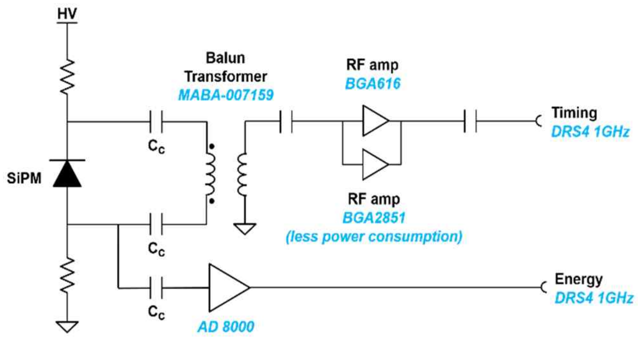

Figure 1. High-Frequency Electronics

2. Materials and Methods

Various high LY scintillation crystals (**Figure** 2), including LGSO, LYSO:Ce:Ca, LYSO:Ce:Mg crystals, were investigated to measure relative LY and achievable CTR values under differing physical conditions such as crystal pixel size and reflector material. Three types of commercial single SiPMs with the same SPAD size, 40 µm, but with different active areas and peak PDE wavelengths were chosen. For a fast timing channel, high-frequency readout electronics were constructed employing passive compensation for the SiPM

Figure 2. Tested Scintillation Crystals (left), Coincidence Event Data Acquisition Setup (right)

detector capacitance (**Figure** 2**)**. The passive compensation was implemented using a 3 GHz balun transformer (Macom MABA-007159 (MACOM 2018) (50 Ω impedance and 1:1 turn ratio)) [3] connected between the cathode and the anode of the SiPM so that a balanced-to-unbalanced converted signal propagates into the following RF amplifier(s). For the RF amplifiers, BGA 616 was used to amplify the fast timing signal with wide signal bandwidth. All experiments were conducted with the overvoltage from 2V to 6V and in a room temperature condition. The optimal threshold level was found by varying the digital leading-edge discriminator thresholds for each experiment.

3. Results

A pair of representative signals from the timing and the energy channels is illustrated in **Figure** 3. Overvoltage of 6V was applied to the both detectors. The fast timing output showed a rise edge shorter than 5ns. The high slew rate of the rise edge of timing signal enabled sub-200 ps CTR values.

With the optimal leading-edge threshold, the measurements yielded a CTR value of 177 ps for LGSO crystal wrapped with ESR film, 142 ps for Teflon, and 377 ps for the black paint (**Figure** 4). The Teflon yielded not only the best relative light yield but also in terms of the CTR among different reflector materials. With the crystal wrapped with black paint, the light yield significantly deteriorated, which also caused the worst CTR value.

The tested double-doped crystals showed similar or slightly better CTR values than the LGSO crystals, which corresponds to the tendency of the increased light yield.

4. Acknowledgements

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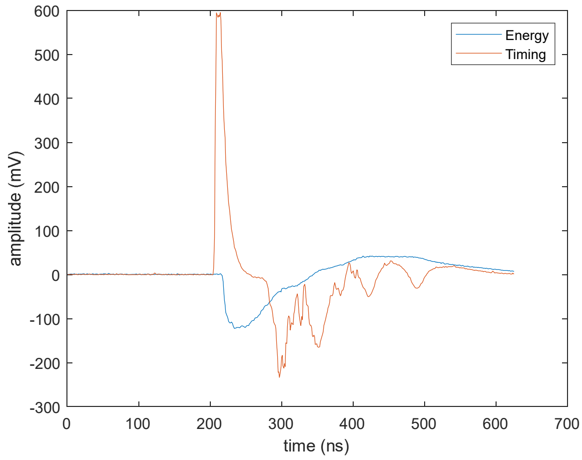

Figure 3. Representative Timing and Energy Signal Output

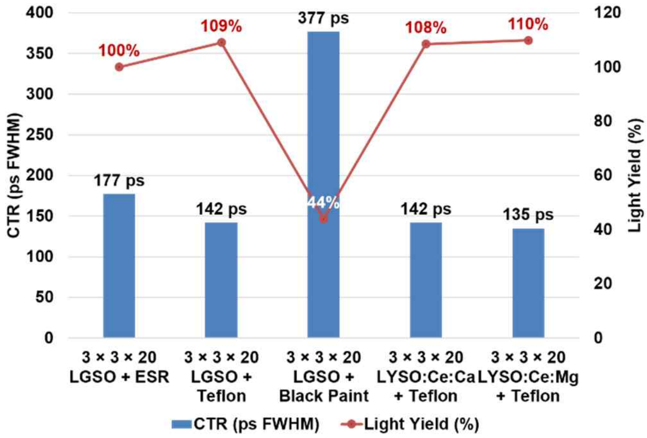

Figure 4. CTR values and Relative Light Yield values

5. References

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