Investigation of Light Collection Enhancement in Scintillation Detectors via Micro-lens Array

Suyeon Hyeon[1], Min Sun Lee[1*]

[1]Electrical Engineering and Computer Science, Daegu Gyeongbuk Institute of Science and Technology, Daegu, Korea

*Corresponding Author Email: leems@dgist.ac.kr

One of the fundamental limitations in scintillation detectors is the significant light loss due to Total Internal Reflection (TIR) at the interface between the high-refractive-index scintillator and the photosensor. This phenomenon restricts light extraction, consequently degrading both the energy resolution and timing characteristics of the detector. To mitigate this, integrating a Micro-Lens Array (MLA) on the scintillator surface has been proposed [1]. This study investigates to enhance light extraction by designing various micro-lens geometries and evaluating the transmittance within an effective collection angle of 30° to assess both total transmittance and central light concentration. We present a simulation-based analysis investigating the relationship between the geometric parameters of the MLA, optical transmittance, and the angular focusing capability.

To analyze the optical behavior of the MLA-integrated scintillator, Finite-Difference Time-Domain (FDTD) simulations were performed as shown in Figure 1(a), where MLA with tens of micrometer scale structures were placed in between LYSO crystal and photosensor glass window. Four MLA geometries were simulated and Figure 1(b) presents the best structure among them. The effectiveness of the micro-lenses was evaluated based on the E-field and Poynting vector distributions derived from the simulations and compared with the airgap condition (bare crystal).

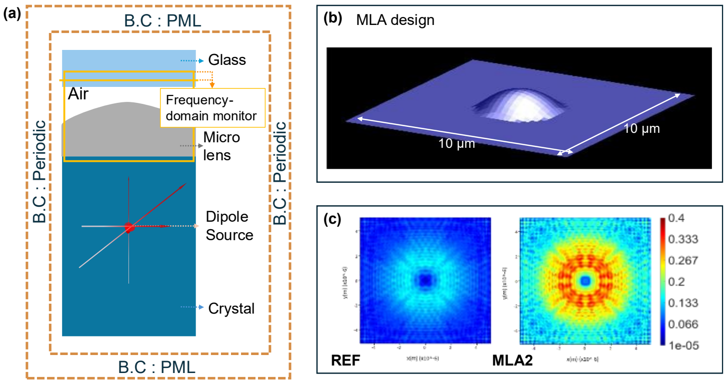

Figure 1. (a) Illustration of the FDTD simulation domain illustrating the boundary conditions and monitor placement. (b) Schematic view of the proposed micro-lens unit geometry. (c) E-field intensity maps (λ= 446 nm) of bare LYSO crystal and the MLA structure integrated LYSO.

Simulation results showed that total transmittance from scintillator to photosensor window was significantly enhanced in all MLA-integrated structures, achieving up to 2.67-fold enhancement compared to the bare crystal. Not only the total transmittance, we also evaluated effective transmittance, which was strongly influenced by the angular focusing capability of MLA designs. Here, the effective transmittance was evaluated as transmittance within a 30° acceptance angle, calculated based on the escape cone at the scintillator-air interface (NA ≈ 0.5). Under this criterion, three MLA structures exhibited negligible gain. In contrast, one MLA structure (Figure 1(b)) exhibited a strongly concentrated electric field distribution, as shown in the E-field intensity map of Figure 1(c). Consequently, this structure achieved a 2.67-fold enhancement in total transmittance compared to the bare crystal and a 2.59-fold enhancement in effective transmittance within the 30° collection angle by 2.59-fold undergoing light redirection.

These results suggest that applying MLA to a scintillation detector can increase the total transmittance by redirecting escaping photons. Additionally, the evaluated effective transmittance can be a meaningful consideration in assessing whether the MLA structure effectively bypasses the dead area of the photosensor and reduces light loss.

1. X. Chen *et al.*, "Light extraction enhancement and directional control of scintillator by using microlens arrays," *Opt. Express*, **26**, 23132-23141 (2018).

This research was supported by National Research Foundation of Korea grant funded by Ministry of Science and ICT (No. RS-2025-02316993).