Synthesis of halide perovskite quantum dot liquid scintillator for particle detection

JEON Min Hyeong , KIM Eun Min , JOO Kyung Kwang ,
KANG Tae Yeong
Center for Precision Neutrino Research(CPNR), Department of Physics,
Chonnam National University

Introduction

Motivation

- We aim to develop a liquid scintillation solution (LS) for particle detection in the low-energy range (~keV)
- Utilizing the unique luminescent and scintillation characteristics of perovskite quantum dots.
- LS based on perovskite quantum dots is designed to resolve the limitations of existing scintillators and achieving enhanced light emission at a particular wavelength.
- We try to develop a simple synthesis method that can be expanded at room temperature & pressure without the need for special high costing equipment for the next generation neutrino experiment

Experiment Setup

- $MAPbBr_3$ perovskite quantum dots were synthesized and coated with Oleic acid (OA) and Oleylamine (OAm), using toluene as the solvent.
- The synthesized sample was centrifuged into upper and lower fractions and a sediment, and then the particle size distribution and luminescence of both fractions were analyzed to assess sample stability.

Development of Perovskite-based LS (PVLS)

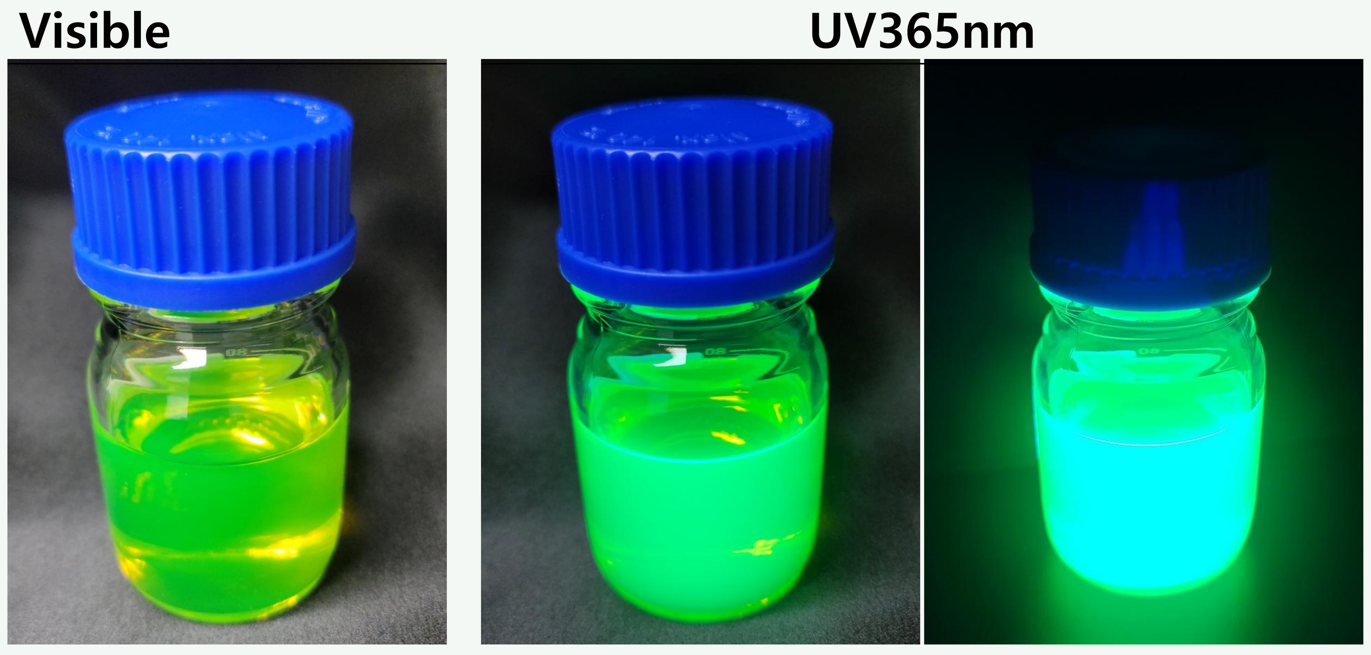
1. Fabrication of perovskite precursor
   1) Dissolve 2.5 mmol of $PbBr_2$ in 5 ml of DMF for 4 hours, then pour 0.08 ml of OA and 0.45ml of OAm and mix for about 2 hours.
   2) After loading 2.5mmol of MABr, mix.

2. Fabrication of perovskite-based LS
   1) Pour 1 ml of precursor solution into 30 ml of toluene and mix using a stirrer for about 2 hours.
   2) Perform centrifugation at 15,000 rpm for 30 minutes to remove the precipitate and obtain the supernatant.
   3) To improve transmittance, adjust the concentration of the perovskite-based LS or use PPO to shift the fluorescence.
      a. If it is necessary to shift the fluorescence additionally, pour 1.8 ml of the solution from step 2-1) into 98.2 ml of toluene, load PPO at a concentration of 3 g/L, and mix using a stirrer for 1–2 hours.
      b. Adjust the concentration by adding toluene so that there are $3.006*10^{-5}$ mol of perovskite crystals per 100 ml of toluene.

   If the fluorescent wavelength band is shifted, Br is replaced with Cl using TMCS (TMS-Cl, $(CH_3)_3SiCl$) in process 2-1) or 2-2).
   An additional centrifugation step was conducted when TMCS was used.

$MAPbBr_3$+ PPO

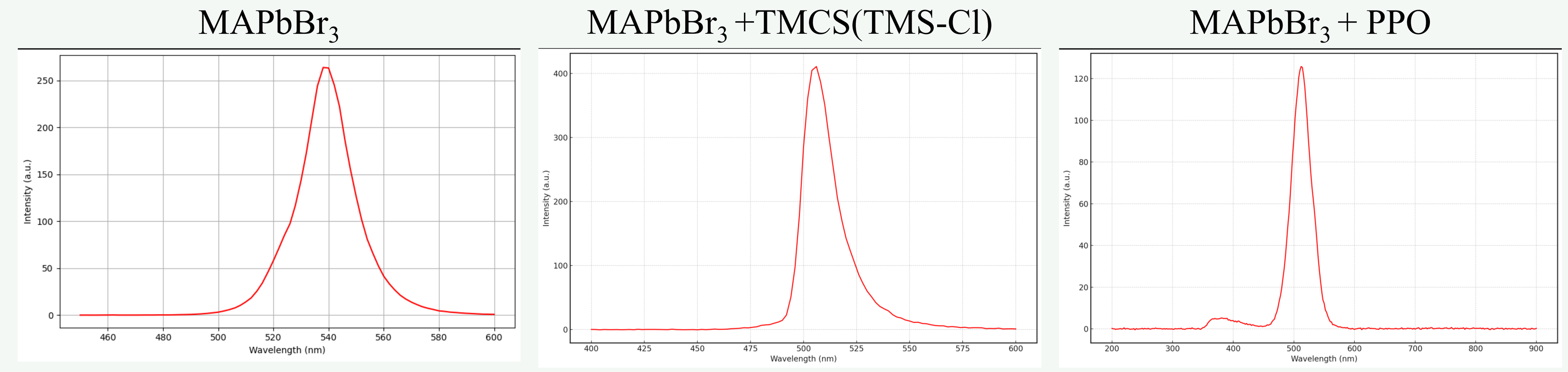
Visible | UV365nm



Material Characterization

Fluorescence Measurement

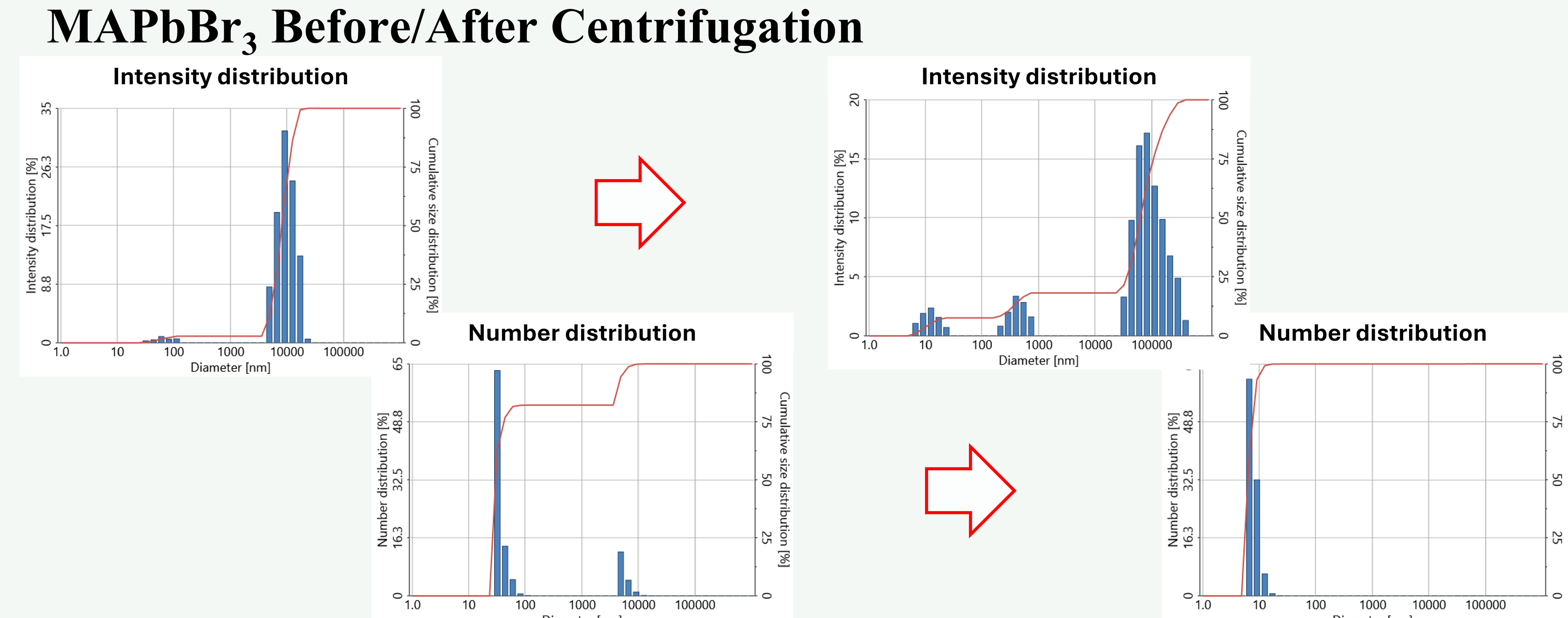
$MAPbBr_3$ | $MAPbBr_3$ +TMCS(TMS-Cl) | $MAPbBr_3$ + PPO



- The $MAPbBr_3$ quantum dots exhibited a strong emission peak near 538 nm in the fluorescence spectrum.
- After the addition of TMCS (TMS-Cl), a similar emission peak was observed around 506 nm, indicating a slight blue shift.
- This suggests that a substitution (Br to Cl) occurred between TMCS and the quantum dots.
- After the addition of PPO, a similar emission peak was observed around 515 nm, indicating a slight blue shift.
- This suggests that energy transfer occurred between PPO and the quantum dots. PPO was added to investigate the energy transfer phenomenon.

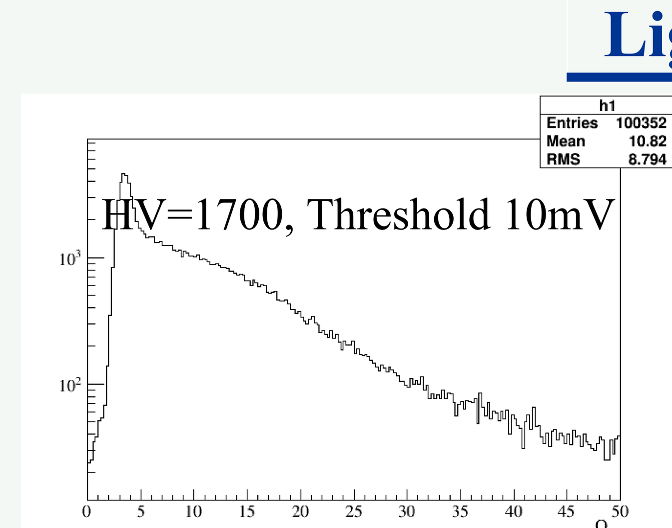
Particle Size Distribution

$MAPbBr_3$ Before/After Centrifugation



- Before) The particle size is distributed across 50–100 nm and 5000–8000 nm ranges, resulting in relatively large dispersion.
- After) The particle size distribution was reduced to a smaller range (7–15 nm), and the overall dispersion was decreased.

Light Yield Measurement



✓ Light yield measurement using a radioactive source(^{137}Cs)
✓ The Compton edge appears around Q_{tot} values of 18 to 20.

Summary &Future Plan

✓ Through the synthesis of PVLS, promising results can be observed as a result of improved stability and consistent light emission.
✓ Results showed that the emission wavelength band of PVLS was adjusted using TMCS (TMS-Cl) and PPO (2,5-Diphenyloxazole).
✓ Using the centrifugation method, the particle size can be adjusted from 50–100 nm to 7–15 nm to achieve a smaller and more uniform distribution.
✓ Subsequent studies will focus on enhancing the scintillation efficiency of PVLS and improving sample stability.

Reference :
William R. LEO,"Techniques for Nuclear and Particle Physics Experiments ", 2 ed, Springer (1994)
Creutz et al., Chem. Mater. 2018, 30, 4887–4891. DOI: 10.1021/acs.chemmater.8b02100.
E. M. Kim et al. *Poster*, KSHEP Fall Meeting, UNIST, 2024.