Increasing light collection efficiency of liquid argon detector for low mass WIMP search

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Abstract. Liquid argon (LAr) is known as an excellent target material for weakly interacting massive particle (WIMP) dark matter direct-detection search experiment. In WIMP searches, distinguishing signal events from electronic recoil (ER) backgrounds is essential. The reduction of ER power using pulse shape discrimination (PSD) improves as light collection efficiency increases. However photosensors, which have to be operational in a cryogenic environment, have no high quantum efficiency (QE) at the 128 nm VUV scintillation light of argon. Therefore, a wavelength shifter, i.e. tetraphenyl butadiene (TPB), is evaporated on the inner surface of the detector to convert VUV to visible light that can be detected by photosensors.

Thus, we constructed a well-controlled TPB evaporation system to ensure reproducibility and measured the amount of TPB on the surface using a quartz crystal microbalance. We obtained the world's highest light yield (~11.5 PE/keVee) by optimizing the amount of evaporated TPB. We describe our efforts to improve light collection efficiency.

1. Introduction

Liquid argon (LAr) is a good scintillator for direct weakly interacting massive particle (WIMP) search[1, 2]. Two components of LAr scintillation light can distinguish nuclear recoil events from ER backgrounds. The ER reduction power using pulse shape discrimination (PSD) becomes stronger as the light collection efficiency increases. However, the 128 nm VUV scintillation light of argon cannot be detected directly using high QE photodevices. Therefore, a wavelength shifter, i.e., tetraphenyl butadiene (TPB) is evaporated on the inner surface of the detector to convert VUV to visible light that can be detected by high QE photosensors[3].

2. Construction of the detector with the high light collection efficiency

We constructed the single-phase compact detector, shown in Figure 1 to confirm the maximum light yield. The detector has a fiducial volume of 5 cm height with a 6.4 cm diameter (LAr: 225 g). The detector material is a polytetrafluoroethylene (PTFE), and the photodevices used to detect scintillation light are two PMTs (HAMAMATSU, R11065; QE$\sim$ 30%). The inner surface of the detector is covered with a reflector film (3M$^{\mathrm{TM}}$ Enhanced Specular Reflector, ESR).

TPB is evaporated onto the PMT window and the ESR using a well-controlled evaporator (inner pressure$< 5 \times 10^{-3}$ Pa). Figure 2 shows the validation results of the TPB parameters to maximize light collection efficiency. The amount of evaporated TPB is measured using a quartz crystal microbalance and a stylus surface profiling system. The wavelength shifting efficiency is validated by a gaseous argon light test. The transmittance of visible light is validated by a

LED light (420 nm) test. In this validation, the wavelength shifting efficiency increases and the transmittance decreases as the amount of TPB icreases. Furthermore, the wavelength shifting efficiency is maximized above 25 μg/cm^2. Therefore, we evaporated $\sim$ 27 μg/cm^2 TPB onto a PMT window, $\sim$40 μg/cm^2 onto a ESR. The thickness of TPB on the PMT window was $\sim$ 1 μm (filling rate $\sim$ 30%).

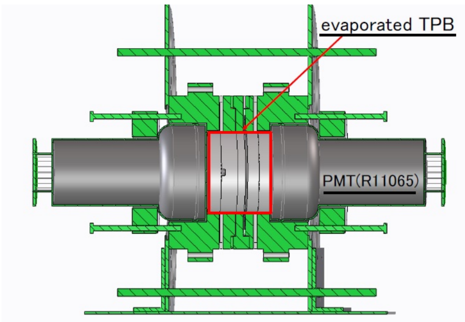

Figure 1. Cross section of the compact detector

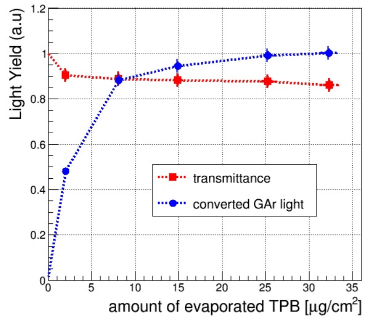

Figure 2. TPB validation result

3. Measurement of light collection efficiency

Light yield is measured using external radioactive γ sources under a null electric field at the LAr test stand at Waseda University. Figure 3 shows the scintillation spectrum for the ^{137}Cs γ source (662 keV). We confirmed the high light yield ($\sim$ 11.5 PE/keVee) by fitting the 662 keV full absorption peak with a Gaussian function, two error functions and a constant. In this detector, the light yield limit of PMT QE is $\sim$12 PE/keVee (initial scintillation light: 40 photon/keVee[4], PMT QE: $\sim$30%). We achieved high light collection efficiency by optimizing amount of evaporated TPB.

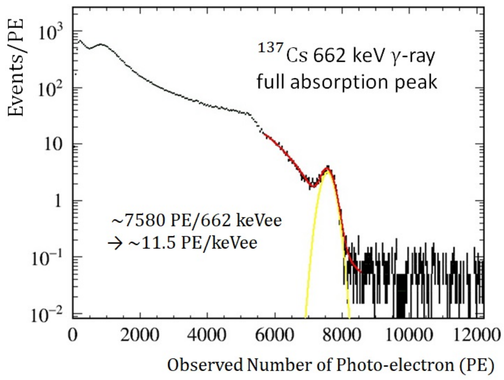

Figure 3. ^{137}Cs spectrum and fitting for full absorption peak

4. Summary and Prospect

The reduction of ER power using PSD improves as the light collection efficiency increases. We achieved high photon collection efficiency ($\sim$11.5 PE/keVee) using a wavelength shifting technique with a compact detector. R&D to improve light yield is ongoing. The TSV-MPPC[5] is a leading candidate as a photo device (expected 25 PE/keVee).

5. Acknowledgments

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