Study on Wavelength Shifters and Multilayer Half-Mirror for High-QE PMT

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Abstract

In the near-UV range of 300–400nm, where fluorescent lights from air showers induced by cosmic rays are emit, quantum efficiency of normal photomultiplier tubes are about 20%. On the other hand, a GaAsP photocathode has quantum efficiency of about 40% while its sensitive wavelength is longer than the near-UV range. In order to use this advantage of a GaAsP photocathode, we have produced wavelength shifter films from near-UV to visible and a half-mirror filter which transmits near-UV photons and reflects visible photons converted by the above wavelength shifter. With our concept, one can gain twice in near-UV signals than the traditional PMTs.

1. Basic Concept

Fig.1 shows examples of quantum efficiency (QE) for bi-alkali and GaAsP photocathodes. Since the fluorescence observational technique in extreme high

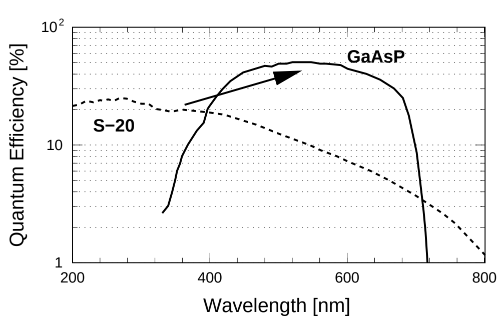

Fig. 1. Example of quantum efficiency for bi-alkali and GaAsP photocathodes.

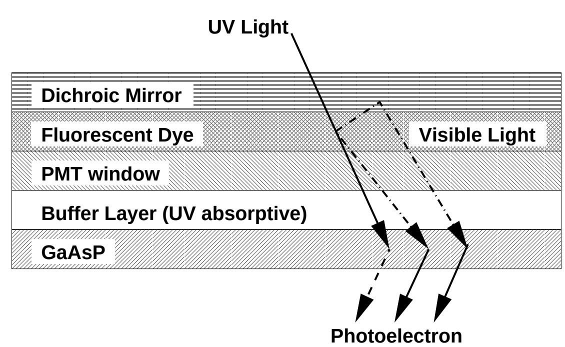

Fig. 2. Conceptual design to use a GaAsP photocathode in near-UV.

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energies above 10^{19}eV is inherently "photon hungry", this advantage of a GaAsP photocathode is an attractive solution to make a qualitative improvement.

For this purpose, we have preliminary made (1) wavelength shifters which absorb near-UV photons and re-emit visible photons, and (2) a half-mirror filter which transmits near-UV photons and reflects visible photons as shown in Fig.2. Here, we plan to use this conceptual detector for a position-sensitive detector such as a multianode photomultiplier HAMAMATSU R8900-M25 whose pixel size is 5mm $\times$ 5mm. The thickness of wavelength shifters, therefore, needs to be less than 100μm; but a thinner shifter converts near-UV photons inefficiently. Furthermore, a half-mirror should reflect visible photons re-emit by wavelength shifters efficiently. These are the items to make this concept work well.

2. Half-Mirror

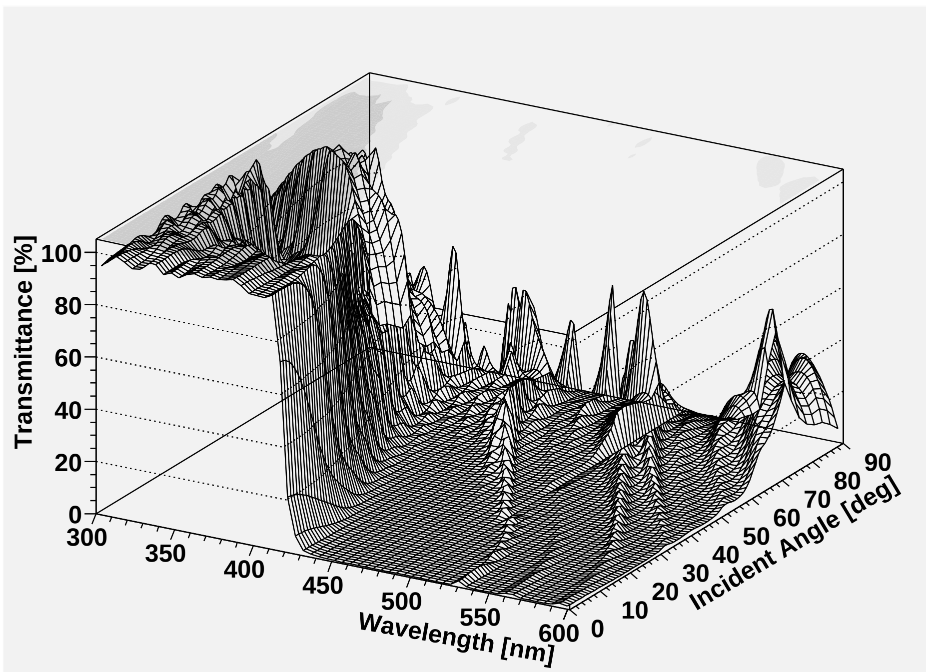

Fig. 3. Designed transmittance of a dichroic mirror.

We designed and produced a multilayer UV half-mirror. It is required to transmit UV photons below ∼400nm and to reflect visible photons above ∼400nm. The structure of layers is the following:

$$\text{substrate} \,/\, 0.5L \quad 0.824H \quad (0.824L \quad 0.824H)^{12} \quad 0.91L \quad 0.91H \quad \backslash$$
$$(L \quad H)^{10} \quad 1.1L \quad 1.1H \quad (1.2L \quad 1.2H)^{10} \quad 0.5L \quad / \text{ air}$$

The total number of layers is 71 and the total thickness is 5,717nm. Fig.3 shows its transmittance; and the transmittance sharply decreases around 420nm for vertically incident photons. This critical wavelength for obliquely incident photons slightly decreases with increasing the incident angle upto 30°.

3. Wavelength Shifters

We have selected '(Sc)POPOP' as a wavelength shifter:

$C_{24}H_{16}N_2O_2 = 364.4$; $\lambda_{abs}{}^{peak} \simeq 360\text{nm}$; $\lambda_{abs}{}^{peak} \simeq 420\text{nm}$,

and hostpolymer is 'polystyrene'. We ground them with 10wt% mixtures, sandwiched them between fused quartz with a 25μm separator, and then heated them up until 240°C. This temperature 240°C is just above the melting point of polystyrene, and it is higher than that of POPOP. Fig.4 shows the fluorescent

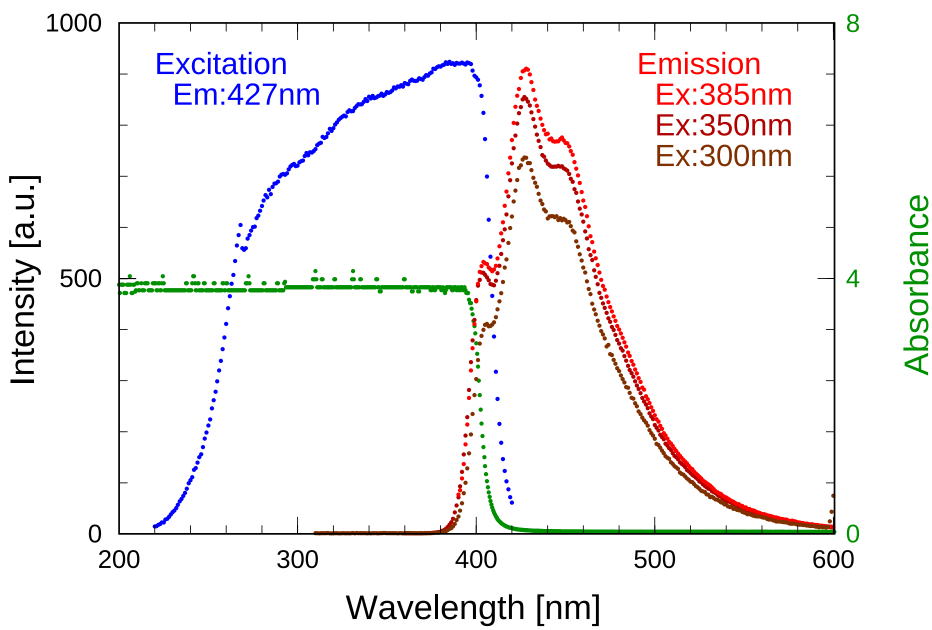

Fig. 4. Fluorescent/absorption spectra of the hot-pressed POPOP/polystyrene film.

/ absorption spectra of this hot-pressed film. The left (blue) curve indicates the excitation spectrum scanned at the emitted wavelength $\lambda_{Em} = 427$nm. The right (red) curves are the emission spectra excited by the exciting wavelength $\lambda_{Ex} =$ 300nm, 350nm and 385nm. The intensity of the emission spectra at 427nm are essentially identical with the intensity of the excitation spectrum at 300nm, 350nm and 385nm, respectively. The absorbance is shown by another left (green) curve with the left-sided axis and it is saturated below 400nm. So, the hot-pressed POPOP/polystyrene film converts UV photons to visible photons quite efficiently.

However, the peak wavelength of this emission spectrum is not large enough in comparison with the critical wavelength described in §2. So, we have selected 'Coumarin 152A' as a secondary wavelength shifter:

$C_{14}H_{14}N\,O_2F_3 = 385.27$; $\lambda_{abs}{}^{peak} \simeq 405\text{nm}$; $\lambda_{abs}{}^{peak} \simeq 510\text{nm}$,

and hostpolymer is 'PMMA'.

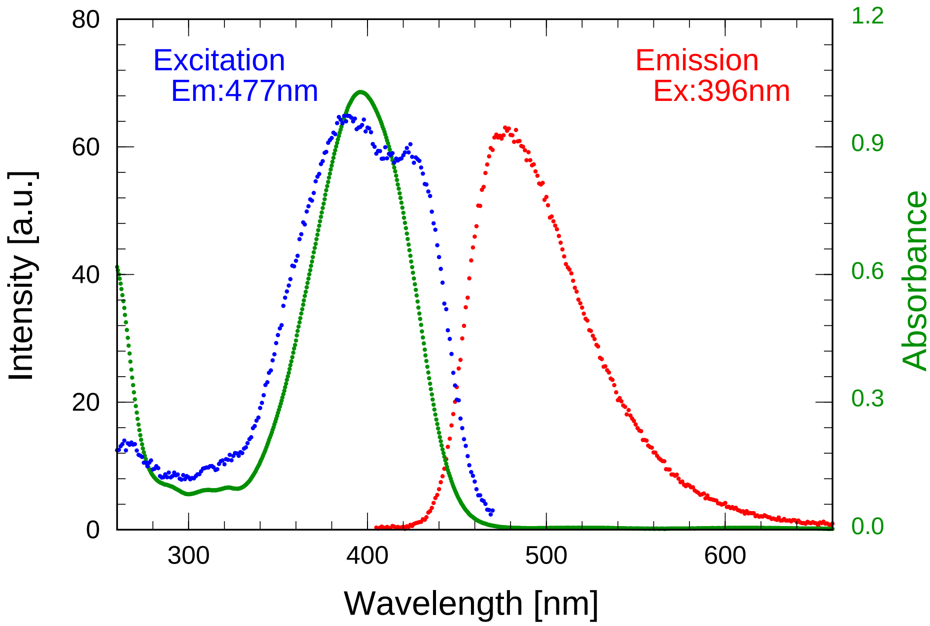

Fig. 5. Fluorescent/absorption spectra of the spin-coated Coumarin152A/PMMA film.

Fig. 5 shows the fluorescent / absorption spectra of this spin-coated film with 10wt% mixture. The absorption and emission profiles are good for use; but the intensities are rather small. This is the important point to be improved.

4. Summary

We have successfully made the POPOP film doped in porystyrene with the hot-pressed method, and tried the spin-coated film with Coumarin 152A / PMMA. The first sample of the UV half-mirror was produced. The total performance of these components with improved data will be presented in this Conference.

Acknowledgements

Author (MT) thanks the special postdoctoral researchers program in RIKEN. We made this concept the patent application #2002-320102.

1. The EUSO Collaboration, 2003, A series of presentations in this Conference.