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Development of a small-scale prototype of Fresnel optics for cosmic ray observation

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Abstract. For the optical detection of high-energy cosmic rays, wide field of view telescope is effective. We have developed the small-scale prototype of Fresnel optics to establish for the large-aperture, wide field refracting optics. This optics consists of two double-sided Fresnel lens, BG3 filter and the focal plane detector with the readout system. Diameter of Fresnel lens is 40cm and 1mm pitch grooves on spherical substrates. For the focal plane detector we used a 64-channel multianode photomultiplier (R5900-M64) with UV glass entrance window and standard assembly unit (H7546UV). For the readout system we have developed the original system, which consist of charge amplifier, peak hold and trigger.

1 Introduction

Recently many groups has observed high-energy cosmic ray (VHE gamma rays and EHE cosmic rays) by optical telescope. Their telescopes are basically constructed by reflecting optics. Such kind of telescope is suitable for observing specific point sources but for the narrow view, we have to arrange many telescopes to observe wide field of view. If we have a wide field of view telescope, we can use it for a source and tangent event survey so this kind of observation may will be the breakthrough of these study.

Tradeoff for the high angular resolution such as astronomical telescope, refracting optics has advantage to developing the wide field of view telescope because we do not need the high manufacturing accuracy than refracting optics. Moreover, to use Fresnel lens for the refracting optics we can make a low weight, a low photon absorption telescope. This kind of optics has applied to a basic design of EUSO (L.Scarsi (2001)).

We have developed the small-scale prototype of Fresnel optics to establish of large-aperture, wide field refracting optics. In this report, we will describe about the Fresnel optics we have developed.

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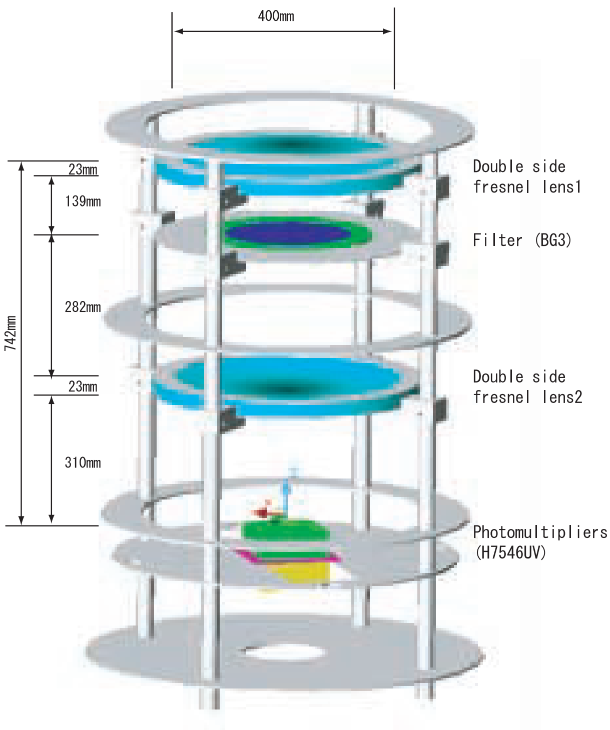

Fig. 1. A schematic view of small-scale prototype of Fresnel optics. This optics consist of double-sided Fresnel lenses with filter and detector at focal plane.

2 Development of small-scale prototype of Fresnel optics

The design of our Fresnel optics is shown in figure 1. This optics consists of two double-sided Fresnel lens (40cm diameter), which has cut on spherical substrates (D.J.Lamb 1998), BG3 filter and 64-channel multianode photomultiplier (PMT) at the focal plane. For the first step we design to use only 16 PMTs at the focal plane. Therefore we have 1024 pixel in 12 cm $\times$ 12cm and filed of view are approximately

0.04 sr. Each part of them is described below.

From the size of lens, threshold of observable energy will be few TeV but considering for the detector and electrical noise, threshold, and maximum sampling rate threshold energy will be few hundred TeV.

The response of our optics from Čerenkov light has estimated by assuming for the Čerenkov photon at the ground level and consider for the acryl transmittance (for tow lenses), BG3 transmittance and PMT quantum efficiency. Figure 2 shows the response of our optics depend on the Čerenkov photon. Figure also shows the efficiency of each part. As figure shows the peak efficiency comes around 380nm and the lens design has optimize to this region.

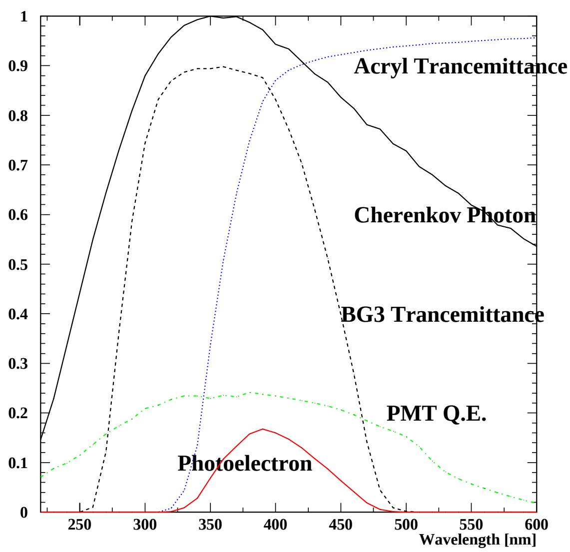

Fig. 2. The response of our Fresnel optics. The line of Photoelectron shows the response from the Čerenkov photon considering of acryl transmittance (for tow lenses), BG3 transmittance and PMT quantum efficiency.

2.1 Fresnel Lens

The diameter of Fresnel lens is 40cm with 23mm thickness and the material is PMMA. Note that we do not use the UV

Table 1. Fresnel lens general feature

	Lens1		Lens2	
	S1	S2	S4	S5
Material	PMMA		PMMA	
Shape	SR900.24		SR900.24	
Lens diameter (mm)	400		400	
Fresnel pitch [mm]	1.0		1.0	
Groove angle [deg]	0 - 22.9	0 - 1.12	0 - 26.8	0 - 2.95
Groove height [mm]	0 - 0.19	-0.25 - 0	0 - 0.73	-0.18 - 0

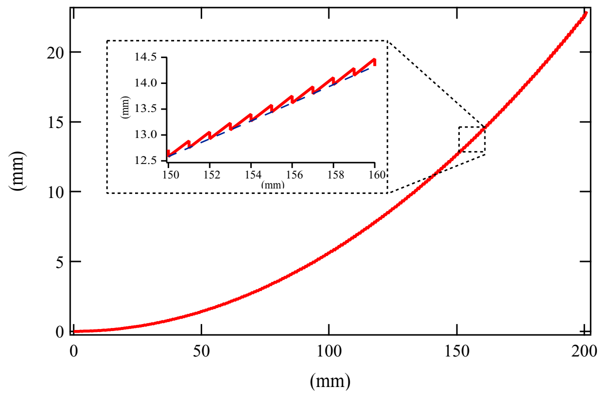

Fig. 3. The Fresnel lens design. As this figure shows 40cm diameter Fresnel lens has cut on spherical substrates. This figure shows the S1 surface.

transparent Acryl. Table 1 shows the general feature of the lens. Each surface of two lenses is called S1, S2, S3 and S4 respectably. S1 surface design are shown at the figure 3 for example. Note that lens S2 surface will came above of this curve so the graph will be upside-down when we mount on the our optics.

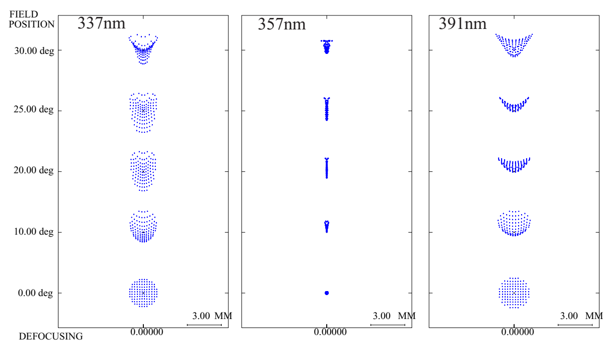

Fig. 4. The spot size of each photon incident angle. (0,10,20,25,30 degree). Three wavelengths (337nm, 357nm, 391nm) has shown in this figure.

Table 2. RMS spotsize

Wave length (nm)	RMS spot size (mm))				
	0°	10°	20°	25°	30°
337	1.82	1.86	2.08	2.13	1.58
357	0.17	0.49	0.89	0.99	0.69
391	1.94	1.88	1.59	1.46	1.81

To optimize the lens design for our purpose, we carry out the ray tracing with changing the wavelength and the incident angle of photons. Figure 4 shows the spot size at the focal plane for the incident angle of 0, 10, 20, 25 and 30 degree with three wavelength 337 nm, 357 nm and 391 nm respectably. Table 2 shows those RMS spot size. These results shows that our optics will fit to our 2mm $\times$ 2mm pixel focal plane detector.

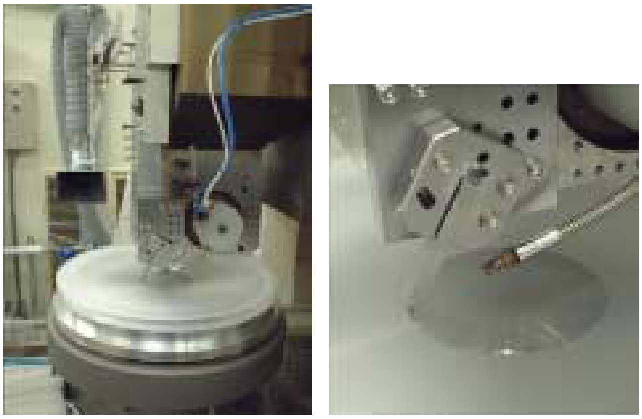

Fig. 5. The photograph of fablicating the Fresnel lens by ultraprecision cutting/grinding machine.

The lens has fabricated by ultra precision cutting/grinding machine at RIKEN. The figure 5 shows the photograph of developing the lens by this machine. This machine has 10nm feed resolution for each linear axis.

2.2 Detectors

For the focal plane detector we use multianode PMT Hamamatsu R5900-M64 (Y.Yoshizawa et al.) with UV glass entrance window and standard assembly unit (H7546UV). The anode size is 2mm $\times$ 2mm and 64 anodes are distributed in 8 $\times$ 8 format with the spacing of 0.3mm. Specification of H7546 are shown at the Table 3 (Hamamatsu (1999)).

Table 3. General features and characteristis of H7564

Spectral Response	: 300 - 650 nm
Photocathode material	: Bialkali
Window material	: Borosilicate
Dynode stages number	: 12
Anode size	: 2 $\times$ 2 mm
Gain	: 3 $\times$ 10^5 @-800V
Quantum efficiency at 390nm	: 20%
Uniformity among all anodes	: 1:3
Cross-talk (with 1mm optical fiber)	: 2%

For the first step we characterize our PMTs for the gain uniformity and crosstalk in each channel (H.M.Shimizu (2001)). For the characterization, we used UV light emission diode (UV-LED) for light source, which emits photons in the wavelength region of 350-400 nm with peak at 370 nm. The UV photons going through a 100μ m diameter pinhole collimator and illuminate the PMT entrance window in 0.22 mm spot size. The UV-LED with pinhole are mounted on x-y stage and scan through 20 mm $\times$ 20 mm area in 0.5 mm step. For this measurement we supplied -800V to PMT. The measured distribution of the output level is shown in figure 6. The pixel-to-pixel non-uniformity and inside-pixel non-uniformity of the output voltage are visualized in this figure.

The crosstalk was about 3 % in average and almost independent to the incident angle of the beam but it shows that the pixels which located at the edge of PMT has higher crosstalk than the pixels which located at the middle. The average are 4% for the edge and 2% for the inside pixel.

Note that we only carry out this test for a one PMT and to obtain more general characteristics we have to carry out this work further.

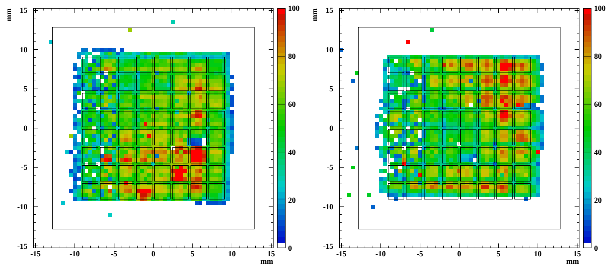

Fig. 6. Distributions of PMT output level for two different units (GA0055 and 8M10A2) of H7546UV. The anode pixels and the PMT window are superimposed in the figure.

2.3 Readout system

For the readout system we require the large dynamic range. For example if we assume the 1000 photoelectrons and the PMT gain as 3.0 $\times$ 10 ^{5}, we need more than 48pC with 10 bit.

In the first step we design to use 16 PMTs for our focal plane detector so we need 1024 channel readout system. Therefore we must make them in small system and also low cast. We cannot find the suitable readout system for our purpose in the reasonable cost so we developed the original readout system by operation amplifier.

The block diagram of readout system has shown in figure 7. PMT output has directory connected to a preamplifiers, which consist by charge amplifier and shaper. The rise time of a preamplifier is $\sim 1\mu$ second.

A preamplifier output will connect to the trigger circuit and the peak holder parallel. The trigger circuit has a discriminator for each channel with common threshold level. The trigger signal will provide from the majority logic, which will decide from the number of the discriminator output channel. This logic has advantage to the Čerenkov observation, which usually hit several pixels at once. Without this logic our readout system dose not works so fast and we may lose most of the real event.

Once it occur the trigger, all channels will hold at the peak of a preamplifier output and, through the multiplexer (MUX), ADC value of each channel will store in the PC. We used the commercial 16 bits ADC mounted on the PCI board. Actually 16 bits is over spec for our use but consider for the

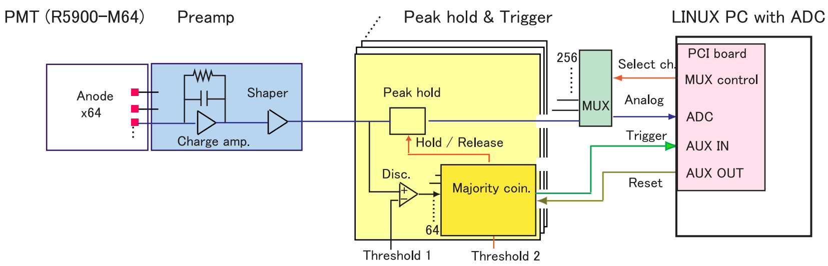

Fig. 7. Block diagram of readout system.
PMT output will directory connected to a preamplifiers which consist of charge amplifier and shaper. A preamplifier output will connected to the trigger (discriminator + majority logic) and the peak hold circuits. Once the trigger occurred each channel wills readout by ADC through the MUX.

noise of preamplifier, peak hold, MUX and ADC, resolution will be about 10 bit. Total acquisition time for readout 1024 channels will be $\sim$ 20 millisecond.

3 Sumarry

We have developed the large-aperture, wide field of view Fresnel lens optics. Now we are working on for the several tests to prove such kind of optics can use it for the Čerenkov observation. Recently we have held the test of observing the Čerenkov light and backscatter light from UV laser irradiate above our optics. This observation has carry out at AKENO observatory. The result of this test will describe in this conference (Y.Kawasaki (2001)).

For the feature, we are planning to develop more large optics that can really use for the cosmic ray observation scientifically. In this case we have to study further for several items.

Developing few meter lenses)
We cannot make such large lens at once so we have to divide in several pieces. We have never developed such kind of optics and there are few subject to study.

Readout system)
We have to improve the circuit to make smaller, low power and fast acquisition system to drive more than 1000 channels. We may have to develop the ASIC to realize such kind of front-end.

Detector)
The effective area of H7546UV is 36 % and there are a large dead area so even if we make the array of the PMTs, we cannot observe the complete shower images. Therefore, we have to develop an additional reduction optical component such as tapered light guides to increase the fraction of effective area. Another way to solve these problems is find out or develop the new detector. For example the Flat Panel PMT which coming up on 2002 from Hamamatsu has more than 90 % effective area of it physical area and this may suit for our purpose.

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