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Development of 144 Multi-Anode HPD for Belle Aerogel RICH Photon Detector

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We have developed a new hybrid photon detector having 144 multi-anode pixels with Hamamatsu Photonics. This device is supposed to be implemented as a photon detector in a ring imaging Cherenkov counter for the Belle upgrade. The photon detector must be sensitive to a single photon with a position resolution of $\sim 5 \times 5$ mm^2 and has to be immune to a high magnetic field of 1.5 Tesla. In addition, active area should be as large as ~ 70 % with respect to a package size. A test sample was delivered in December 2006, and basic properties such as gain and noise have been tested. A clear response to a single photon light was observed.

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1. Introduction

In the upgrade program of the Belle spectrometer, a study of a proximity focusing ring imaging Cherenkov counter (RICH) based on a silica aerogel radiator has been going on[1]. This detector is considered to be installed as a new particle identification device in the forward end-cap region to extend a π/K separation capability up to more than 4σ at 4 GeV/c. Since a space available for this device is quite limited due to the end-cap detector layout, a proximity focusing configuration, where an expansion distance is about 200 mm, is an only choice. Several test beam experiments have been carried out at KEK to establish a principle of operation using a prototype counter[2]. By introducing a new concept, in which multiple aerogel radiators with different indices are accumulated, we have achieved 5.5σ π/K separation at 4 GeV/c with $\sim$ 10 photoelectrons detected[3, 4]. In the prototype counter, we used an array of the H8500 multi-anode PMTs from Hamamatsu as a photon detector and these PMTs are not operational under a magnetic field although real detector has to be located inside an axial magnetic field of 1.5 Tesla. R&D on the photon detector is, therefore, a critical issue to develop our detector system. The fundamental requirements on the photon detector are: (1) sensitive to a single photon, (2) immune to a magnetic field, (3) pixelated with a resolution of $\sim 5\times5$ mm^2, (4) large effective area, (5) compact due to a limited space. As a first photon detector candidate, we have been developing a hybrid photon detector (HPD) or a hybrid avalanche photon detector (HAPD) with Hamamatsu. Fig. 1 (left) indicates a schematic view of a hybrid photon detector and typical specifications are summarized in Table 1. Cherenkov photons enter from an entrance window and generate photoelectrons from a photocathode. Then, photoelectrons are accelerated along a voltage gradients, where typical voltage is 8$\sim$10 kV, and they are bombarded onto a photon detector (PD) or an avalanche photon detector (APD), in which an additional gain of 2$\sim$3 (10$\sim$15) for PD (APD) is obtained when a bias voltage is provided. The photon detector consists of 4 diode chips, each of which is pixelated into 6×6 pads for a position measurement, and each pad has 5×5 mm^2 size. The test production of this new photon device started a couple of years ago, however it was very difficult to fabricate due to some technical problem like a vacuum seal. The latest HPD sample, shown in Fig. 1 (right), was produced on December 2006 and was delivered for our test. We have evaluated some key features of this new HPD.

In this paper, experimental set-up and fundamental behavior of diode chips in the photon detector are described in the next section. The section 3 will be devoted to measurements of single or multiple photon(s) responses. The uniformity measurement will be given in the section 4, and the section 5 will summarize this paper.

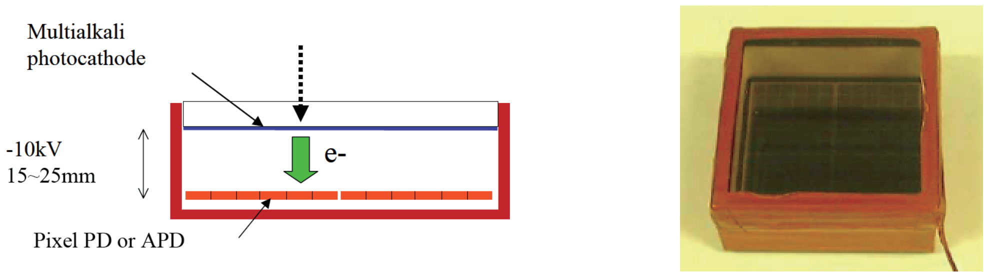

Figure 1: Schematic drawing of a hybrid photon detector(left) and a photograph of the latest sample(right).

package size	72×72 mm^2
# of pixels	12×12 (6×6/diode chip)
pixel size	5×5 mm^2
effective area	64 %

Table 1: Summary of hybrid photon detector specifications.

2. Experimental set-up and diode noise study

The experimental set-up is denoted in Fig. 2. The HPD is located inside a light shield box and a high voltage is supplied through a protection circuits. Output signal is extracted from an anode, where a reverse bias voltage is provided to a cathode as shown in the figure. Then, a charge-sensitive pre-amplifier (ClearPluse 580K) and a shaping amplifier (ClearPluse 4417) are used to integrate output charge, which is recorded by a multi-channel analyzer controlled by a personal computer. The LED light with a wave-length of 420 nm is illuminated in front of the HPD surface. In this measurement, one channel was fed to the pre-amplifier and all other channels were floated.

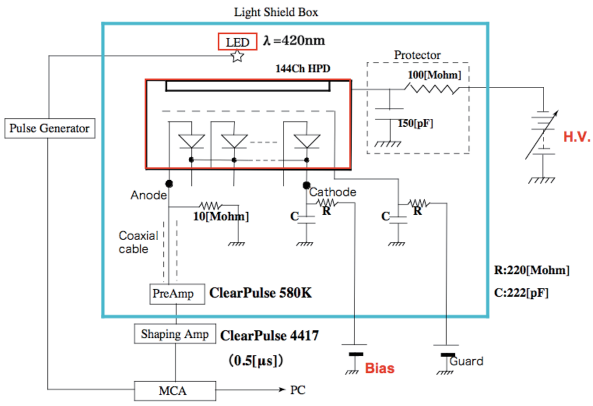

Figure 2: Experimental set-up.

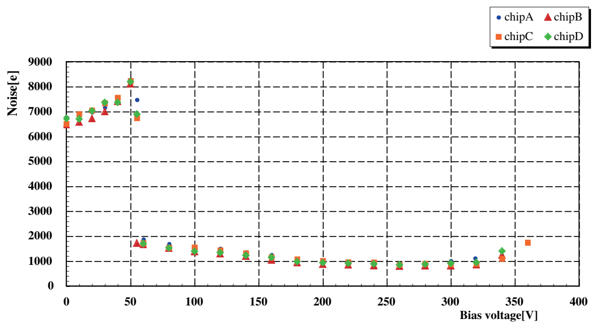

Figure 3: Noise level(electron) as a function of the bias voltage(V) for 4 diode chips equipped in the HPD. The noise level was estimated from a pedestal sigma by fitting to a gaussian function.

As a first check, we measured a noise level of the signal channel by applying a bias voltage. Here, high voltage was not turned on. The noise level was estimated as a sigma value by fitting a pedestal distribution to a gaussian function. We tested one channel for each diode chip in the HPD, and the obtained values are plotted in Fig. 3. As can be seen in figure, noise level quickly decreases at the bias voltage of 50 V, where full depletion is formed in the silicon diode. Then, minimum noise is obtained around 300 V, and it gradually increases by leakage current. We confirmed that diode behaviors for all 4 chips , when the bias voltage was turned on, were consistent with what we expected. In what follows, the bias voltage value, at which the noise level was minimum, was always set.

3. Pulse height spectra

Single photon detection capability was examined by attenuating the LED light yield equivalent to one or less photon level. Fig. 4 (left) shows the obtained pulse height spectrum for one diode chip, where high voltage of -8.5 kV and bias voltage of 319 V are applied. We can detect a clear peak corresponding to a single photon light. From this measurement, we obtained a total gain of $\sim$ 7500 with a signal-to-noise ratio of S/N= 4.9. When more light yield from the LED is illuminated, up to $\sim$ 7th photoelectron peaks can be observed as shown in Fig. 4 (right). We repeated the same procedure for all diode chips and clear single photon response were obtained for all of them.

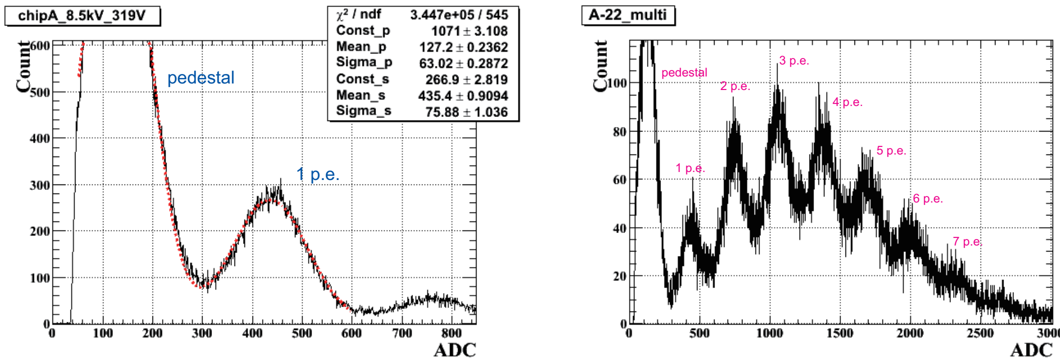

Figure 4: Pulse height distributions for a single photon(left) and multiple photons(right).

4. Uniformity

The gain, noise and S/N for all channels were examined to check uniformities among pixels in one diode chip. The single photon response from each channel was measured by flushing the LED light source, and gain and noise level were calculated. Here, high voltage and bias condition are identical to those used for the previous single photon measurement. Fig. 5 summarizes gain, S/N and noise levels for all channels in one diode except for 2 bad channels. One can see a clear single photon signal for all channels. The relative gain variation is about $\pm$ 9 % and S/N is better than 4.3 for all of them. The noise is stable with $\sim 1,300$ electrons.

5. Summary

We have developed a new HPD with Hamamatsu for the Belle aerogel RICH. Using the first sample delivered, fundamental characterizations have been evaluated using the LED light source. It

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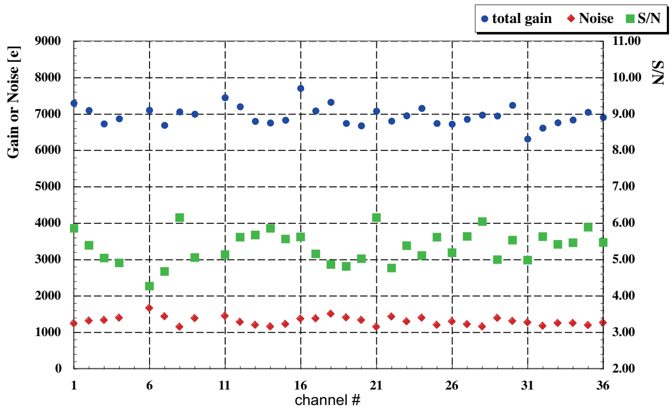

Figure 5: Summary of gain(blue), noise(red) and S/N(green) as a function of channel number in one diode chip.

was confirmed that for all diode chips single photon detection is possible and various uniformities are reasonably stable so that output signals are considered to be managed.

The second version of this device, which is supposed to have higher gain of $\sim$ 10000, will be delivered in this year, and we will plan to examine it as soon as it is available.

Acknowledgments

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