Novel Large Aperture EBCCD

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Abstract

A novel large aperture electron bombardment charge coupled device (EBCCD) has been developed. The diameter of its photocathode is 10 cm and it is the first EBCCD with such a large aperture. Its gain shows good linearity as a function of applied voltage up to -12 kV, where the gain is 2400. The spatial resolution was measured using ladder pattern charts. It is better than 2 line pairs / mm, which corresponds to 3.5 times the CCD pixel size. The spatial resolution was also measured with a copper foil pattern on a fluorescent screen irradiated with X-rays (14 keV and 18 keV) and a 60 keV gamma-ray from an americium source. The result was consistent with the measurement using ladder pattern charts. The output signal as a function of input light intensity shows better linearity than that of image intensifier tubes (IIT) as expected. We could detect cosmic rays passing through a scintillating fiber block and a plastic scintillator as a demonstration for a practical use in particle physics experiments. This kind of large aperture EBCCD can, for example, be used as an image sensor for a detector with a large number of readout channels and is expected to be additionally applied to other physics experiments.

Key words: EBCCD, IIT

1. Introduction

An electron bombardment charge coupled device (EBCCD) is an imaging device [1]. Photoelectrons produced at its photocathode are accelerated by high voltage and directed to a CCD, where they are multiplied. There is little fluctuation in this multiplication and therefore, good linearity can be expected between the input light intensity and the output signals. However, until now, EBCCDs have typically had small apertures and low gains. In order to make up for these disadvantages, EBCCDs are often used with large aperture image intensifier tubes (IIT). IITs have been used in particle physics experiments before because of their large apertures and high gains. For example, 24 IITs were successfully used in the SciFi detector of the K2K experiment [2]. The IIT gain was high enough to detect single photoelectrons and one IIT could read out 11k scintillating fibers at once. In an IIT, phosphor screens and, in some case, micro channel plates (MCP) are used to increase its gain. At a phosphor screen and an MCP, an input signal is smeared and linearity between input and output is somewhat degraded.

Therefore a high gain and large aperture EBCCD is desirable. If such an EBCCD is used as a readout image sensor of a scintillating fiber detector for example, good particle identification can be expected from energy loss (dE/dX) measurements.

The EBCCD reported here has a bi-alkali photocathode of 10 cm diameter (Fig.1). Electron demagnification by electron lens allows for this large aperture. A backside thinned CCD specifically developed for electron multiplication and detection is also used [3]. The device specifications are summarized in Table 1. Unfortunately there is no gating function this time.

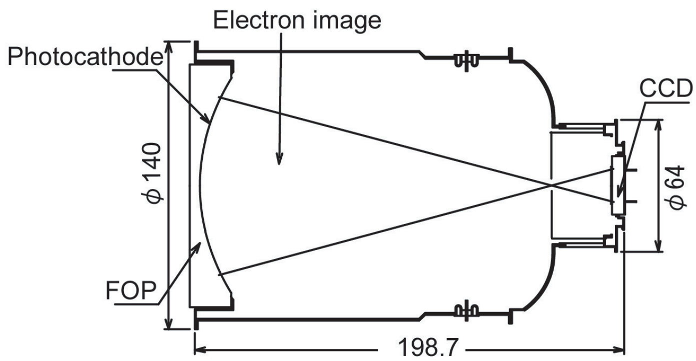

Figure 1: Structure of the EBCCD.

2. Basic performance

2.1. Gain measurement

The gain was measured as a function of applied voltage. The linearity is good up to -12 kV as shown in Fig.2. Above -12 kV, the CCD may be damaged by discharge. A maximum gain of 2400 is limited by this maximum applied voltage but it is high enough to detect single photoelectrons.

2.2. Spatial resolution

The spatial resolution was measured by two methods. First, it is measured using ladder pattern charts. An image of a ladder

Table 1: Device specifications

Parameters		Description/Value	Unit
Spectral response		300 to 650	nm
Photocathode	Material	Bi-alkali	–
	Effective area	46 × 36	mm
Window material		Fiber optic plate (FOP)	–
Magnification		1/5	–
Target	Type	FT-CCD	–
	Effective area	9.0 (H) × 6.7 (V)	mm
	Number of pixels	640 (H) × 480 (V)	–
	Pixel size	14 × 14	μm
Frame rate		30	Hz

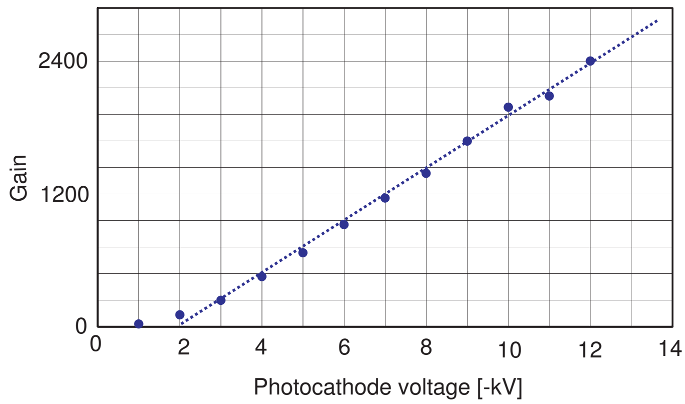

Figure 2: Gain as a function of applied voltage.

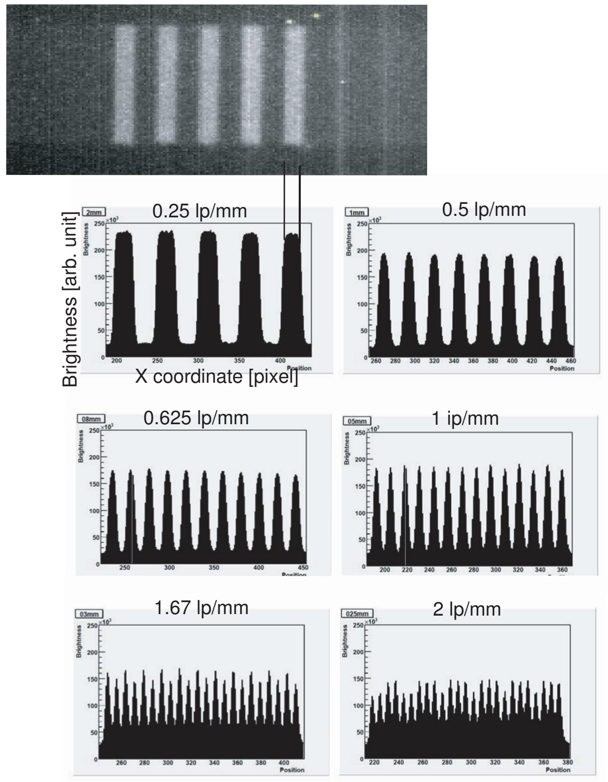

Figure 3: A typical image of a ladder pattern chart is shown in top. Brightness distributions as a function of the X coordinate for ladder patterns of 0.25 lp/mm, 0.5 lp/mm, 0.625 lp/mm, 1 lp/mm, 1.67 lp/mm, and 2 lp/mm are shown, respectively.

pattern chart is shown in top of Fig.3. We measured the brightness distribution as a function of the X coordinate of ladder pattern charts with various spacings. The distributions shown in Fig.3 are those of ladder pattern charts with 0.25 lp/mm, 0.5 lp/mm, 0.625 lp/mm, 1 lp/mm, 1.67 lp/mm and 2 lp/mm, respectively. Although the peak to valley ratio degrades with finer ladder spacings, we can see clear peaks and valleys up to 2 lp/mm . This corresponds to 3.5 times the CCD pixel size.

The spatial resolution was also measured with a copper foil pattern on a fluorescent screen [4] irradiated with X-rays (14 keV and 18 keV) and a 60 keV γ-ray from an ^{241}Am source. Fig. 4 shows a picture of the copper foil pattern (upper left) and the setup for the measurement (upper right). The thicknesses of the copper foil and the fluorescent screen are 50 μm and 500 μm, respectively. We can see gaps in the foils up to about 0.25 mm in the pattern image (lower left in Fig.4). This result corresponds to 2 lp/mm and is consistent with the measurement using ladder pattern charts.

The effective area is limited to 46 mm × 36 mm by the current CCD camera, but the spatial resolution is expected to be consistent over the full tube diameter (10 cm).

2.3. *Linearity between input and output*

Output signals were measured as a function of input light intensity. The setup is shown in Fig.5. We irradiated a 0.7 mm diameter scintillating fiber from its side with a blue LED and guided the scintillating light to the center of the photocathode. The input light intensity was monitored by a reference PMT. The output signals showed good linearity over wide range as shown in Fig.6 (filled circles). The same measurement was done for an IIT. This result is also shown in Fig.6 (open circles). The EBCCD shows better linearity than an IIT as expected.

2.4. *Cosmic ray detection*

As a demonstration for a practical use in particle physics experiments, we tried to detect cosmic ray muons passing through a scintillating fiber block. It is made of layers of 0.7 mm diameter scintillating fibers. The cross sectional view of the block is shown in the top of Fig.7, and a typical cosmic ray image by the block is shown in the bottom of Fig.7. The light yield in one fiber is several photoelectrons. Background hits are random in-time (33 msec) thermal noise.

Cosmic ray muons were also detected by plastic scintillator. The size of the scintillator is 80 mm × 20 mm × 20 mm (top of Fig. 8). A typical cosmic ray image is shown in the bottom of Fig. 8.

3. Summary

A new large aperture (10 cm diameter) photocathode based EBCCD has been developed. Its gain shows good linearity up to

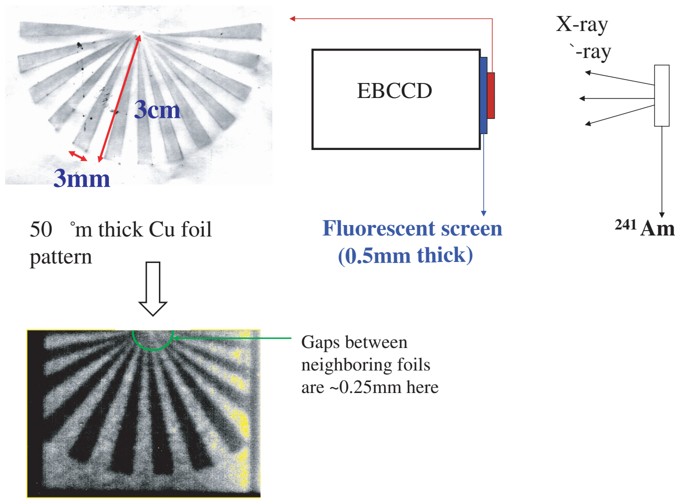

Figure 4: Spatial resolution measurement using a copper foil pattern. The pattern is set on a fluorescent screen and irradiated with X-rays and γ-ray from an ^{241}Am source. We can see gaps in the foils up to about 0.25 mm in the pattern image (lower left).

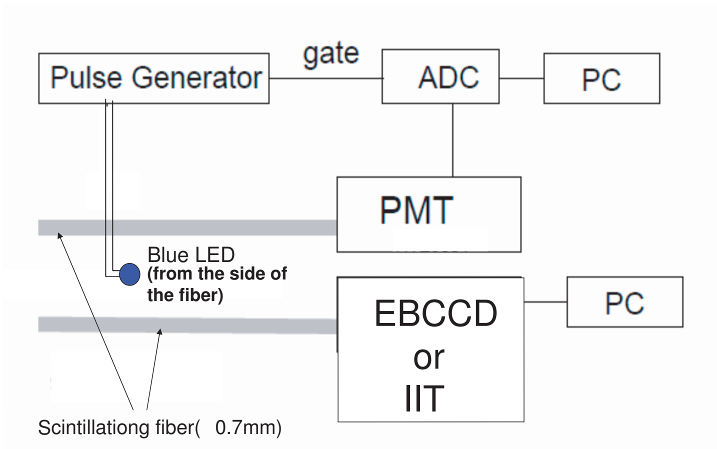

Figure 5: Linearity measurement setup.

-12 kV applied voltage with a maximum gain of 2400. The spatial resolution was better than 2 lp/mm (0.25 mm). The output signals showed better linearity than those of an IIT as a function of input light intensity and we were able to detect cosmic rays using this device.

From these measurements, we can expect to apply this kind of large aperture EBCCD to a variety of particle physics experiments in the future, for example, as an image sensor for a detector with a large number of readout channels. And in addition to imaging by X-ray and γ-ray irradiations, imaging by neutron irradiation with this EBCCD is expected if protons scattered by neutrons can be detected with a scintillator, which means nondestructive inspection by neutron beam.

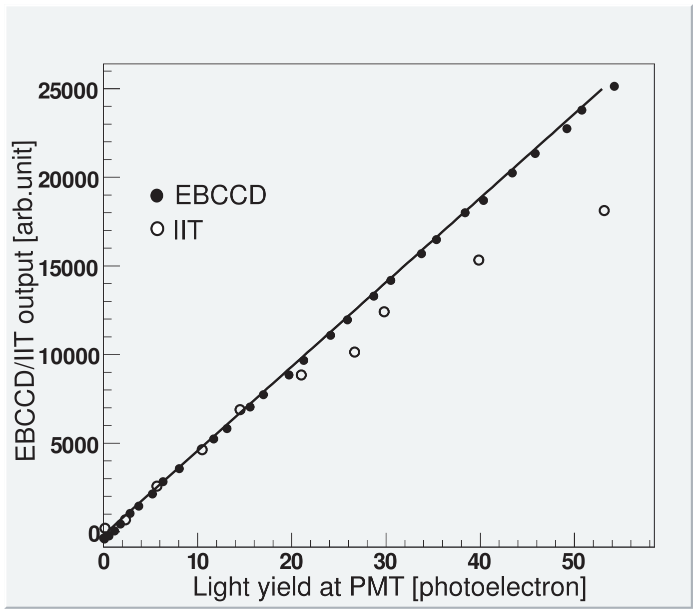

Figure 6: Output as a function of input light intensity of the EBCCD (filled circle) and an IIT (open circle).

4. Acknowledgements

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References

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[4] Toshiba Materials Co., Ltd. D-series intensifying screens, made of blue light-emitting calcium tungstate ($CaWO_4$) phosphors.

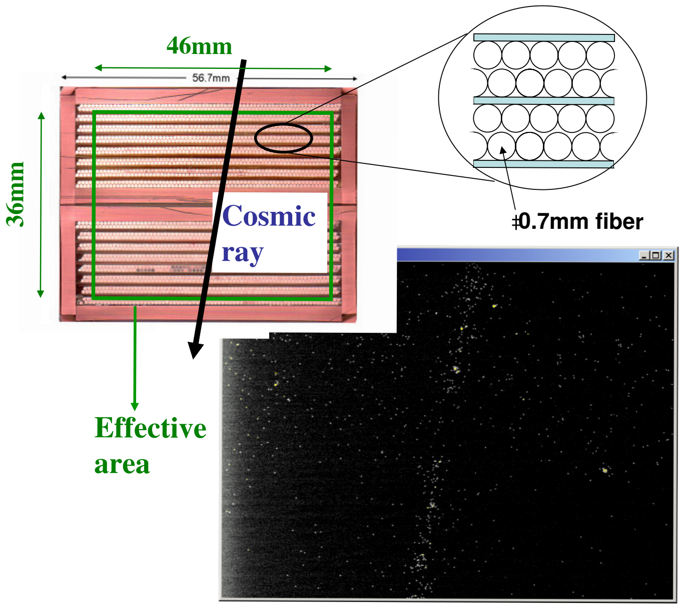

Figure 7: Cross sectional view of the scintillating fiber block (top) and typical cosmic ray image in a scintillating fiber block (bottom).

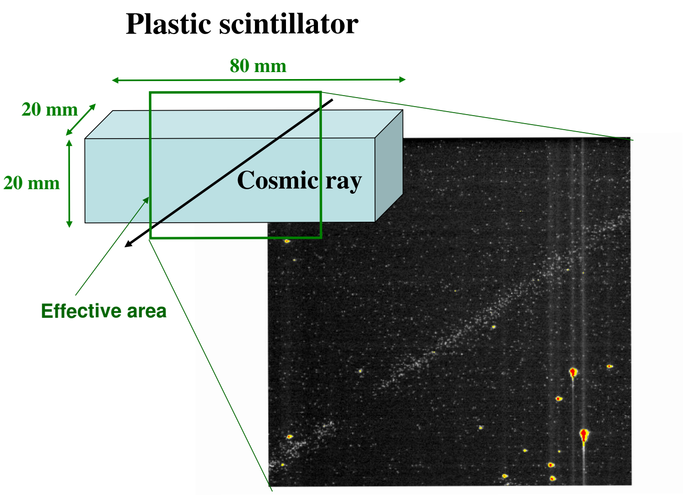

Figure 8: Typical cosmic ray image in a plastic scintillator.