R&D Status and Plan for FPCCD Vertex Detector

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Fine Pixel CCD (FPCCD) is a candidate of for the sensor of the vertex detector at ILC. We have just started R&D for FPCCDs. We report on the status and plan of the FPCCD R&D.

1 Introduction

Many types of sensor technology have been proposed for the vertex detector at ILC experiment. Fine Pixel CCD (FPCCD) is one of the candidate technologies [2]. FPCCD has a pixel size of about 5 μm square. Because of large number of pixels per unit area, the pixel occupancy due to pair-background can be less than 1% even if the signal is accumulated for one train. By accumulating the signal during a train as electric charge and reading out between trains, FPCCD can be completely free from the electro-magnetic interference (EMI) caused by the beam bunches. Small pixel size of FPCCD gives excellent spatial resolution and two-track separation capability.

Standard CCDs usually have non-depleted region in the epitaxial layer. For charged particle detection, this non-depleted region causes spread of signal charge. For large pixel CCDs, this charge spread is preferable to get good spatial resolution using charge sharing method. In the case of FPCCD, this charge spread makes large number of hit pixels and pixel occupancy becomes unacceptable level. Therefore, fully depleted epitaxial layer is essential for FPCCD in vertex detector application at ILC.

As the first step of FPCCD R&D, we developed fully depleted CCDs. In this report, we describe study results of the sample CCDs, and mention about near future plan for FPCCD R&D.

2 Development of fully-depleted CCD

Several types of back-illuminating CCDs which are variants of type S7170 with higher resistive epitaxial layer have been developed by Hamamatsu Photonics. In order to see if the epitaxial layer is fully depleted, we injected focused laser light from the backside and measured the signal spread at the potential minimum. Substrate of back-illuminating CCDs is removed by back-thinning, and the image area consists of only epitaxial layer. If there is non-depleted region in the epitaxial layer, signal charge generated very close to the back surface spreads in the non-depleted region by thermal diffusion because there is no electric field in the non-depleted region. On the other hand, if the epitaxial layer is fully depleted, the signal charge quickly moves to the potential minimum near the gate, and the charge spread is very small.

In the test experiment, green laser light (λ = 532 nm) was expanded to about 1 cm diameter beam by a laser beam expander, and then focused to a thin line using a cylindrical lens to illuminate a sample CCD. The width of the focused line was much less than the pixel width of 24 μm, associated with broader tail due to spherical aberration of the cylindrical

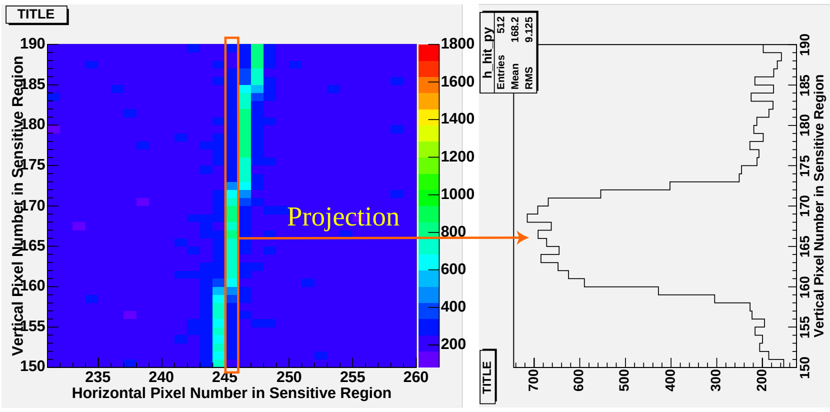

Figure 1: Image of one shot of line-focused laser illumination (left) and the projection of one column (right).

lens. By giving a small angle between the focal line and the direction of the pixel grid of the CCD, we can effectively make a scan inside a pixel. Figure 1 shows one shot of the laser illumination. From the histogram of the projection of one line, we can evaluated the charge spread.

We have measured the charge spread with gate voltages of $V_{gate} = -7$ V and $V_{gate} = +6$ V during the laser pulse illumination for each CCD sample. As shown in Figure 2, the thickness of non-depleted region changes with the gate voltage. If the distributions of the signal (right figure of Figure 1) for $V_{gate} = -7$ V and $V_{gate} = +6$ V are same, we can conclude that the CCD is fully depleted in both cases.

The results of the measurements are shown in Figure 3 and Figure 4 for typical samples. For the sample of S7170-Deep2-FF16-011, the distributions are widely spread and different in two gate voltage cases. On the other hand, for the sample of S7170-SPL24-22-20, the distributions have sharp edges and are same for both gate voltage cases. From this measurement, we can conclude that S7170-SPL24-22-20 is fully depleted even at the gate voltage of -7 V.

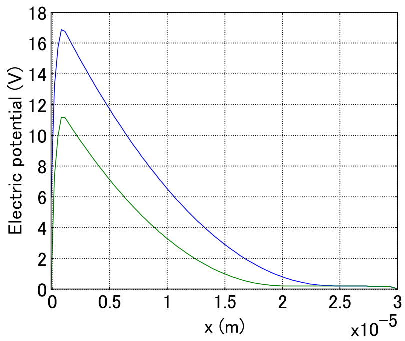

Figure 2: An example of potential as a function of depth for gate voltages of 0 V (lower peak) and 6 V (higher peak) for a CCD with 30 μm epitaxial layer thickness. The region where the potential is flat corresponds to non-depleted region.

3 Summary and future plan

Fully depleted epitaxial layer is the key issue of FPCCD vertex detector. The signal distributions of a newly developed CCD, S7170-SPL24, at two different gate voltages of -7 V and $+6$ V during the laser light illumination were same. From this result, we can conclude

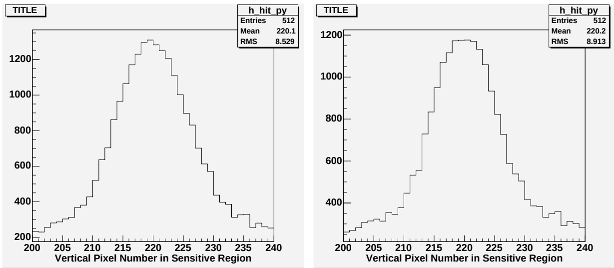

Figure 3: Charge distribution of S7170-Deep2-FF16-011 with gate voltage of −7 V (left) and +6 V (right).

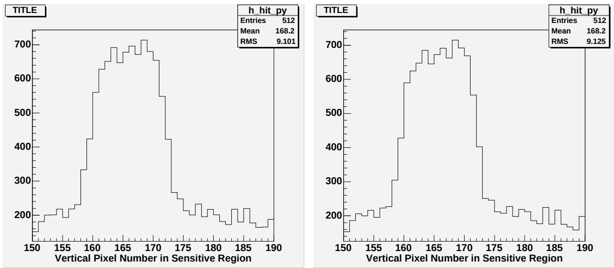

Figure 4: Charge distribution of S7170-SPL24-22-20 with gate voltage of −7 V (left) and +6 V (right).

that S7170-SPL24 is fully depleted even at the gate voltage of −7 V.

As a future plan, measurement of Lorentz angle and study of radiation hardness of the fully depleted CCD are planned in near future. Fabrication of smaller pixel, multi-port readout CCD and ASIC for readout of the multi-port CCD are also planned.

Acknowledgments

This work is partly supported by Grant-in-Aid for Scientific Research No. 17540282 and No. 18GS0202 from Japan Society for the Promotion of Science (JSPS), and No. 17043010 and No. 18034007 from Ministry of Education and Science in Japan.

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