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Timing in thick silicon detectors - an update

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Abstract

Thick silicon detectors are becoming widely used with reliable detectors available. They are often considered as a part of coincidence setup, where the timing resolution is of a crucial importance. Since over-biasing of thick detectors is sometimes impractical, the timing resolution can be compromised in thick detectors. For this article the electric and Ramo fields in a 1.4 by 1.4 mm² pad size and 1 mm thick pad detector were calculated. GEANT4 was used to determine the tracks of the interaction electron produced in photon interactions, and the drift of ionized carriers in the detector was simulated. The signals were processed using a virtual preamplifier, a CR-RC shaper with a shaping time of 200 ns and a leading edge discriminator. The distributions of delay of the trigger after the event were compared to the measurements and a good agreement was found, allowing for additional noise in experimental setup. We proposed and evaluated an alternative readout strategy reading signals from 9 nearest pads which greatly reduces the effects of inhomogeneous Ramo field on the timing resolution.

Keywords

silicon pad detectors; principles of detector operation; timing properties

1 Introduction and model application

Our group has been using thick silicon pad detectors for test-bench prototypes of PET [1] and Compton camera [2]. When timing performance was measured [3] a mismatch between the simulated data and measurements was encountered. As a contrast to constant Ramo field used previously, true field in a pad detector is considered in this study, complemented by algorithms for signal detection and processing from earlier work [4].

In present applications $d=1$ mm thick detectors are used, in 256 or 512 pad arrangement, with each pad being a 1.4 by 1.4 mm² square. The full depletion voltage ($V_{FD}=150$ V) is low given d . Since sensor's lateral dimensions are much greater than d , electric field E equals that of a diode.

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Ramo field E_w is different than in a simple diode (pad size $\ll d$). Figure 1 shows Ramo potential and Ramo field ¹. Potential stretches into the adjacent pads and Ramo field varies with depth. In Figure 1b peaks close to the pad side (readout electrode) are illustrated for field profiles along sensor depth, when the profile axis is moved away from the pad center. Both physical and Ramo field have peaks at a similar depth allowing any readout strategy which reduces this imbalance to improve the timing resolution. Hence it is tempting to add signals from 8 nearest neighbors to central pad, effectively making Ramo field constant. However, adding 9 signals introduces a 3-fold increase in the timing jitter which might compromise benefits of Ramo field uniformity.

2 Simulation results

A simulation of detection of 662 keV photons emitted from a ¹³⁷Cs source was made, with GEANT4 [5] used to determine the paths of interaction electrons. The drift of ionization was tracked and virtual electronics applied, composed of a charge sensitive preamplifier, a CR-RC shaper ($\tau = 200$ ns) and a leading edge discriminator (threshold 15 keV). Events were histogrammed with respect to the trigger delay and deposited energy. Also, one dimensional projections on the delay axis were formed with data split into three equiprobable energy bins ². In experiment, a Compton camera layout was used, with a trigger pulse (10 ns FWHM resolution) from scintillator-PMT assembly (detecting scattered photons) used to determine the interaction time.

Figure 2 shows a comparison of the simulated and the collected data in the middle third of events. If we stretch Gaussian noise from 10 ns to approximately 25 ns the simulation matches the data. The assumption is still to be verified, but the matching is consistent for bias voltages from 200 to 400 V.

Figures 3 and 4 show results of the simulation. In Figure 4 we can determine the effects of summed readout on timing performance. Looking at the top third we assume a negligible time-walk and all blurring depth-related. At 200 V the summed output provides a 4 ns FWHM resolution, and even by adding a 6 ns jitter noise ³ we improve on a single pad performance at 400 V (8 ns FWHM).

3 Conclusion

This article reports simulation of the timing properties of silicon pad detectors in a sample application. We show that the depth related blurring can have a significant effect on the overall performance, and that by adding 9 nearest pads the effect can be reduced. Assuming a viable time-walk compensation, a timing resolution below 10 ns FWHM is achievable in the pad detector geometry even at a moderate sensor bias. This is in the range of the present detectors used in nuclear medicine, and thick pad detectors can be a viable alternative, especially where good energy and spatial resolution is sought.

References

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¹Calculated by TCADTM; SILVACO International, <http://www.silvaco.com>.

²Ranges: [−106 keV], [107 keV – 249 keV] and [250 keV –].

³The measured jitter was below 2 ns FWHM [3].

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Fig. 1.

(a) Ramo potential on plane through pad center, perpendicular to sensor back-plane and parallel to one of pad edges. (b) Ramo field profiles along sensor depth. Locations of profiles marked on image.

Fig. 2.

Distribution of events with respect to trigger delay, for 662 keV photons emitted by ^{137}Cs source. Measurement and simulation with added Gaussian noise, as pointed out in figure. Events with energy from 106 keV to 250 keV. shown, to reduce effects of time walk. Sensor bias 200 V.

Fig. 3. Scatter plots of events versus trigger delay and deposited energy. Top row: single pad readout; bottom row: sum of 9 pads. Bias voltage from 200 V to 400 V.

Fig. 4.

Distribution of events with respect to trigger delay. Events divided into thirds according to deposited energy. For comparison, thirds at U=200 V and single pad readout are shaded on all graphs. Top row: U=200V, 9 pads; middle row: U=400 V single pad; bottom row: U=400 V, 9 pads. For top third timing resolution is quoted.