A new high resolution X-ray imaging detector with fast read-out

A. Castoldi[a],*, E. Gatti[b], C. Guazzoni[b], A. Longoni[b], P. Rehak[c], L. Strüder[d]

[a] Università degli Studi di Milano, Dip. di Fisica, via Celoria 16, 20133 Milano, Italy
[b] Politecnico di Milano, Dip. Elettronica e Informazione, P.za L. da Vinci 32, 20133 Milano, Italy
[c] Brookhaven National Laboratory, Upton, NY 11973, USA
[d] MPI Halbleiterlabor, Paul-Gerhardt-Allee 42, D-81245 München, Germany

Abstract

A new silicon detector design suitable for X-ray imaging is presented. The new detector features energy and position resolution comparable with a fully depleted pn-charge coupled device and read-out times of few tens of microseconds.

1. Introduction

A novel X-ray imaging detector, called Controlled-Drift Detector (CDD) has been recently proposed [1]. During the charge integration phase the signal electrons are rapidly collected from the entire wafer thickness (typically 300 μm) and are stored in a matrix of integration wells. During the read-out phase the stored electron packets are transported to the read-out electrodes by an electrostatic field. The key feature of the new detector is the high read-out speed, proportional to the applied drift field.

In this work we focus on some relevant operational aspects (e.g. maximum read-out frequency, allowed photon flux, full charge capacity) of the new detector. A comparison study between the expected performances of the CDD and the ones of a mature imaging X-ray detector like the fully depleted pn-charge-coupled device [2] is reported.

2. Working principle of the Controlled-Drift Detector

The basic structure of the so-called CDD "front-driven" is sketched in Fig. 1. A detailed description of this and other CDD structures is given in Ref. [1]. The n^+ collecting anodes and the p^+ field strips are biased in order to completely deplete the detector wafer. An array of deep p-implants (channel-stops) separate each column of pixels facing one n^+ anode from the adjacent columns.

During the read-out phase, the bias voltages of the p^+ field strips of the front side increase linearly with the distance from the read-out electrode, thus producing a nearly constant drift field. During the
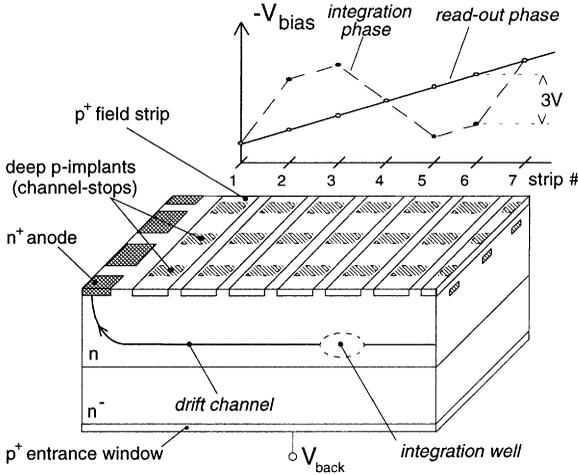
Fig. 1. Perspective view and biasing scheme of the CDD.

Fig. 2. Maximum operating frequency vs. processing time.

integration phase barriers along the drift direction are generated by changing the voltages of p^+ field strips in order to approximate a sinusoidal-like ripple (see Fig. 1). The period of the ripple sets the pixel side along the drift direction and, together with the voltage change applied to the strips, determines the height of the potential barriers at the depth of the integration wells. As shown in Fig. 1, one cycle of the ripple is reproduced with six strips. A 3 V change of the strip bias voltages assures drift barriers of 1.2 V at about 12 μm depth.

3. Expected performances of the CDD

For simplicity we will restrict our attention to a Controlled-Drift Detector of length $L = 1$ cm biased at the typical drift field $E = 300$ V/cm. The drift time, that is the time required to transfer the charge packets stored in the pixels to the corresponding anode, is given by $T_d = L/(\mu E)$ which is 2.5 μs in our case. In the CDD the read-out time T_r of a 1 cm long column of pixels is the sum of the drift time T_d and of the processing time T_{proc} of a single pulse, generally imposed by the required energy resolution. With a processing time of 10 μs, typical for high resolution X-ray spectroscopy, a read-out time of about 12.5 μs is therefore expected.

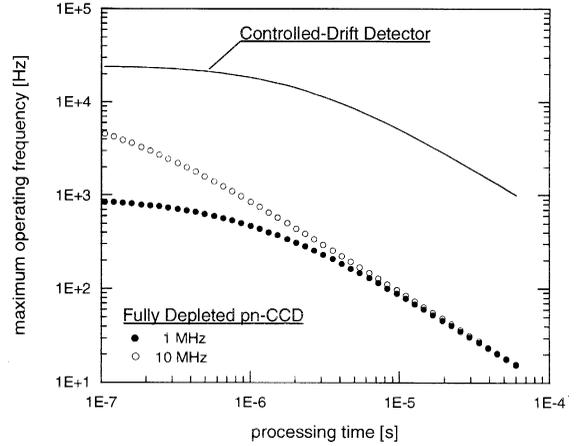The read-out time limits the maximum operating frequency of the device defined as $f_0 = 1/$ $(T_{int} + T_r)$, where T_{int} is the integration time. Assuming $T_{int} \geq (15 T_r)$ to assure that the probability of integrating one or more events during read-out is lower than 1%, an operating frequency of about 5 kHz is obtained for $T_{proc} = 10$ μs.

The photon flux incident on the detector is limited by the occurrence of pulse pile-up. When the processing time is much greater than the drift time only one event per column is allowed. The maximum allowed photon flux for single-pulse read-out is therefore of the order of $\Phi_{max} \sim 1/(LW\,15T_r)$ where W is the width of the read-out channel. On the other hand, when the time needed to process a single pulse is smaller than the drift time more events per column can be processed during the same read-out phase, not affecting the maximum operating frequency. The average number of events per column is now given by $k = (1 + T_d/\Delta t)$, where Δt is the requested time separation between the signal pulses, and the maximum photon flux becomes $\Phi_{max} \sim k/(LW\,15T_r)$. The previous expressions still hold also in the case of partially overlapping pulses ($\Delta t < T_{proc}$). However in this case a more sophisticated multiple-pulse processor is needed and the resolution in amplitude and time worsen by a factor of 2 when Δt equals two standard deviations ($\Delta t = 2\sigma_{proc} \cong T_{proc}/3$) [3].

Figs. 2 and 3 show the calculated maximum values of the operating frequency and of the photon flux, respectively, assuming a pixel of 150×150 μm^2. The effect of electron broadening, due to
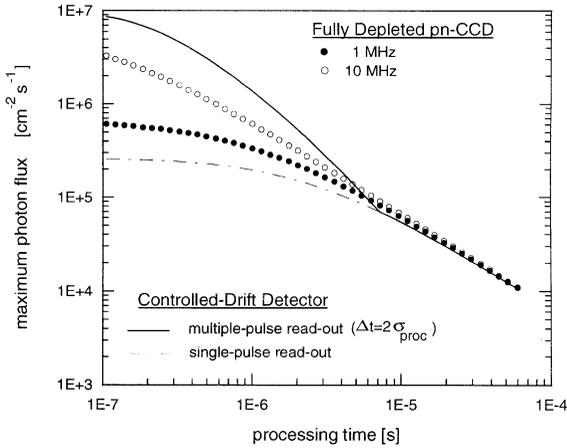
Fig. 3. Maximum photon flux vs. processing time.

thermal diffusion, during the transfer to the anode has been included. For comparison plots of the same quantities for a fully depleted pn-charge-coupled device operated in full-frame mode are also shown. In the pn-charge-coupled device all the $m = L/150$ μm pixels in the column are individually processed. The resulting read-out time is therefore $(T_{tr} + mT_{proc})$ and is always greater than the read-out time in the CDD (assuming the transfer time T_{tr} in the pn-charge coupled device equal to the drift time T_d in the CDD). On the contrary at short processing times this read-out mechanism leads to higher photon fluxes with respect to the CDD with single-pulse read-out.

The full charge capacity of the CDD is limited by the lateral barriers generated by the channel-stops like in a pn-charge-coupled device. The resulting full charge capacity is therefore similar for both devices and it has been estimated in the range 10^5–10^6 electrons per pixel for $W = 150$ μm.

The noise performance obtainable with the CDD is expected to be also comparable with the one obtainable with the pn-charge-coupled device. Both devices feature a low output capacitance, independent of the active area of the detector, and require the same fabrication process and material.

References

[1] A. Castoldi, C. Guazzoni, A. Longoni, E. Gatti, P. Rehak, L. Strüder, IEEE Trans. Nucl. Sci. NS–44 (1997) 1724.
[2] H. Soltau et al., Nucl. Instr. and Meth. A 377 (1996) 340–345.
[3] E. Gatti et al., Nucl. Instr. and Meth. A 274 (1989) 469–476.