

CCDs fabricated in pn-technology, originally designed as X-ray detectors, can find their niche in optical applications as well. They offer a wide range of pixel sizes ($36\mu\text{m} - 150\mu\text{m}$), high quantum efficiency (close to 100% from $300\text{nm} - 1000\text{nm}$), a uniform fill factor and massive parallel fast readout. The present limitation for light detection is dominated by readout noise while the contribution of the detector leakage current is negligible. Optimizing the readout may even allow single photon detection.

Different to many other CCD concepts, the pnCCD is depleted from both sides of the silicon substrate. By increasing the voltage at the rear contact, the potential minimum is shifted towards the registers at the front side of the device, thus forming spatially well defined potential wells for charge collection. The readout anode of each channel is connected on-chip with a first stage of amplification.

Different approaches for an on-chip amplifier were realized respectively are under study at the semiconductor laboratory:

- **JFET** amplifier, operating in a source follower mode, gives a high dynamic range of $2 \cdot 10^5$ and a low readout noise, summing up in combination with following amplification stages to less than 3 electron (rms) total noise contribution.
- A multiple non-destructive readout through a double **DEPFET** arrangement (DEPLETED Field Effect Transistor). In such a device, the signal charges are swapped several times between the two internal gates. Each time the signal is amplified and read out. After N cycles the theoretical noise reduction limit is given by \sqrt{N} . Although readout time is increased by the same factor N , high frame rates (typically 500 per second) are still possible since the multiple signal reading is done in parallel for all columns of a CCD. As compared to existing devices, this concept, apart from the superior readout speed, maintains output linearity down to signals from very few or single photons.
- An **avalanche** structure, being operated in either proportional or Geiger mode, for a direct amplification of signal electrons after their transfer to the readout anode. Not reducing electronic noise of signal amplification stages, it increases the signal to noise ratio by a factor of 100 e.g., allowing a detection of single optical photons. When operated in a proportional mode, information about the number of signal electrons per pixel will be obtained. Technology and device simulations as well as design studies are currently in progress at the semiconductor laboratory.

References:

- L. Strüder et al., *Astron. Astrophys.* 365 (2001) L18
- L. Strüder, *Nucl. Instr. And Meth.* A454 (2000) 73-113

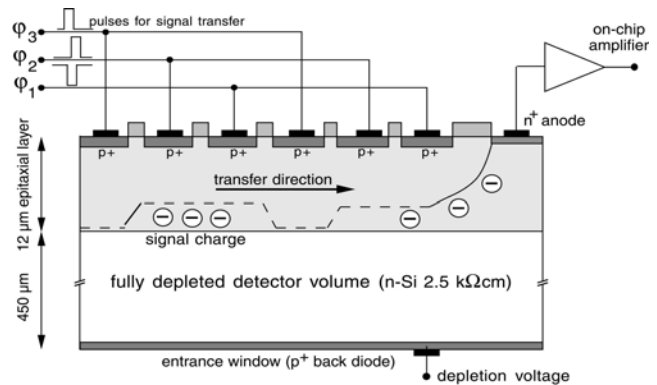


Fig. 1: Schematic cross section of a pn-CCD

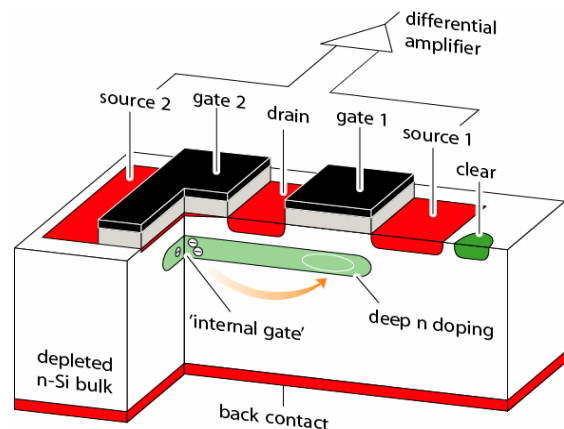


Fig. 2: Double DEPFET arrangement for multiple, non-destructive readout