Topmetal-L: A pixel sensor for charge tracking imaging of LPD

Lirong Xie[a], Chaosong Gao[b,*], Hongbang Liu[a], Dong Wang[b], Shiqiang Zhou[b], Xiangming Sun[b], Ming Yang[a], Siyao Zhao[a], Tianya Wu[c]

[a]School of Physical Science and Technology, Guangxi University, 530004, China;
[b]PLAC, Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, China
[c]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, China
* Corresponding author: chaosonggao@ccnu.edu.cn

Abstract

Topmetal-L is a large-area pixel sensor optimized for LPD (Low-energy Polarization Detector). It has a chip size of 16.9mm × 24.0mm and consists of 356 rows × 512 columns, with a pixel pitch of 45μm.The pixel circuit includes a low-power, low-noise folded cascode amplifier, a feedback structure with a 1fF capacitor and an NMOS in parallel, a two-stage source follower readout structure. The simulation results indicate that the gain of the pixel channel is 122mV/ke-, and the ENC is 20.0e-@1ke-. Total chip power consumption is 820mW. A checkpoint readout method for pixel array has been proposed, and achieving a readout frame rate of 2.7kHz.

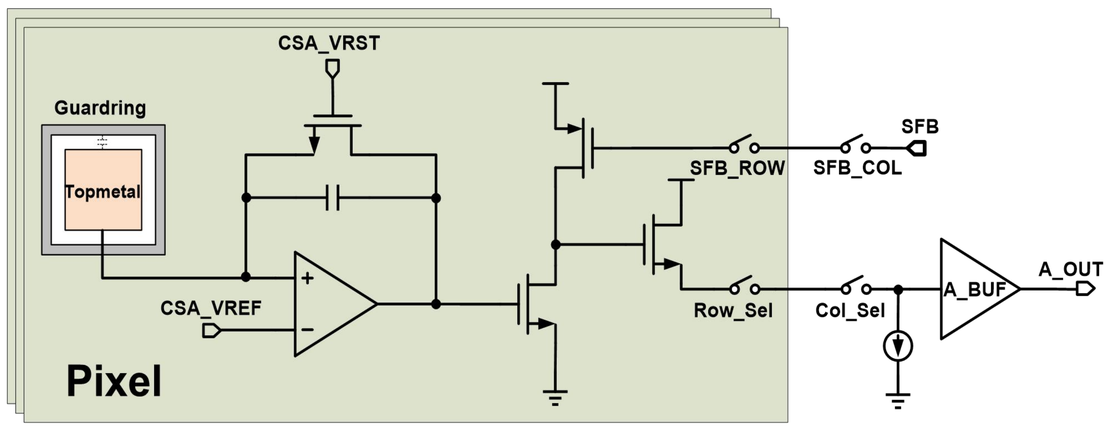
Introduction

- LPD represents one of the effective payloads for the Polar-2 mission, characterized by wide field of view and large sensitive area capabilities. The primary objective of the LPD is effectively to measure low-energy X-ray polarization in the gamma-ray bursts. The pixel sensor is responsible for collecting and processing charges amplified by GMCP(gas microchannel plate) for imaging.
- In the space, X-ray radiation from gamma-ray bursts undergoes rapid fluctuations within a short period, while energy resources are limited and there is significant heat dissipation pressure.Hence, the pixel sensors are needed to possess the features of large arrays, high spatial resolution, high energy resolution, and fast readout capabilities at the low power consumption.

Pixel Structure

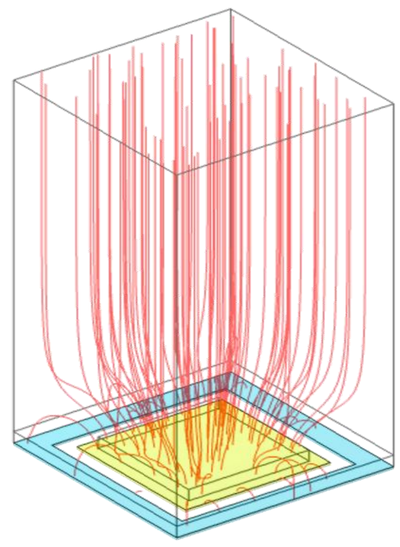
Analog channel structure:

- Particle information analog signal readout.
- The two-stage source follower is adopted to reduce crosstalk during scan readout.
- Output stages share analog buffers for enhanced drive capability.



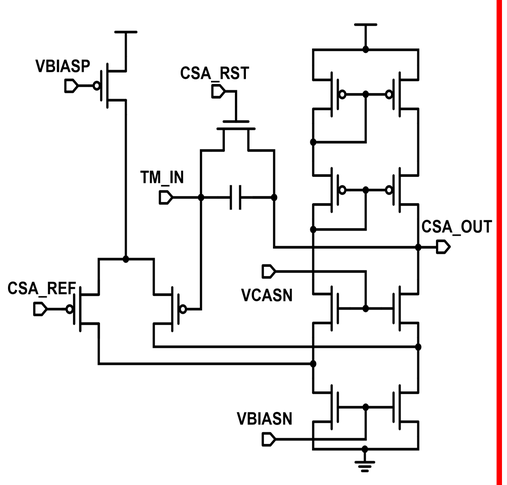
Pixel and Topmetal

- Pixel pitch: 45um
- Window: 26um×26um
- Proportion of window: 33.4%
- Topmetal surrounded by guardring. The coupling capacitance is 5.5fF, which can be used as an input test capacitor.
- Electric field simulation with negative bias applied to guardring. After the electric field stabilizes, the charge collection efficiency exceeds 70%.



CSA

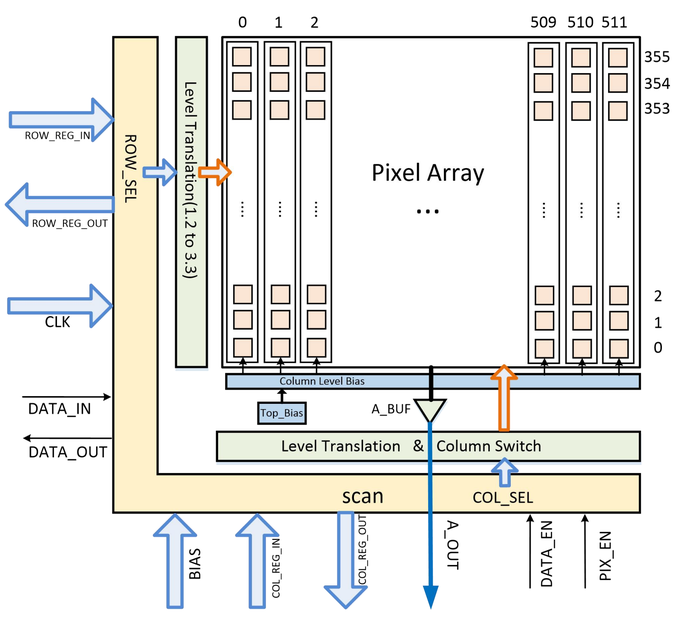
- Folded cascode amplifier structure is used to achieve larger dynamic range and higher gain.
- The feedback structure with a 1fF capacitor and an NMOS in parallel to provide amplification and adjustable decay time.
- Amplifier static current is as low as 280nA, ENC<20.0e-, gain is 160mV/ke-.



ASIC and Readout Structure

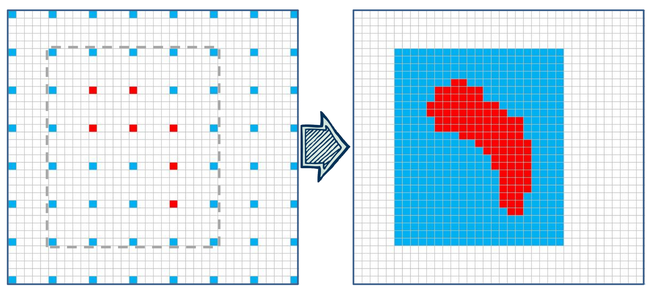
Overall framework

- The overall architecture of the chip consists of pixel array, level converter, scanning module, bias system and output stage.
- The scanning module uses 1.2V power supply to reduce power consumption.
- The scan module can define the readout area of the array according to the requirements.



Checkpoint Readout

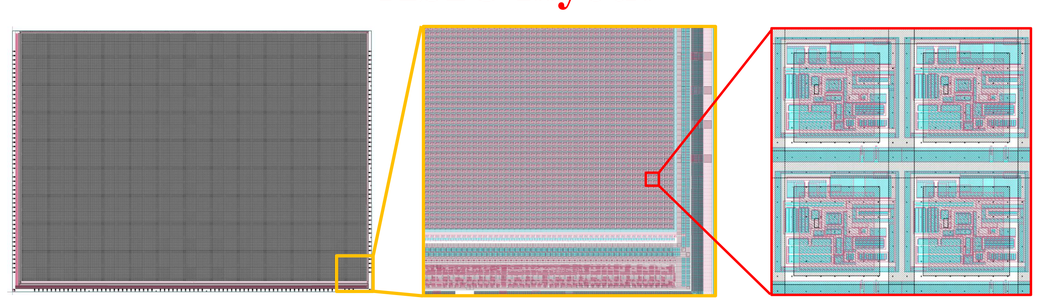
- Sentinel readout mode is a scanning method proposed for X-ray polarization detection.
- Pronciple: Interval point scan is adopted for large array, and the scanned points are checkpoints. Scan and read the area of the checkpoint crossing the threshold.



Remark:
- white pixel: do not read pixels;
- blue pixel: the pixels that need to be read, but does not receive a signal;
- red pixel: the pixels that need to be read and receive the signal.

	Topmetal-M2	Topmetal-L
Pixel Array	400 × 512	356 × 512
Pixel Size /μm²	45 × 45	45 × 45
Pixel Electrode / μm²	10 × 35	26 × 26
ENC	~ 18.0 e-	~ 20.0 e-
Power Consumption	~ 4 W @3.3 V	~ 0.82 W @3.3 V
Clock	5 MHz	20 MHz
Frame Rate	417 Hz	2.7 kHz@Checkpoint Readout
Readout Mode	Rolling Shutter	Rolling Shutter/Checkpoint Readout
Readout Channel	16	1

ASIC layout



Conclusions

- The top-metal of Topmetal-L pixels surrounded by Guardring are used for charge collection, with a window area of 26×26μm², accounting for about 33.4% of pixel. Negative bias can be added to the Guardring to effectively improve the efficiency of charge collection.
- The simulation results show that the overall static power consumption of Topmetal-L is about 820mW.
- The front end of Topmetal-L is optimized for low noise, achieving a single channel with an ENC as low as 20.0e- at 1ke- input.
- The frame frequency can reach 2.7kHz by using checkpoint readout.

Reference

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[3] Ren W, Zhou W, You B, et al. Topmetal-M: A novel pixel sensor for compact tracking applications[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2020, 981: 164557.