The Wide Field Imager for the International X-ray Observatory

Lothar Strüder¹,², Peter Lechner¹,³ on behalf of the IXO-WFI consortium

1) Max-Planck-Institut für extraterrestrische Physik, 2) PNSensor GmbH, 3) MPI Heidelberg

Introduction

Since May 2008 the International X-ray Observatory (IXO) mission is under assessment as a joint European-Japanese-American unified vision of the previously independent projects MOS and Constellation-X with an interlinked launch date around 2020. IXO aims to study the high-energy universe with unprecedented sensitivity using large-area, high-resolution X-ray optics on a deployable optical bench and interchangeable complementary sensor systems. The focal plane instrumentation includes a micro-calorimeter, a wide field imager, a grating spectrometer, a hard X-ray camera, a high time resolution imaging spectrometer, and an X-ray polarimeter. For the Wide Field Imager (WFI) the key optics with large collecting area and good angular resolution, the wide band, the required high radiation tolerance and high-speed flexible readout have stimulated the development of a new detector. The baseline WFI is a monolithic, back-illuminated silicon Active Pixel Sensor based on the integrated detector-amplifier structure DePFET which unifies the science driven specifications in one device. A first prototype of devices is in compliance with the IXO specifications.

The DePFET principle

The DePFET (Depleted P-channel Field Effect Transistor) is an integrated detector-amplifier device. It consists of a p-channel FET on a n-type bulk that is fully depleted by a reverse biased backside biased diode. The applied voltage and deep implantations generate a local potential minimum for electrons under the channel. Signal electrons are collected in the “internal gate” and mediate the transistor current by inducing positive image charges in the p-channel, and the RET current is a function of the energy absorbed in the depleted volume.

The matrix arrangement of a number of DePFETs with common bulk and back contact results in an Active Pixel Sensor (APS) with:

- In-pixel signal storage and amplification,
- 100 % fill factor, no insensitive regions,
- Back-illumination through a homogenous thin entrance window,
- Scalable pixel size from 30 µm to 1 cm2,
- Low power, as the DePFET is only turned on for readout,
- Random accessible pixel size under flexible readout modes:
  - Sequential, CCD-like full frame mode,
  - Window mode with free selectable regions of interest,
  - Mixed mode, combined window & full frame mode,
- Fast timing mode, max. readout speed on a limited area with reduced energy resolution (e.g. 10 µs/channel, 16 x 16 pixels),

Column-parallel readout:

- Row-wise connection of control contacts (gate, clear, clear-gate),
- Column-wise connection of readout nodes, i.e. drain contacts,
- Global contacts (source, drain ring, substrate, back contact),
- Cyclic readout of rows,
- One active row with DePFETs turned on,
- Active row is selected optically through the pixel matrix,
- Other DePFETs turned off, still integrating signal,
- Integration time = (number of pixel rows) x (row processing time).

Prototype devices (Fig. 4) with 64 x 64 pixels, 75 x 75 µm pixel size, and 450 µm pixel thickness have been fabricated in a dedicated process technology including two poly-silicon layers and two metal layers and characterized at IDO-representative conditions at -60 °C with a readout speed of 2 pixels per second.

Process quality

- Leakage current level 10 nA/pixel @ Et (~ 100 µA/cm² @ ET),
- Offset and gain variations < 3 %, noise dispersion < 10 %,
- No dead or bright pixels.

Spectral resolution

- AE ≤ 126 eV @ 6 keV (FWHM) @ -60 °C,
- AE = 140 eV @ 2 keV (FWHM) @ 5.5 °C, -60 °C.

IXO Wide Field Image

The specifications of the IXO Wide Field Imager are driven by top-level scientific and technical boundary conditions:

- Field of view (fov) > 18 arcmin (@ f/20 lens width 20 m)
- Sensor dimension > 10 x 10 cm²
- 6' wide-field device with ‘round’ corners (Fig. 7),
- World’s largest monolithic X-ray imaging & spectroscopy sensor,
- Fov coverage: > 95.8 % @ 14 arcmin, > 90 % @ 20 arcmin,
- Angular resolution 5 arcsec (peak spread function 500 µm HEW)
- Pixel size 100 x 100 µm², 5 x oversampling of the HEW,
- In total = 1 million pixels,
- Energy range 100 eV – 15 keV
- Ultra-thin radiation entrance window for low energy,
- Full depletion means low noise,
- Photon flux (sampling area 3 mm² @ 1.25 keV, 3 mm² @ 6 keV)
- Parallel-bis-directional readout, 2048 readout channels,
- 2 pixel readout speed per pixel row, full frame rate 1000/sec,
- Raw data rate 2 GByte/sec
- Efficient in-built data reduction algorithm required,
- Bright point source observation
- Window mode with free selectable region of interest,
- Combination with hard energy X-ray camera
- Monolithic, dual technology
- Suspension mounting without mechanical support.

Readout sequence

A measurement of the DePFET current retrieves the signal information stored in the internal gate in a consecutive read-clear-read-sequence:

1. First current measurement: baseline + signal
2. Reset, i.e. removal of signal charges by closing clear and clear-gate,
3. Second current measurement: baseline

The signal amplitude is obtained from the current difference.

VELA readout chip (Politecnico di Milano)
- DePFET-specific development
- 64-channel parallel & filter-amplifier, 64/24 amplifier multiplexer
- Current (integrating) filter with trapezoidal weighting function,
- High dynamic range by current subtraction circuit
- Fast readout: 2 pixel processing time per pixel row (and even below),
- InDePFET: readout speed vs. equivalent noise charge,
- ENC = 4 e- @ 4 psec/√Hz
- ENC = 7 e- @ 1 µsec/√Hz

SWITCHER control chip
- DePFET-specific development
- 6-channel dual-output switching circuit,
- Supply of clocked analog voltages applied to gate, clear, clear-gate,
- High-voltage CMOS, switching amplitude ≥ 20 V
- Switching frequency ≥ 20 MHz,
- Data-convertable for the operation of large format APS.

Frontend Electronics

In a second production DePFET APS prototypes with representative large sensor formats have been processed (Fig. 5):

- 75 µm 12 pixels, 256 x 256 pixels, 1.92 x 1.92 cm² sensitive area,
- 75 µm 12 pixels, 256 x 128 pixels, 0.56 x 0.64 cm² sensitive area

Their characterization is in preparation with the intention to demonstrate the homogeneity of large scale devices and the technology readiness of the DePFET approach for IXO.

Next Steps

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Summary

For the Wide Field Imager of the IXO mission we propose a wafer scale DePFET Active Pixel Sensor.

The DePFET concept unifies the science driven top level requirements of IXO in one device.

A dedicated process technology for the fabrication of DePFET APS has been successfully applied in several prototype runs.

- A DePFET-specific frontend electronics system of readout and control chips has been developed.

- A laboratory data acquisition system scalable for the operation of large sensor formats has been installed.

- The concept of the sensor and frontend electronics has been proven by 64 x 64 prototypes with performance figures in accordance with the requirements of the IXO mission.

- A new generation of sensors with significantly larger formats is available for the demonstration of the DePFET technology readiness.