Spectral performance of 19-cell SDD prototype for eXTP-SFA

Authors: chen, Dr. can, Wang, Dr. Yu-Sa, Li, Dr. Wei, Li, Dr. Zhenjie, Ma, Dr. Jia, Wu, Mr. Qiong, Luo, Mrs. Laidan, Zhang, Mr. Yifan, Zhao, Mr. Zijian, Yang, Mr. Xiongtao, Bao, Mrs. Ziyu, Liu, Miss Yaoguang, Zhu, Dr. Yuxuan, Xie, Mr. Dong, Lin, Miss Yichen, Yang, Miss Fang, Ge, Dr. Mingyu, You, Dr. Yuan, Xu, Prof. Yupeng, Chen, Prof. Yong, zhang, Prof. Shuang-Nan, Feng, Prof. Hua, Liu, Dr. Congzhan, Wang, Dr. Yu-Sa

Date: 2026-03-23T18:42:17+00:00

Abstract

A 19-cell Silicon Drift Detector (SDD) array will be employed as a focal plane detector by the Spectroscopy Focusing Array (SFA), one of the payloads of the enhanced X-ray Timing and Polarimetry (eXTP), to achieve high sensitivity and low background performance. This work presents the spectral characterization of the 19-cell SDD prototype developed by the Institute of High Energy Physics (IHEP). In particular, for monolithic detector arrays fabricated on a single wafer, charge sharing inherently occurs near cell boundaries. Accordingly, we investigate the edge-induced degradation in spectral resolution and counting efficiency, and evaluate the feasibility of event reconstruction for this first 19-cell SDD prototype.

Full Text

Preamble

Spectral performance of 19-cell SDD prototype for eXTP-SFA Can Chen, Yusa Wang, Wei Li, Zhenjie Li, Jia Ma, Qiong Wu, Laidan Luo, Yifan Zhang, Zijian Zhao, Xiongtao Yang, Ziyu Bao, Yaoguang Liu, Yuxuan Zhu, Dong Xie, Yichen Lin, Fan Yang, Mingyu Ge, Yuan You, Yupeng Xu, Yong Chen, Shuang-Nan Zhang, Hua Feng, and Congzhan Liu 1 State Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People' s Republic of China.

Spallation Neutron Source Science Center, Dongguan, Guangdong, 523803, China Multi-discipline Research Center, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People' s Republic of China.

University of Chinese Academy of Sciences, Chinese Academy of Sciences, Beijing 100049, People' s Republic of China.

A 19-cell Silicon Drift Detector (SDD) array will be employed as a focal plane detector by the Spectroscopy Focusing Array (SFA), one of the payloads of the enhanced X-ray Timing and Polarimetry (eXTP), to achieve high sensitivity and low background performance. This work presents the spectral characterization of the 19- cell SDD prototype developed by the Institute of High Energy Physics (IHEP). In particular, for monolithic detector arrays fabricated on a single wafer, charge sharing inherently occurs near cell boundaries. Accordingly, we investigate the edge-induced degradation in spectral resolution and counting efficiency, and evaluate the feasibility of event reconstruction for this first 19-cell SDD prototype.

Keywords

eXTP, SFA, Multi-cell SDD, Spectral response, Charge sharing, Event Reconstruction

INTRODUCTION

The Silicon Drift Detector (SDD) has gained remarkable traction in fields such as fluorescence analysis[ ] and space astronomy[ ] due to its excellent energy resolution, as well as outstanding counting and timing performance.

Tradi- tional single-cell SDDs have been widely adopted and com- mercialized by vendors such as AMPTEK, KETEK, and PNdetector[ ]. However, driven by scientific objectives in certain cutting-edge research fields, the requirements now ex- tend beyond superior spectral performance and throughput capability to also include high-performance imaging func- tionality. Consequently, traditional single-cell SDDs are no longer sufficient, giving rise to the development of multi-cell SDD arrays.

Over the past decade, multi-cell SDDs tailored for diverse fields have been developed[ ], such as "TRISTAN" for elec- tron detection[ ], "PixDD" for X-ray applications[ ], and "Hera" for synchrotron applications[ ], to name a few. Owing to their compact size, on the one hand, the

leakage current of a single SDD can be minimized, improv- 20

ing energy resolution—even enabling room-temperature op- eration without active cooling. On the other hand, the reduced cell size allows SDDs to be used in high-throughput scenar- ios. After the transition from single-cell to multi-cell array architecture, SDDs offer certain imaging capabilities, thereby increasing the dimensionality of the acquired information.

SDDs are also gaining traction in X-ray astronomy.

In 27

2017, NASA launched the Neutron Star Interior Composi- tion Explorer (NICER) payload, the first mission to employ This work is the supported by China’s Space Origins Exploration Program and the Strategic Priority Research Program on Space Science, Chinese Academy of Sciences (XDA15020500).

Yusa Wang, Institute of High Energy Physics, Chi- SDDs as focal plane detectors in orbit[ ]. Benefiting from the superior performance of SDDs, NICER has delivered key scientific advances, including X-ray pulsar navigation[and insights into neutron star physics[The upcoming enhanced X-ray Timing and Polarimetry (eXTP) will carry SDDs as its focal plane detectors. With a planned launch in 2030[ ], its primary science goal is explore the physics and astrophysics under extreme den- sity, gravity, and magnetic fields, as well as playing a key role in the time-domain and multi-messenger astronomy[The eXTP mission mainly comprises three main payloads, i.e., SFA-T, SFA-I, and PFA, as well a secondary payload W2C (Wide-band and Wide-field Camera). SFA stands for Spectroscopy Focusing Array, and PFA stands for Polarime- try Focusing Array, the latter dedicated to X-ray imaging po- larimetry. The letters “T” and “I” denote their primary sci- entific functions: timing and imaging, respectively. In total,

the eXTP comprises nine focusing telescopes: five for SFA-T, 47

one for SFA-I, and three for PFA, as illustrated in Fig.

T & SFA I & PFA Cameras

9 Mirror Modules

Key parameters Basic requirement Design goal Focal Length 5.25 m 5.25 m Energy range 0.5 10 keV 0.3 10 keV Energy resolution ≤ 180 eV @ 6 keV ≤ 150 eV @ 6 keV Time accuracy ≤ 2 μ s ≤ 1 μ s Time resolution ≤ 10 μ s ≤ 6 μ s Dead time ≤ 5% @ 1 Crab ≤ 3% @ 1 Crab

To achieve high sensitivity for celestial targets in the com- plex space radiation environment, the SFA-T payload em- ploys a 19-cell SDD as its focal plane detector. Its central cell collects the focused X-rays, whereas the 18 surrounding cells act as a reference for background subtraction, including contributions from charged particles, the cosmic X-ray back- ground, and secondary radiation. Table summarizes the key design specifications of SFA-T, including the performance re- quirements for the focal plane detector. To meet these require- ments, the Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, has developed a monolithically inte- grated 19-cell SDD. Meanwhile, Max Planck Institute for Ex- traterrestrial Physics (MPE) will also provide eXTP-SFA with an alternative focal plane detector design based on 19-cell SDDs[ ]. The exact numbers of the in-house developed detectors and that to be provided by MPE, for the total of five focal plane detectors to be onboard SFA-T in the future, will be determined at a later stage.

This work presents a spectral performance study of a self- developed 19-cell SDD prototype in response to soft X-rays. mance of the 19-cell SDD with its edges blocked, focusing on the dependence of spectral response and energy resolution on micro-zones at the SDD cell edges and characterizes their be- havior. Finally, based on the experimental results, Sec. evaluates whether the first prototype of the self-developed 19-cell SDD meets the engineering requirements. This assessment supports both the detector’ s design optimization to fulfill instrument specifications and its on-orbit operation to achieve scientific objectives.

EXPERIMENTAL SETUP 19-cell SDD The eXTP-SFA focusing mirror assembly requires an an- gular resolution Half Power Diameter (HPD) of no greater than 1 arcminute, with a focal length of 5.25 m. To concen- trate approximately 100 of photons into a single cell, the cell size must be at least 3.2 mm. Additionally, to reduce dead area between adjacent cells, the detector is configured as a regular hexagonal honeycomb array. Accordingly, IHEP has developed the first 19-cell SDD prototype tailored for the SFA-T telescope, building on an SDD previously designed for synchrotron radiation[ ]. This 19-cell SDD comprises 19 in- dependent, identical hexagonal cells, each with a side length of 3.2 mm, integrated on a wafer measuring approximately 33 31 mm.

The 19 identical SDD cells share the same three nega- tive bias voltages: the backside high voltage (the X-ray incident side, the high voltage of the first drift ring (RING1), and the high voltage of the last drift ring RINGN). For the first prototype 19-cell SDD, the values RINGN RING1 were optimized and set to -80 V, -40 V, and -20 V, respectively. Further details regard- ing the design, fabrication process, and characterization of the detector’ s physical performance (e.g., the leakage current distribution of the detector) will be presented in subsequent papers by our research group.

In this study, the 19-cell SDD is packaged on a Multi-Layer Ceramic Substrate (MLCS), as illustrated in Fig. . Featuring high rigidity and low thermal resistance, the ceramic substrate

provides robust mechanical support for the sensor and also 110

meets the requirement of the SDD operating at low tempera- tures (-40 Entrance Window of SDD Multi Layer Ceramic Substate

FPC to B ackend E lectronics

B. Front-end Electronics and Data acquisition 113

Each of the 19 SDD cells is coupled to a dedicated reset- type charge-sensitive preamplifier (CSA), and the resulting

outputs are transmitted to the electronic box via a flexible 116

printed circuit (FPC). The primary functions of the electronic 117

box are to buffer and secondarily amplify the output signals of the CSA. In addition, it is responsible for supplying the bias voltage required by the SDD and the reset signal required by the CSA. In the adopted reset strategy for the charge-sensitive preamplifier, whenever the signal amplitude of any of the 19 channels exceeds the voltage threshold (set to 3 V), a reset signal of approximately 1 s is simultaneously sent to all 19 CSAs to discharge the accumulated charge on the feedback capacitors. A key advantage of this design is the elimination of additional crosstalk between channels that would result from asynchronous resetting.

During the performance evaluation of the 19-cell SDD prototype, the backend electronics employed a 4 channel PXI Digital X-ray Processor, namely the xMAP developed by XIA LLC, for signal filtering, data acquisition, and storage[

From the 19 analog voltage signals output by the electronic box for the 19-cell SDD, four channels were selected and connected to the four input terminals of the xMAP processor, enabling simultaneous recording of timestamps and energy for all four channels.

Vacuum and Cooling Cooling the SDD is a common practice to reduce detector leakage current and achieve high energy resolution. In this work, a dedicated vacuum cryogenic test system was designed and developed to characterize the performance of the 19-cell SDD. The system consists mainly of a vacuum chamber, various vacuum pumps, a temperature control system, and a PLC-based control system.

The vacuum chamber has an approximate length of 0.6 m and an inner diameter of 0.4 m. It is equipped with two sets of turbomolecular pumps backed by mechanical pumps, and one cryopump as a backup. This configuration enables the chamber to achieve a pressure lower than Pa from atmospheric pressure within 3 hours. The ultra-high vacuum prevents condensation on the detector during cooling. A two-dimensional translation stage is installed inside the vacuum chamber for mounting components such as apertures. By adjusting the aperture positions, the exposure area on the detector can be controlled, enabling micro-zone performance studies. The evolution of the spectral response under pencil beam irradiation will be presented in Sec.

III B For temperature control, the system uses a low temperature thermostatic bath as a constant-temperature cold source. The cooling medium is delivered via pipes to the copper block at the bottom of the detector inside the vacuum chamber. A flexible thermal pad provides thermal conduction between the MLCS (on which the detector is mounted) and the copper heat sink. Anhydrous ethanol is adopted as the cooling medium because it is readily available and has a freezing point of - C at atmospheric pressure, which meets the operating temperature requirement of the 19-cell SDD (-40 X-ray Source To study the spectral performance of the 19-cell SDD, a dedicated experimental setup has been established. Both a multi-target fluorescent X-ray source and a conventional X-ray source are used for spectral performance testing[For the conventional X-ray source, X-rays are generated as follows: a heated cathode filament emits electrons via ray Source olecular Electronic Box emperature hermostatic

thermionic emission. These electrons are accelerated by the 176

electric field between the cathode and anode and bombard the anode, producing characteristic X-rays of the anode material along with bremsstrahlung. In this study, apertures will be employed to constrain the beam spot for micro-zone perfor- mance research.

A multi-target fluorescent X-ray source operates as fol- lows: a conventional X-ray source generates high-flux X-rays onto a high-purity target material, producing characteristic fluorescent X-rays free of bremsstrahlung. By rotating and selecting different target materials, monochromatic X-rays at distinct energies can be obtained.

The source exit window is positioned approximately 1.2 m from the 19-cell SDD, which is mounted on a flange at the far end of the vacuum chamber, as shown in Fig.

RESULTS AND DISCUSSION Given the consistency of the electric field design and per- formance across all 19-cell, this work presents only the per- formance of the central cell and its three adjacent cells. For clarity, the 19-cell are numbered, as shown in Fig. . More-

over, due to the significant performance variation between the 196

cell center and its edge, the spectral response is tested and dis- cussed separately in Sec.

III A (cell center) and Sec. III B (cell edge). Cell center Prior to investigating the influence of cell edges on the spectral performance, an edge block made of tungsten, with a thickness of 0.1 mm and a distance of about 2 mm from the SDD surface, was designed to shield the edges of the cells, as shown in Fig. , with the shielding area covering a 1 mm- wide region retracted inwards from the cell edge, and the final

mechanical design of edge block will be further refined. 207

Energy resolution is one of the most prominent advantages of SDDs over other types of detectors. However, the energy

(a) Black line represent the edge of cell, the gray region represent edge block made of tungsten, the yellow region represent no block region of SDD. (b) Edge block install in front of 19-cell SDD.

itself but also by the design of the conditioning circuit. Gen- 211 erally, the energy resolution is represent with Full width at half maximum (FWMH), which can be expressed as[ENC/e where is Fano factor of silicon, is the deposited pho-

ton energy, w is the average ionization energy, ENC is the 216

equivalent noise charge, and is the elementary charge. In a detector system, a key parameter to optimize is the shaping

time of the conditioning circuit, as it directly affects the ENC. 219

The ENC can be expressed as[where is the capacitance of the detector, is the gate- to-source capacitance of the FET, is the shaping time, is the thermal noise power density of the FET, is the shot noise power density induced by the detector, the FET, and the biasing resistor, is related to the power density of the flicker noise of the FET, and are constants that depend only on the shape of the filter output pulse.

Thus, SDD noise sources fall into two categories: series noise and parallel noise[ ]. Parallel noise is dominated by SDD leakage current, while series noise arises mainly from white and flicker noise in the circuit. shows

that as shaping time increases, total noise initially decreases 233

with reduced white noise contribution. At longer shaping times, however, noise contribute from leakage current be- comes dominant, causing total noise to rise.

An experiment was performed to determine the optimal

shaping time that minimizes noise and achieves the best en- 238

ergy resolution. However, an excessively long shaping time increases the system dead time, while an overly short shaping time may lead to ballistic deficit [ ]. Therefore, a trade-off is required when selecting this parameter.

The detector was irradiated with fluorescent X-rays of dif- ferent energies generated by a multi-target fluorescent X-ray source, including Al (: 1.49 keV), Ti (: 4.51 keV, 4.93 keV), Cr (: 5.40 keV, : 5.95 keV), Fe (: 6.40 : 7.06 keV), and Cu (: 8.04 keV, : 8.90 keV), as shown in Fig. . The FWHM variation for cells 1 to 4 of the 19-cell SDD, measured at shaping times of 0.2, 0.4, 0.6, 1, 2, and 4 s, is shown in Fig. . The measured dependence of energy resolution on shaping time agrees with the descrip- tion in Eq. . The optimal energy resolution is achieved at a shaping time of approximately 0.6 s, reaching 151 eV at 6.4 keV at a detector temperature of -40 C. A single cell among the 19 channels was chosen, demonstrating how the energy resolution varies with different characteristic X-ray energies, as shown in Fig. , which satisfied the energy resolution re- quirement in Table

Cell edge Compared other silicon-based detectors (e.g., Avalanche Photodiode), the SDD forms its sensitive detec- tion region using a lateral depletion approach. This design leads to a weak transverse electric field at the detector edges.

When X-rays interact with the detector at its edges, the generated electron-hole pairs drift slowly[ ]. This not only increases the probability of carrier recombination but also makes electrons more susceptible to capture by defect-related traps.

Conventional commercial single-cell SDDs employ a collimator at the front end to prevent X-ray photons from interacting with the detector edge regions, which would otherwise degrade performance metrics such as energy resolution. For instance, the "FAST SDD" from AMPTEK uses collimation to define an effective detection area of 17 within its 25 sensor area[The spectral response of the cell edges was investigated in two stages. First, we compared the spectrum with and without edge block under flat field X-ray illumination. Second, we used a X-ray pencil beam to study the spectral response of micro-zones at the cell edges.

1. With Flat-Field Illumination

Two types of collimators were designed according to the

mechanical dimensions of the 19-cell SDD, as shown in 282

in Fig. . The other type exposes only the central region of cells 1 to 4, as shown in Fig. , while shielding the cell edges by retracting 1 mm inward from each edge.

The 19-cell SDD was exposed to fluorescent X-rays gen- erated by a multi-target fluorescent X-ray source. With the energy threshold set to 0.3 keV in xMAP to ensure that low- energy X-ray photons could be recorded. The energy spectrum collected in cell 1 under Cr fluorescence irradiation is shown in Fig. . The Cr-K (5.41 keV) and Cr-K (5.95 keV) lines are clearly distinguishable in both spectrum, while a sig-

nificant tail appears on the low energy side of the peak when 294

the SDD was exposed without edge block. The energy resolu- tion was approximately 167 eV and 195 eV with and without edge block, respectively. Additionally, a noticeable increase in counts was observed in the low-energy region of the spec- trum, which could be attributed to incomplete charge collec- tion or charge sharing induced by X-rays at the cell edges.

When charge carriers generated by a single event induce signals in two adjacent cells, they typically exhibit temporal correlation. To further confirm the origin of the low energy tail in the characteristic line, a coincidence method was em- ployed to identify charge sharing events based on the event ar- rival time recorded by the xMAP. A 200 ns coincidence time window was set. Events occurring in adjacent cells within this time window were attributed to the same photon, and their energies were summed to correct the energy of the primary event. To ensure the validity of the time window selection and to prevent excessive independent events from being misiden- tified as split events, the probability of events occurring within a time interval is given by the Poisson distribution as follows:

$$P (k) = (\lambda t) k e - \lambda t$$

where is the average count rate (6 kcps in this experiment), is the time window (200 ns in this experiment), and is the number of event occurrences. Then, the probability that two or more photons arrive within the 200 ns time window of a single cell is expressed as follows:

$$P (k \geq 2) = 1 - P (k = 0) - P (k = 1) . (4)$$

The probability of two or more photons simultaneously ar- riving at two cells is the product of the probabilities for each individual cell. Therefore, the probability of misidentifying two independent events as charge sharing events is approximately . From the energy spectra obtained with and without edge block in Fig. , the proportion of events

(a) Without edge block. (b) With edge block. with charge loss or charge sharing events should be higher than that of misidentified events.

Coincident events from adjacent cells were selected to plot a two-dimensional histogram of their energies, and the energy reconstruction of these events was analyzed. A negatively correlated band-like distribution appears in the lower-left cor- ner of the two-dimensional histogram, as shown in Fig. indicating that the charge carriers generated by the primary (5.41 keV) and Cr- (5.95 keV). photon are linearly partitioned between the two adjacent cells.

A linear fit to the band-like data is shown as a red dashed line

in Fig. 10 [FIGURE:10] . If no losses occurred during charge partitioning

and collection between two neighbor cell, the intercept of the linear function would equal the energy of the characteristic line (5.41 keV). However, the linear fit is expressed as:

$$E \text{ cell } 3 = - 0 . 97 \times E \text{ cell } 1 + 4315 \text{ eV} , (5)$$

where cell 1 cell 3 are the energies recorded by cells 1 and 3, respectively. The total energy recorded by the two cells is about 4.315 keV, while the incident Cr characteristic X-ray energy is 5.41 keV, indicating charge loss occurs when an X-ray photon strikes the edge of an SDD cell. The black dashed lines in Fig. mark several events, each arising from independent events in cell 1 and cell 3, respectively.

The energies of events in adjacent cells within the co- incidence time window were summed to obtain the recon-

structed energy spectrum, as shown in Fig. After en- ergy reconstruction, the characteristic line of Cr was recon-

structed. However, the peak positions show a significant shift to the left, with a decrease of about 1.1 keV, indicating significant energy loss, which is consistent with the result shown in A peak with an energy twice that of the characteristic en- ergy is shown by the green curve in Fig.

This peak originates from two independent characteristic fluorescence photons arriving at the detector within 200 ns, which are then misidentified as a charge-sharing event. Moreover, the misidentified counts are consistent with the previously calcu- lated misidentification probability, as shown in Eqs.

Events without charge sharing (i.e., single events) were se- lected in cell 1 using a time window restriction, as shown by the red curve in Fig. . The spectrum of single events is nearly identical to the original energy spectrum of cell 1, indicating that a significant number of charge sharing events or events suffering from charge loss remain unidentified. This is because when the interaction position of an X-ray photon lies at the cell edge, substantial energy loss occurs, so that one of the two charge components partitioned between the two cells is completely lost and therefore not triggered. This conclu- sion can be verified by the spectral response results at the cell edge obtained using a pencil beam, as presented in Sec.

III B In addition, to further verify the rationality of the time win- dow, event reconstruction was performed with different coin- cidence time windows (20 ns to 1000 ns). The reconstruction efficiency varies significantly with the coincidence time window, leading to differences of one to two orders of magnitude, as shown in Fig. . The reconstructed counts of the fluo- rescent line shows almost no difference when the time win- dow exceeds 200 ns. Moreover, the larger the coincidence window, the higher the number of counts in which two inde- pendent fluorescent photons are misidentified as coincident events. Therefore, setting the coincidence time window to 200 ns is optimal for this detector system, as it not only en- sures that the vast majority of charge-sharing events are identified but also minimizes the number of misidentified events.

2. With Pencil Beam Illumination

Spectral response is degraded at the cell edges, and only a small number of charge sharing events are captured using the coincidence-based reconstruction method. Therefore, we fur- ther investigated the counting and spectral response character- istics of micro-zones at the cell edges, including the triple-cell junctions.

X-rays comprising both a continuous spectrum and the characteristic lines of Fe are generated by a conventional X- ray tube with an iron anode. The divergent

X-ray beam was collimated with a 0.1 mm diameter aperture to produce a pencil beam. This beam was then used to scan the regions of interest. The experiment layout is illustrated in Fig. . Since the aperture was sufficiently close to the surface of SDD, the divergence of the beam spot from the aperture to the SDD surface was negligible, so the diameter of the pencil beam

remained approximately 0.1 mm. By scanning the aperture

horizontally and vertically across the detector using a translation stage, the spectral response and counting performance of individual micro-zones were characterized.

The energy threshold of xMAP was also set to 0.3 keV, and a 1mm 1mm area scan was performed at the junction of cell 1, 3, and 4 with a step size of 0.1 mm to obtain the count rate distribution, as shown in Fig. . It can be observed that the

count rate is relatively uniform in the the cell center, with ap-

proximately 6 kcps, whereas within 0.3 mm of the cell edges,

the count rate decreases significantly from approximately 1

kcps to 3 kcps, indicating the presence of event loss in the region of cell edges.

When we focus on the evolution of the energy spectrum at different distances from the edge, for example, in Fig , the horizon position is fixed at 9.7 mm, and the pencil beam is scanned from 6 mm to 7 mm in the vertical direction. Spectral distortion occurs within approximately 0.4 mm of the cell edge as the irradiation position changes. This distortion manifests as a leftward shift and a reduction in the intensity of

Vacuum Chamber

Ap erture Φ =0.1mm X - ray tube 19 - cell SDD

the Fe characteristic line when the pencil beam is scanned from cell 3 to cell 4, as shown in Figs. . This finding is consistent with the observation that charge sharing events or events with charge loss cannot be fully eliminated by the time window coincidence method under flat-field X-ray irradiation, as shown in Fig. . Therefore, to achieve a better spectral response, edge block is necessary for the first version of the self-developed 19-cell SDD. For subsequent versions of the 19-cell SDD, the optimization of the electric field, especially at the cell edges, should be taken into consideration[

5 V

ertical=6.4mm

1 V

ertical = 6.6 mm

0.025 Vertical = 6.7 mm

0.025 Vertical = 6.8 mm

0.025 Vertical = 6.9 mm

0.025 Vertical = 7.0 mm

(6.4 keV) is indicated with red dash line.

SUMMARY

The eXTP, scheduled for launch in 2030, will be the first scientific satellite to use a multi-cell SDD as the focal plane detector. For the SFA telescope, we have developed a dedicated 19-cell SDD and present the spectral performance of the prototype. After the installation of the collimator, the energy resolution of the vast majority of pixels meets the requirement of 180 eV at 5.9 keV. At a detector temperature of -40 C and a shaping time of 0.6 s, the better pixels can achieve an energy resolution of 151 eV at 6.4 keV. However, insensitive regions caused by electric field distortion exist near the cell boundaries. Without edge block to shield these regions, photons incident at the cell edges will degrade the detector’ s performance, particularly its spectral response. To address these issues, we plan to optimize key design parameters such as bias voltage, electric field configuration, and substrate resistivity. Furthermore, a future irradiation test focusing on displacement damage will be conducted to validate the device’ s suitability as a space-borne payload.

0.025 Vertical = 6.0 mm

0.01 Vertical = 6.1 mm

0.01 Vertical = 6.2 mm

0.1 Vertical = 6.3 mm

2.5 Vertical = 6.6 mm

(6.4 keV) is indicated with red dash line. G. Utica, E. Fabbrica, M. Carminati, et al ., ARDESIA-16: a 16-channel SDD-based spectrometer for energy dispersive X- ray fluorescence spectroscopy. JINST., (07): P07057 (2021).

G. Utica, M. Carminati, E. Fabbrica, et al ., High Rate SDD- Based Spectrometer for Energy-Dispersive X-ray Fluorescence Detection. In: 2021 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), : 1–3 (2021). 10.1109/NSS/MIC44867.2021.9875684

[3] K. C. Gendreau, Z. Arzoumanian, T. Okajima, The Neu- 471

tron star Interior Composition ExploreR (NICER): an Explorer mission of opportunity for soft x-ray timing spec- 473

troscopy. In: Space telescopes and instrumentation 2012: ul- traviolet to gamma ray, SPIE, : 322–329 (2012). 10.1117/12.926396 Amptek, Inc., X-Ray Detectors (2026).

KETEK GmbH, Silicon Drift Detectors (SDD) (2026). PNDetector GmbH, High Performance Radiation Detectors:

SDD Modules, XRF Spectrometer Systems (2026).

[7] G. Agostini, F. Ambrosino, M. Antonelli, et al ., Sili- 484

con drift detector monolithic arrays for X-ray spectroscopy.

Front. Detect. Sci. Technol., 1551757 (2025). ACKNOWLEDGEMENTS The authors would like to thank the eXTP Telescope De- velopment Team from Max Planck Institute for Extraterres- trial Physics for valuable discussions and constructive sug- gestions. 10.3389/fdest.2025.1551757 M. Gugiatti, P. King, D. Fink, et al ., Towards the TRISTAN detector: Characterization of a 47-pixel monolithic SDD array.

Nucl. Instrum. Methods Phys. Res. A, : 166102 (2022).

M. Gugiatti, P. King, M. Carminati, et al ., Development of a Monolithic 166-pixel SDD-based Module for Electron Detec- tion. In: 2021 IEEE Nuclear Science Symposium and Med- ical Imaging Conference (NSS/MIC), : 1–4 (2021). 10.1109/NSS/MIC44867.2021.9875792 M. Gugiatti, A. Brunero, M. Carminati, et al ., Development of a Monolithic 47-Pixel SDD-Based Module for Electron Detection. In: 2020 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), : 1–3 (2020). 10.1109/NSS/MIC42677.2020.9507856

[11] M. Gugiatti, M. Biassoni, M. Carminati, et al ., Characterisa- 502

tion of a silicon drift detector for high-resolution electron spec- troscopy. Nucl. Instrum. Methods Phys. Res. A, : 164474 (2020).

F. Ceraudo, F. Ambrosino, P. Bellutti, et al ., PixDD: a multi-pixel silicon drift detector for high-throughput spectral- timing studies. In:

X-Ray, Optical, and Infrared Detec- tors for Astronomy X, SPIE, : 1219116 (2022). 10.1117/12.2630450

Y. Evangelista, F. Ambrosino, M. Feroci, et al ., Characteriza- tion of a novel pix- elated Silicon Drift Detector (PixDD) for high-throughput X-ray astrophysics. JINST., (09): P09011 (2018).

[14] M. Sammartini, M. Gandola, F. Mele, et al ., Pixel Drift 515

Detector (PixDD) -SIRIO: an X-ray spectroscopic system with high energy resolution at room temperature. Nucl. In- strum. Methods Phys. Res. A, 163114 (2020).

[15] W. Chen, G. Giacomini, A. Kuczewski, et al ., Development 520

of a large array of Silicon Drift Detectors for high-rate syn- chrotron fluorescence spectroscopy. JINST., (01): P01016 (2023).

[16] W. Chen, D. Elliott, G. Giacomini, et al ., Improvement of 524

SDD-Maia Detector for X-ray Fluorescence Detection. In: 2017 IEEE Nuclear Science Symposium and Medical Imag- ing Conference (NSS/MIC), : 1–3 (2017).

MIC.2017.8532602

[17] W. Chen, G. DeGeronimo, D. Elliott, et al ., A new prototype 529

X-ray fluorescence detector system with silicon drift detec- tor array. In: 2016 IEEE Nuclear Science Symposium, Med- ical Imaging Conference and Room-Temperature Semiconduc- tor Detector Workshop (NSS/MIC/RTSD), : 1–3 (2016). 10.1109/NSSMIC.2016.8069774

[18] K. Gendreau, Z. Arzoumanian, Searching for a pulse. Nat. As- 535

tron., (12): 895 (2017).

[19] J. Mitchel, L. Winternitz, M. Hassouneh, et al ., Sex- 537

tant X-Ray Pulsar Navigation Demonstration: Initial On- 538

Orbit Results. In: Proceedings of the 41st Annual AAS

Rocky Mountain, Breckenridge, United States (2018).

URL: 540

H. Sun, Y. Hao, D. Yao, et al ., A novel framework for ex- perimental validation of X-ray pulsar navigation using NICER observations. Chin. J. Aeronaut., : 104032 (2025).

M. C. Miller, F. K. Lamb, A. J. Dittmann, et al ., PSR J0030+ 0451 mass and radius from NICER data and implications for the properties of neutron star matter. Astrophys. J. Lett., (1): L24 (2019).

S.-N. Zhang, A. Santangelo, Y. Xu, et al ., The enhanced X-ray Timing and Polarimetry mission—eXTP for launch in 2030.

Sci. China Phys. Mech. Astron., (11): 119502 (2025). 10.1007/s11433-025-2786-6 S.-X. Yi, W. Zhao, R.-X. Xu, et al ., Prospects for time-domain and multi-messenger science with eXTP. Sci. China Phys.

Mech. Astron., (11): 119506 (2025). P. Zhou, J. Mao, L. Zhang, et al ., Observatory science with eXTP. Sci. China Phys. Mech. Astron., (11): 119507 (2025).

T. F. Bechteler, A. Altmann, J. P. Reiffers, et al ., FPGA-based reset management for multiple parallelized readout ASICs con- nected to a multi-cell SDD. IEEE Trans. Nucl. Sci., 2934 (2025).

Figure 2

Figure 1: Figure 2

Figure 4

Figure 2: Figure 4

A. Altmann, T. F. Bechteler, R. Strecker, et al ., Sili- con drift detectors for the Spectroscopy Focusing Array of eXTP. Space Telescopes and Instrumentation 2024: Ultravi- olet to Gamma Ray, SPIE, : 130936Q (2024). 10.1117/12.3018813 Z. Bao, Z. Li, Y. Liu, et al ., Development of silicon drift detectors for synchrotron radiation sources. Nucl. In- strum. Methods Phys. Res. A, : 169927 (2024).

Xia Inc., XMAP Support Documentation (2026). Y. Wang, Z. Zhao, D. Hou, et al ., The 100-m X-ray test fa- cility at IHEP. Exp. Astron., (2): 427–445 (2023). 10.1007/s10686-022-09872-7 B. Beckhoff, B. Kanngießer, N. Langhoff, R. Wedell, H. Wolff, Handbook of practical X-ray fluorescence analysis. Springer Science & Business Media (2007).

B. W. Loo, F. S. Goulding, Ballistic deficits in pulse shaping amplifiers. IEEE Trans. Nucl. Sci., (1): 114–118 (1988).

M. Shanmugam, Y. B. Acharya, S. V. Vadawale, S. Mazumdar, Radiation effects on Silicon Drift Detec- tor based X-ray spectrometer on-board Chandrayaan-2 mis- sion. JINST., (09): P09005 (2015). 0221/10/09/P09005

[33] G. Bertuccio, F. Mele, Electronic Noise in Semiconductor- 590

Based Radiation Detection Systems: A Comprehensive Anal-

ysis With a Unified Approach. IEEE Trans. Nucl. Sci., 70 (10): 592

2310–2321 (2023). J. Kim, Signal processing and noise analysis on realistic radiation detector model. Nucl. Instrum. Methods Phys. Res. A, : 166931 (2022).

C. Forstner, K. Urban, M. Carminati, et al ., Investigations of charge collection and signal timing in a multi-pixel sili- con drift detector. J. Instrum., (06): P06013 (2025). 10.1088/1748-0221/20/06/P06013

Figures

Source: ChinaXiv –Machine translation. Verify with original.