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Spectroscopic properties of p-type Si sensors for X-ray spectroscopy

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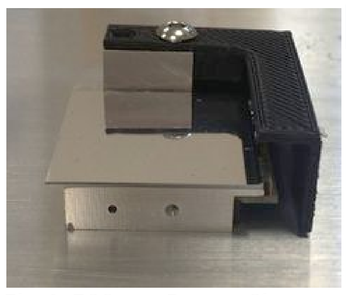
1. Motivation – p-type Si and next-generation devices

- STFC is developing a **new generation of MHz frame-rate cameras** for the detection of hard X-rays (>20 keV).
- At these energies, high-Z semiconductors must be used to ensure sufficient photon stopping power; these materials are typically **electron readout** and has lead to the development of electron-sensitive readout chips.
- Certain applications, however, focus on low-energy photons (2-20 keV); the lower electron-hole-pair-generation energy of Si (3.62 eV cf. 4.67 eV for CZT) offers the potential of **improved lower-energy spectral resolution**.
- Unlike most Si sensors, those of p-type-Si are electron readout, allowing use of a **single ASIC technology across multiple detectors** and applications across multiple energy ranges.

2. Spectroscopic properties at low energy

- P-type Si, purchased from Micron Semiconductors Ltd. [1], was bonded to the STFC HEXITEC ASIC [2] and **tested using a HEXITEC GigE system**. Device specifications and HEXITEC operating conditions are given in Tab.1 below:



Tab.1: **HEXITEC p-type Si properties.**

Quantity	Specification
Pixel Pitch (µm)	250
No. Pixels	80 x 76
Frame Rate (kHz)	1.5
Sensor thickness (µm)	300/500
Applied bias (-V)*	180/300

Fig.1: **500 µm P-type Si sensor bonded to the HEXITEC ASIC.**
*Investigated and selected to achieve both a high collection efficiency and low leakage current

- Each device was **irradiated for 1 hour with an 183 MBq ^{241}Am sealed source** (placed 6 cm from device). Charge-sharing discrimination (CSD) and **Gaussian fits to the resulting 13.94 keV ^{237}Np L_α photopeak** in each pixel provided estimates of the FWHM and thus the spectral resolution at 13.94 keV. Results for 500 µm device 500:A and 300 µm device 300:A are shown in Fig.2. below:

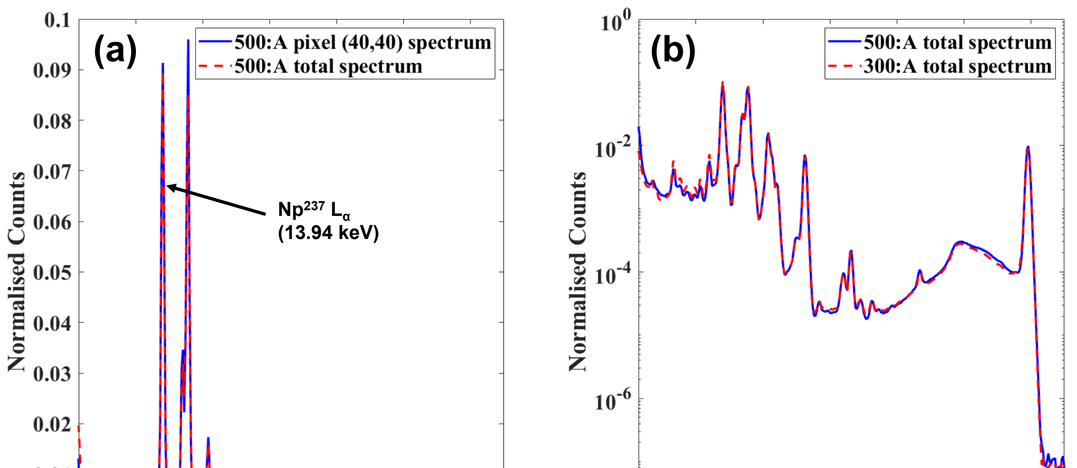


Fig.2: **Spectral results:**
(a) Pixel (40,40) CSD and total histogrammed spectra of device 500:A – 0.2 keV bin width.
(b) Comparison of total CSD histogrammed spectra of devices 500:A and 300:A – 0.2 keV bin width.
(c) Distribution of the 13.94 keV FWHM across device 500:A.

Tab.2: **13.94 keV FWHM of tested p-type Si devices.**

Device	500:A	500:B	300:A	300:B
Thickness [µm]	500	500	300	300
FWHM at 13.94 keV [keV] (σ)	0.52 (0.05)	0.54 (0.06)	0.50 (0.08)	0.49 (0.08)

3. Charge-sharing characteristics

- Results show ~79.97% of events are in a single 250 µm pixel pitch for 500 µm devices operated at -300 V; cf. 84.56% of events for 300 µm devices.
- However, the energy of these remaining events can be recovered - charge-sharing addition (CSA) analysis, shown in Fig.3, reveals **minimal charge loss** within the bulk and inter-pixel gap.

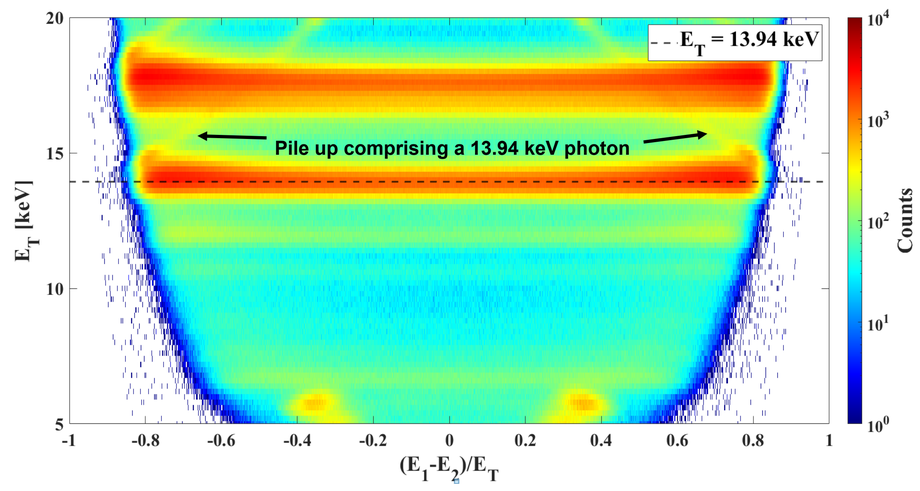


Fig.3: **Plot of the total energy (E_T) and the normalised difference between recorded energies (E_1, E_2) for two-pixel events in device 500:A; charge loss in 13.94 keV events is given by negative deviations from the dotted line.**

4. Temporal stability

- Detector applications at photon-science facilities or in industry may require operation for extended periods; the temporal stability was assessed for device 500:A through continuous operation and **exposure to an ^{241}Am sealed source for ~30 hours** (20 min datasets collected every 80 min).
- Fig.4 demonstrates the spectral stability, with **counts in the 13.94 keV peak (± 1σ) fluctuating by <0.36%** during this period.

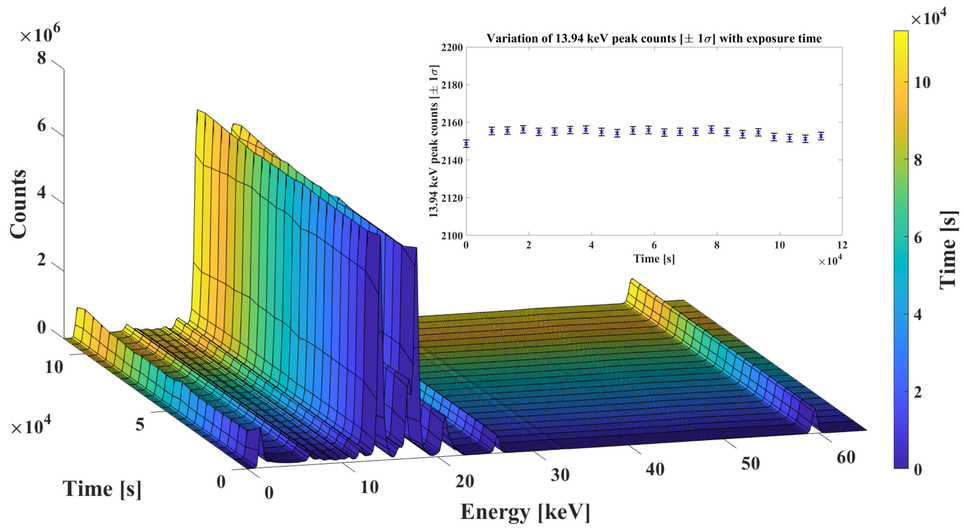


Fig.4: **Evolution of the CSD global spectrum of sensor 500:A over ~30 hours; inset is a plot of the fluctuation of 13.94 keV peak counts (± 1σ) with exposure time.**

5. Conclusion

- All devices tested (Tab.2) **display high resolution and highly-uniform spectroscopic performance** at 298 K. The 0.49 ± 0.08 keV average value measured for device 300:B is the **highest resolution measured to date using HEXITEC** (cf. 0.83 keV at 59.54 keV utilising CZT [3]).

[1] http://www.micronsemiconductor.co.uk
[2] Veale et al, Sync. Rad. News, 31:6, 28-32, 2018
[3] Veale et al Sensors, 20, 28-32, 2747, 2020

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