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APS Facility Update

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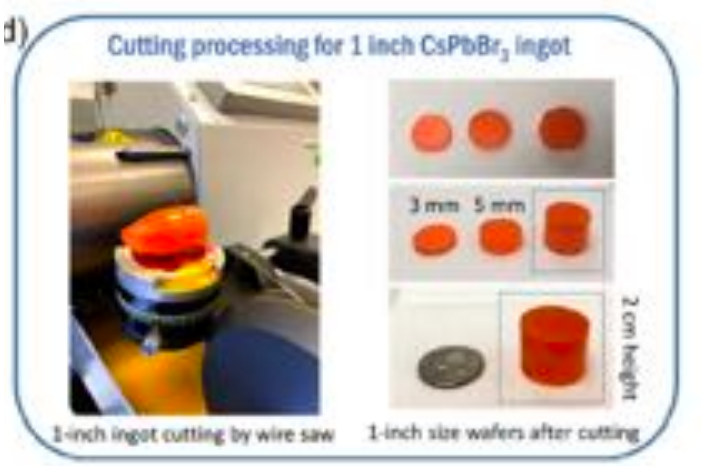
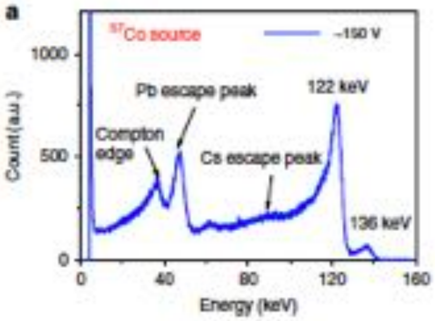
Outline

1. Perovskite $CsPbBr_3$ sensors for pixel arrays
2. High-resolution XRF with TES detectors
3. On-chip digital compression

Perovskite $CsPbBr_3$ for high-Z pixel arrays

- CZT and Ge are mature materials, but each has limitations.
- For gamma-ray spectroscopy applications, perovskite materials, such as $CsPbBr_3$ have attracted much research that can be leveraged for X-ray science applications.
- Perovskite has advantages over Ge and CZT, including:
  - Lower growth costs compared to CZT
  - Should be less sensitive to high flux problems (e.g., polarization) due to lack of deep level defects.
- Northwestern and ANL/MSD have developed this material for gamma-ray spectroscopy applications in the nuclear nonproliferation space. (Mercouri Kanatzidis)
  - https://doi.org/10.1038/s41467-018-04073-3, https://doi.org/10.1038/s41566-020-00727-1
- Main effort of this project will be:
  - Characterization of material at high fluxes at light sources
  - Developing large-scale pixelated sensors to be tested on MM-PAD and ePix10k ASICs.
- Part of the US DOE High-Z Collaboration (Cornell, BNL, SLAC, ANL)





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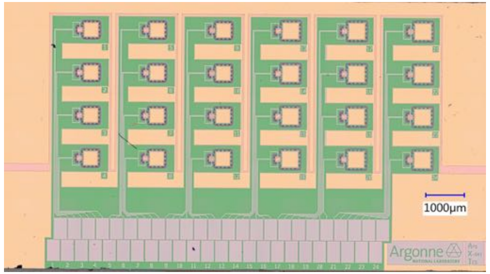
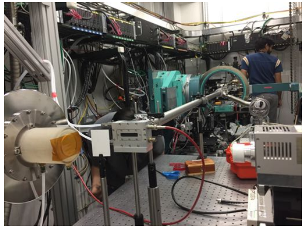
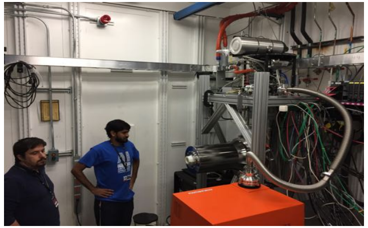
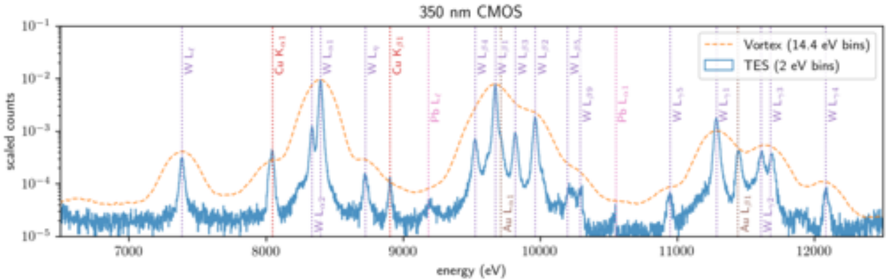
High-resolution XRF with TES detectors

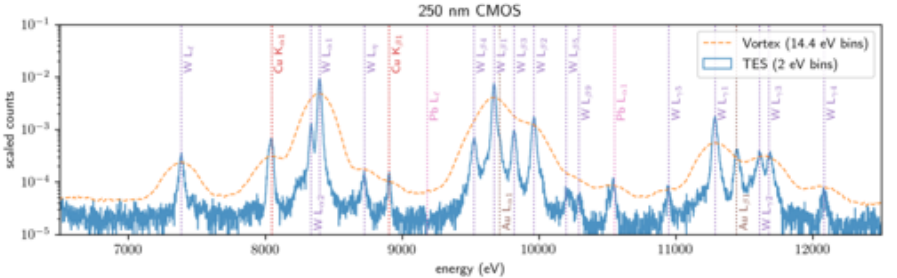
- First light for TES hard X-ray detector @ APS 1-BM-C, November, 2019
  - 24-pixel array
  - Upgrading to 100-pixel array soon

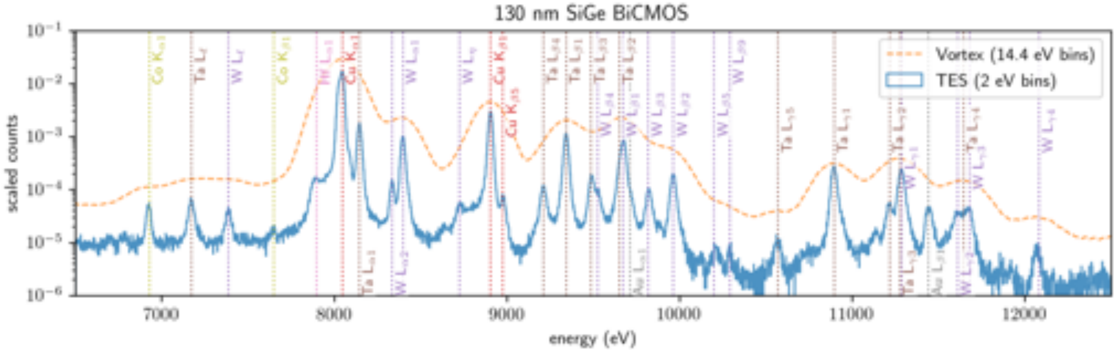












https://dx.doi.org/10.1088/1742-6596/1559/1/012018
https://dx.doi.org/10.1109/TASC.2021.3067246

On-chip compression

- Can we get more data off ASIC to increase frame rates?
- Most pixels are zeros/no photons
  - HE-XRD ~ 80% ptychography ~ 97%, XPCS < 98%
  - *To integrating detector developers: figure out way to implement lower threshold on-chip!*
- We have develop lightweight, stall-free zero-suppression (bit-shuffled first) circuits which takes little space at edge (lossless).
- We have demonstrated average lossless compression ratios of 4x, 7x and 8x for HE-XRD, ptychography & XPCS datasets.
- Currently working on improved compression schemes and how to transform variable to fixed length data to feed high-speed serializers.

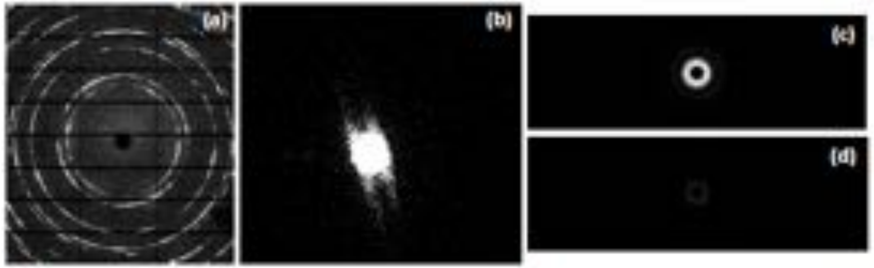


Figure 7. Four representative images for the (a) high-energy XRD, (b) ptychography, (c) XPCS concentrated, and (d) XPCS dilute datasets. Pixel values equal to zero are displayed in black and ≥ 1 in white. Note that the ptychography dataset taken with the Eiger 500K has been cropped to 558 × 514 pixels.

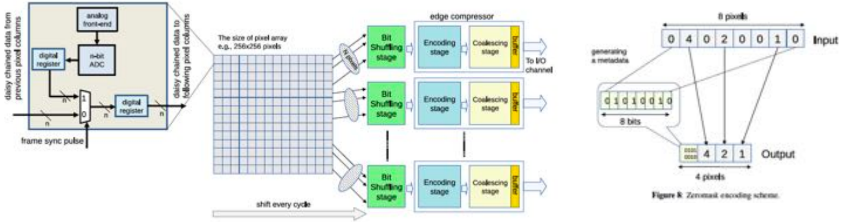


Figure 8. Zeromask encoding scheme.

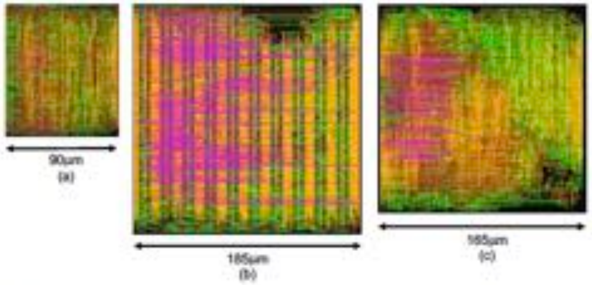


Figure 15. Physical layout of three variants of the ZM compressor in 65 nm CMOS: (a) 8-pixel, (b) 16-pixel, and (c) 16-pixel bit shuffled.

M. Hammer, K. Yoshii, A. Miceli 2021 JINST **16** P01025, https://doi.org/10.1088/1748-0221/16/01/P01025

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On-chip compression – “lossy”

- Do we really need to send 20-bits/pixel? (e.g., in case of Pilatus)
- We have developed efficient encoding schemes (“adaptive encoding quantization”) to reduce number of bits transmitted per pixel.
- Encoding the raw 14-bit photon-counting detector output into only 8 or 9 bits has a negligible effect on the ptychographic image reconstructions.
- Can be implement in-pixel or edge.

Region	Photon Count Range	Number of Photons per Encoded Step	Number of Encoded Steps
1	0-15	1	16
2	16-63	4	12
3	64-255	8	24
4	256-1023	16	48
5	1024-4095	32	96
6	4096-16383	64	192

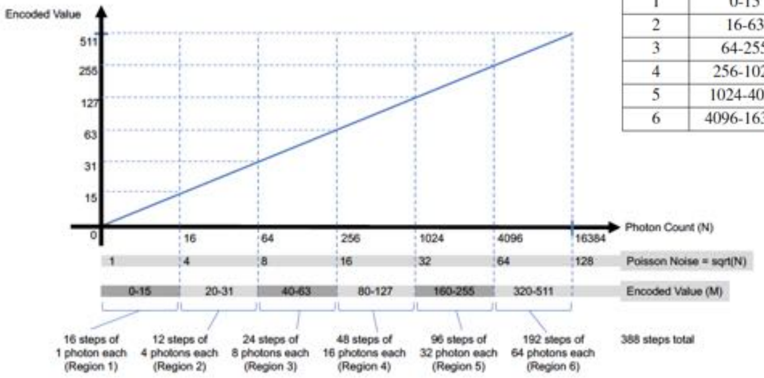
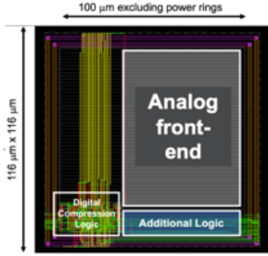
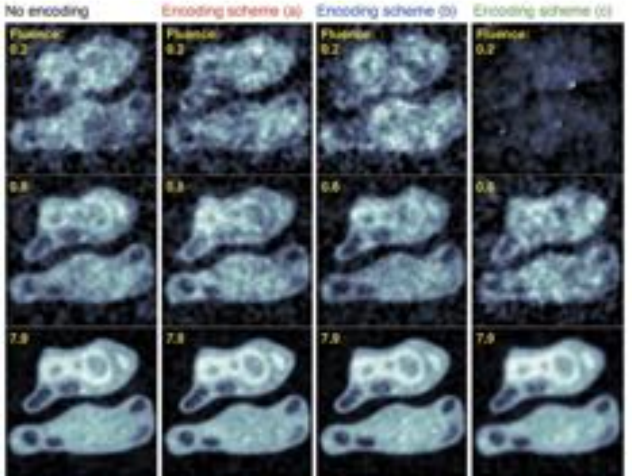


Figure 2: Encoding for a 14-bit photon-counting front-end detector into 9 bits. The photon count range is divided into 6 regions. At the start of each region, the Poisson noise is shown as well as the encoding in each range.





“Fast digital lossy compression for X-ray ptychographic data”, Huang, P., Du, M., Hammer, M., Miceli, A. & Jacobsen, C. (2021). J. Synchrotron Rad. 28, 292-300. https://doi.org/10.1107/S1600577520013326