Characterization of High Flux CZT detectors at the ESRF

Collaboration with IMEM (Parma, Italy)

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Why did we want to work with Redlen HF-CZT

- Better hole transport properties than standard (aka. spectroscopic) CZT
- ⇒ reduced polarization phenomena

	$\mu_e\tau_e$ ($\times10^{-4}$cm^2.V^{-1})	μ_e (cm^2.V^{-1}.s^{-1})	τ_e ($\times10^{-6}$s)	$\mu_h\tau_h$ ($\times10^{-4}$cm^2.V^{-1})	μ_h (cm^2.V^{-1}.s^{-1})	τ_h ($\times10^{-6}$s)
HF-CZT	11±6	940±190	1.2±0.8	2.9±1.4	114±22	2.5±14
Standard CZT	100	1100	11	0.2	88	0.2

Objectives of the collaboration with IMEM

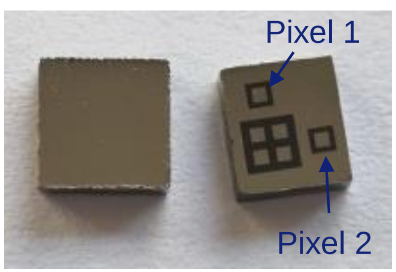
- Reduce the leakage current of the devices obtained with HF-CZT
- ⇒ Electrodes optimization (work done by IMEM)
- Characterize the optimized devices (work done at the ESRF)

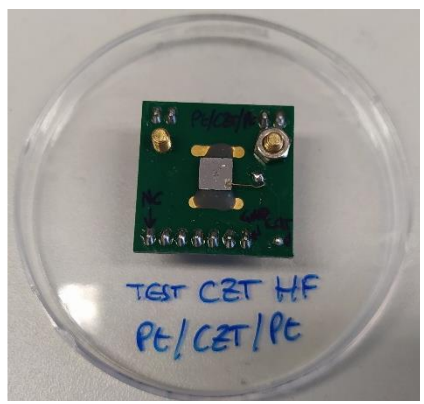
Test samples characteristics

- CZT pixelated detectors were purchased from Redlen and re-processed by IMEM

- Processing at IMEM:
  - *Polishing of existing electrodes*
  - *Deposition of Au (electroless deposition) and/or Pt electrodes (sputtered deposition)*
  - *Substantial work done by IMEM in terms of electrode type and electrode deposition method to reduce the leakage current*

Name	Material	Cathode contact	Anode contact	Geometry (mm^3)	Pixel size (mm^2)
Test sample 1 | AP	Redlen “high flux” CZT	Au	Pt	5 × 5 × 1.5	0.5 × 0.5
Test sample 2 | PP	Redlen “high flux” CZT	Pt	Pt	5 × 5 × 1.5	0.5 × 0.5

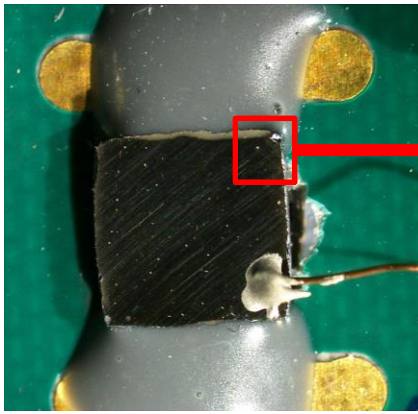




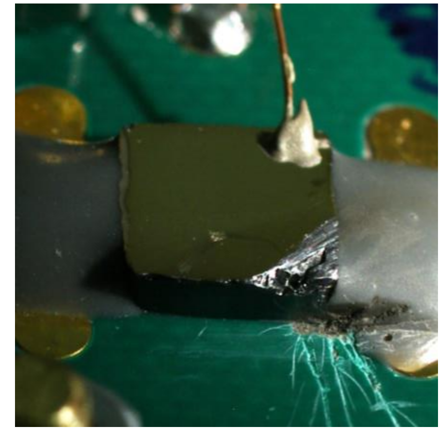
Notation: Test sample 1 – pixel 1 ≡ ts1_px1

GENERAL CONTEXT: A RESCUE STORY

- **Electrical breakdown on one corner**



A round trip to Italy and some sanding paper later…



- **After rescue**
  - I-V characteristics (dark and under irradiation) are back to normal with a slight increase of the leakage current

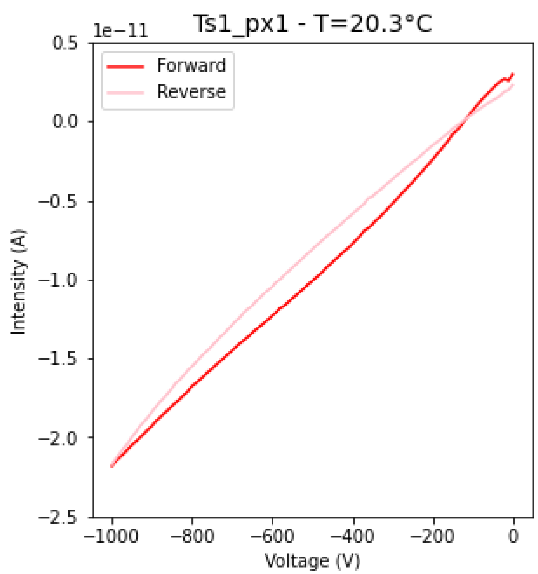
Despite the damages sustained, the performances remain good!

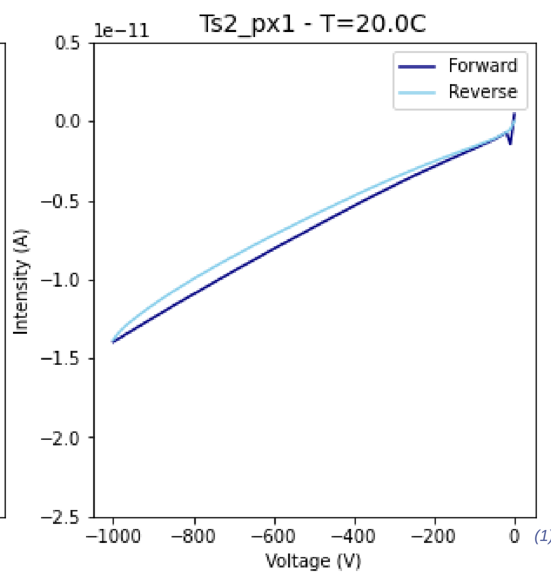
I-V_{dark} measurements

- IMEM: Test sample 1: J_{dark} ≈ 40pA/mm^2 at -800V
  Test sample 2: J_{dark} ≈ 40pA/mm^2 at -800V
- ESRF: Test sample 1: I_{dark}=1.7×10^{-11}A → J_{dark} ≈ 70pA/mm^2 at -800V
  Test sample 2: I_{dark}=1.0×10^{-11}A → J_{dark} ≈ 40pA/mm^2 at -800V

⇒ 1 order of magnitude improvement compared with standard Redlen pixelated HF-CZT[(1)]

⇒ 4 orders of magnitude improvement compared with other electrode configurations tested





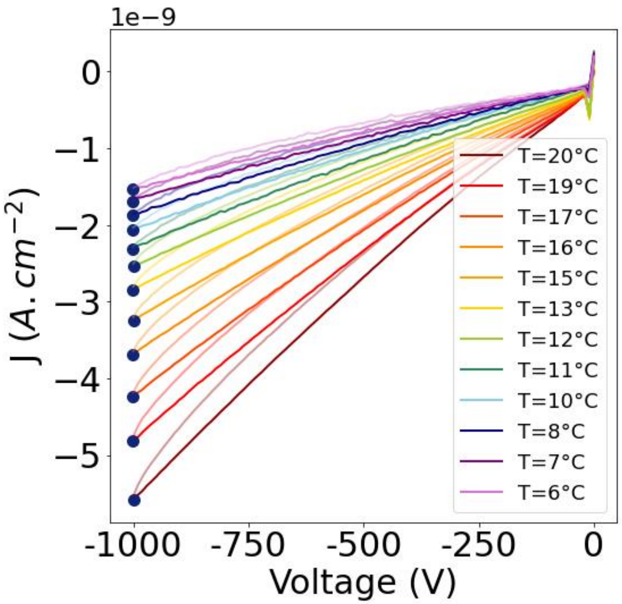
[(1)] *doi: 10.1088/1748-0221/14/12/C12009*

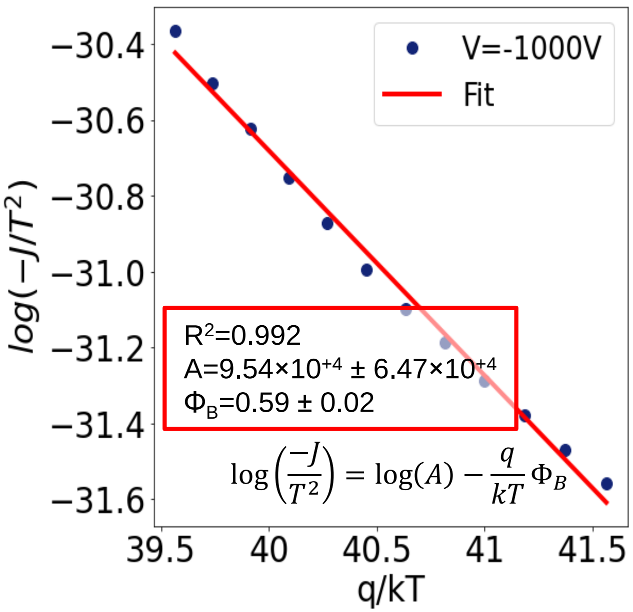
Electrode processing lead to reduction of the leakage current (<100pA/mm^2 @-5kV/cm 20°C).

▪ Estimation of the Schottky barrier height

- Non-ideal Schottky characteristics: low reverse current and linear characteristics
- Using the thermionic emission model the height of the Schottky barrier was estimated to be Φ_B=0.59eV regardless of the bias voltage.

⇒ This is a bit lower than other estimations[1] (0.75eV) because of non optimal conditions for the use of the ITD model (bias voltage too low to reach the thermionic dominated current region).

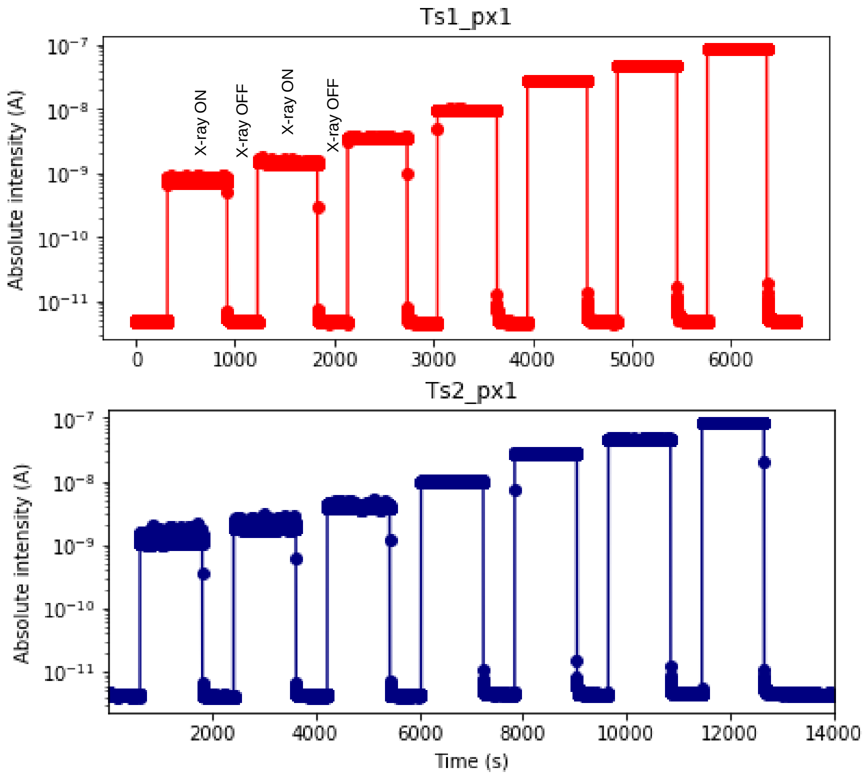


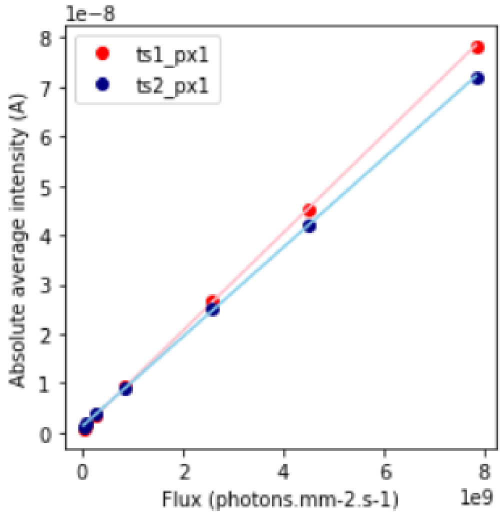


Using the thermionic emission model the height of the Schottky barrier was estimated to be Φ_B=0.59eV regardless of the bias voltage.

(1) doi: 0.1038/s41598-020-70801-9

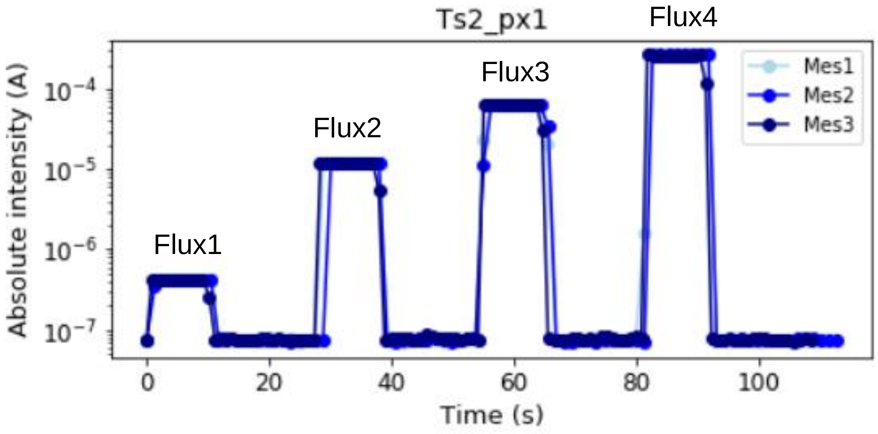
- **Stability and linearity: pulsed irradiation at 20keV, V=-1000V**
  - Fluxes range: 3.10^{+7}photons.mm^{-2}.s^{-1} - 8.10^{+9}photons.mm^{-2}.s^{-1} (Al filters)
  - Test sample 1: 10min under irradiation, 5min without irradiation
  - Test sample 2: 20min under irradiation, 10min without irradiation

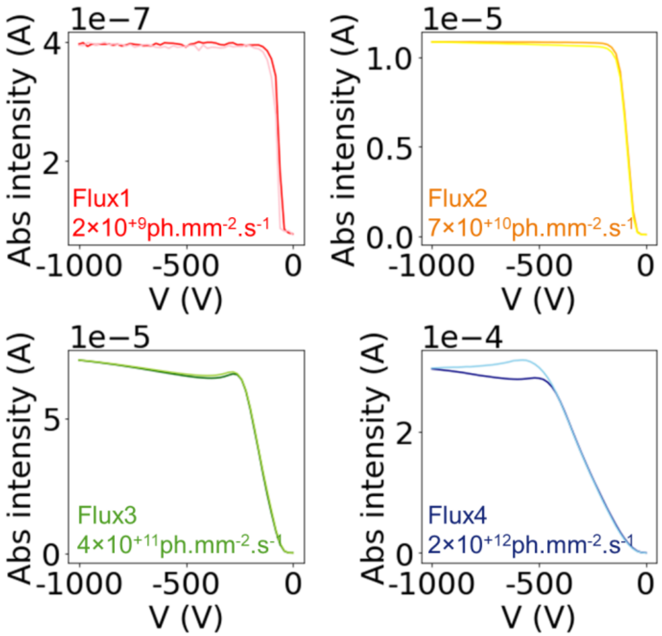




Good linearity and stability in the 10^{+7}-10^{+10}ph.mm^{-2}.s^{-1} range.

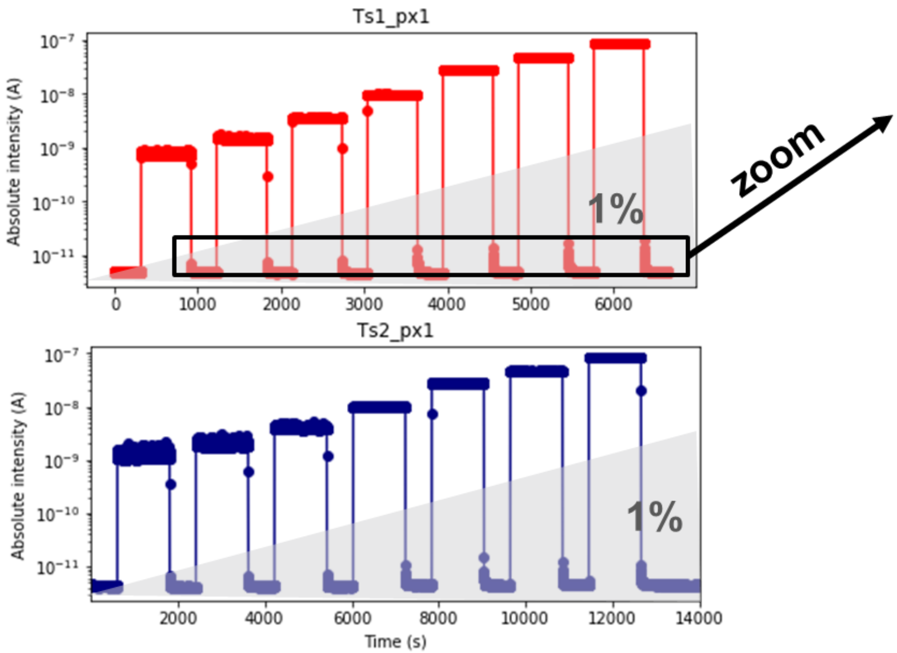
- **Pulsed irradiation at 19keV, V=-500V (ts2_px1 only)**
  - Fluxes range estimated: 2.10^{+9}photons.mm^{-2}.s^{-1} - 1.10^{+12}photons.mm^{-2}.s^{-1} (2 orders of magnitude higher than BM05 flux, flux adjusted using gap between magnets of the undulators)
  - Test sample 2: 10s under irradiation, 15s without irradiation
- **I-V characteristics**
  - Deformed I-V shapes above 10^{+11}photons.mm^{-2}.s^{-1} (Flux 3)

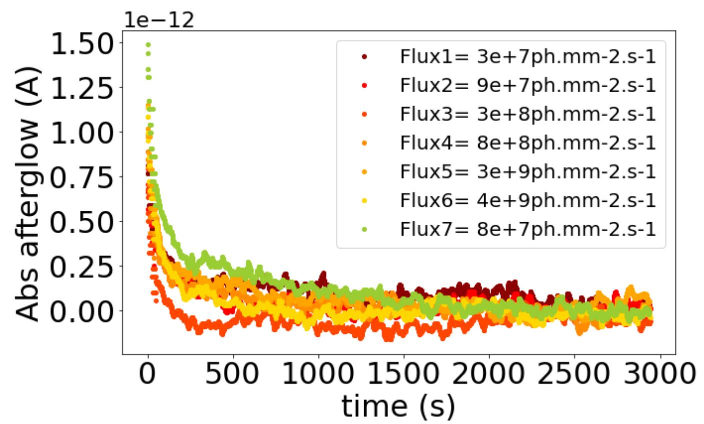


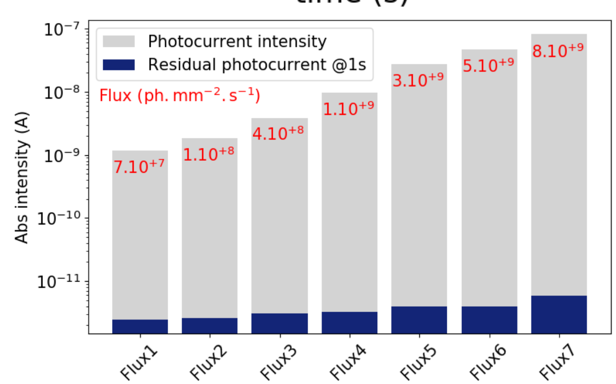


Stable and reproducible behavior up to 10^{+12}ph.mm^{-2}.s^{-1}, deformation and hysteresis appear above 10^{+11}ph.mm^{-2}.s^{-1}

- **Residual signal (aka afterglow) and stabilization time on BM05 results:**
  - Disclaimer: no specific measurement performed, analysis limited to the seconds time range (5Hz rate)
  - Stabilization time: rapid rise of the signal (< 200ms)
  - Residual signal
    - *Rapid initial drop: within less than 400ms the residual signal is below 1% of the photocurrent*
    - *Going back to dark current value: several hundreds of seconds with no clear link between incident flux and residual signal*
    - *Residual signal at 1s*







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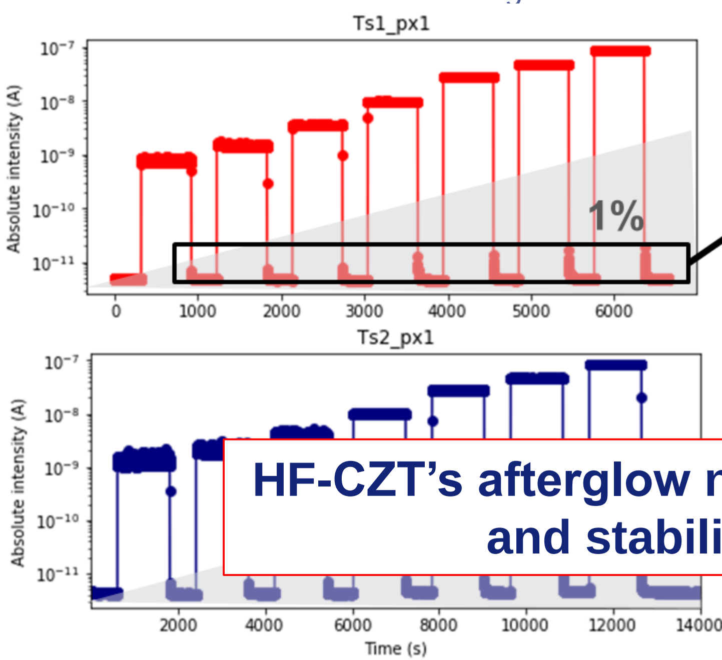
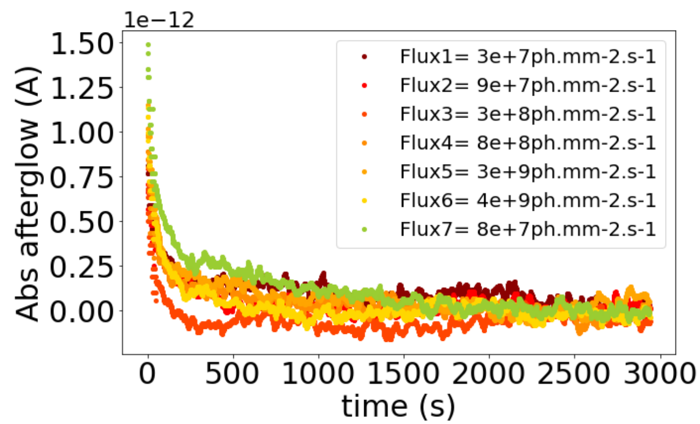
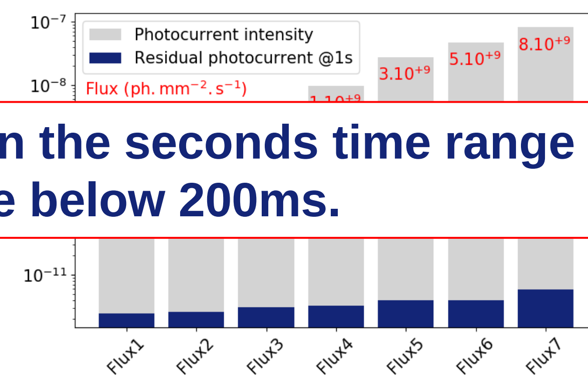


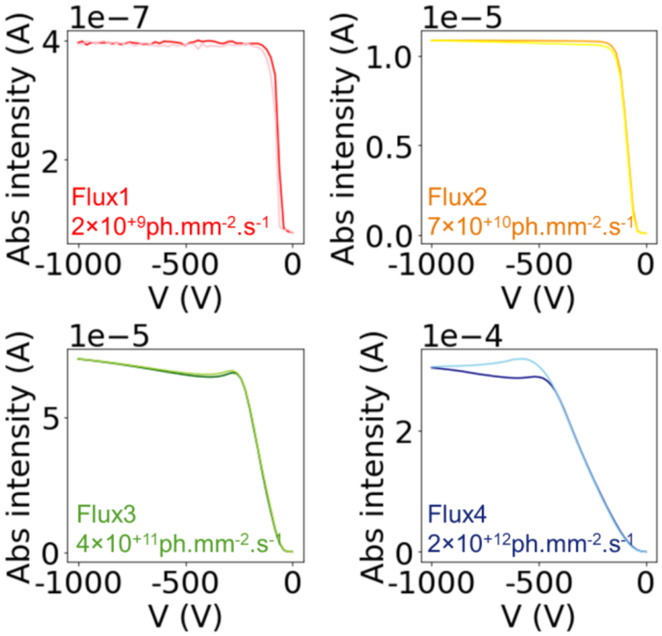




HF-CZT's afterglow negligible in the seconds time range and stabilization time below 200ms.

I-V CHARACTERISTICS SHAPES

- **IV characteristics shape as a function of the incident X-ray flux**
  - From ID19



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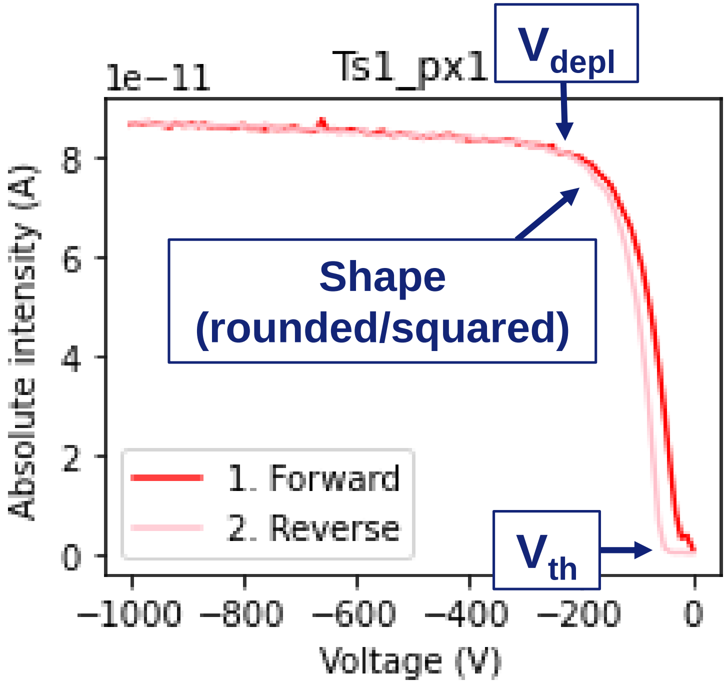
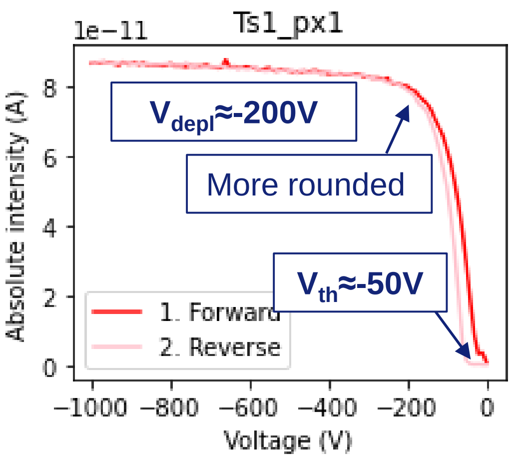
I-V CHARACTERISTICS SHAPES

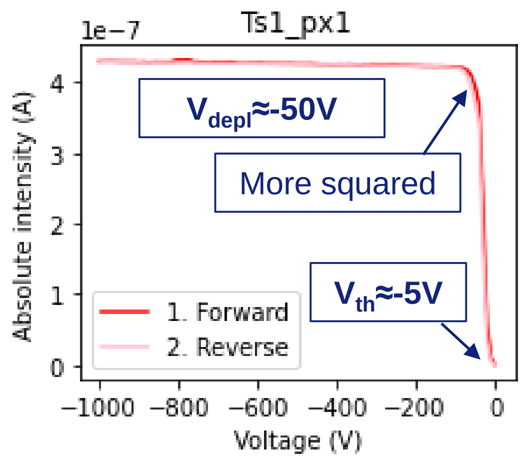
- **IV characteristics as a function of the incident X-ray photons' energy**
  - IV characteristics from BM05 and from laboratory X-ray generator

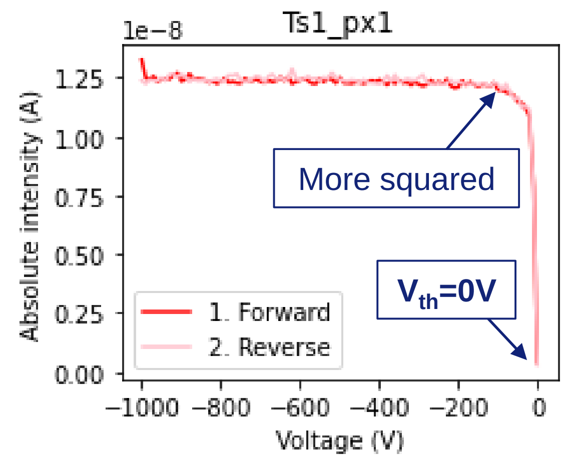


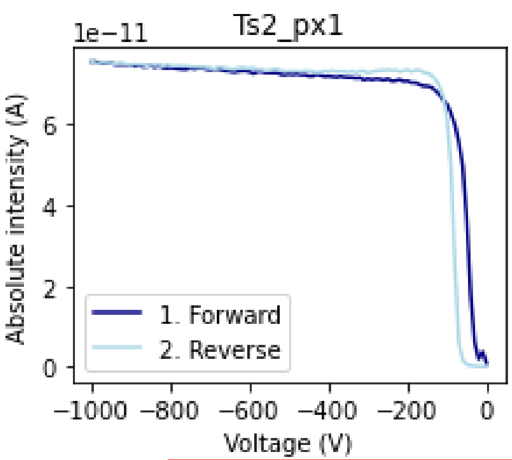
IV characteristics as a function of the incident X-ray photons' energy

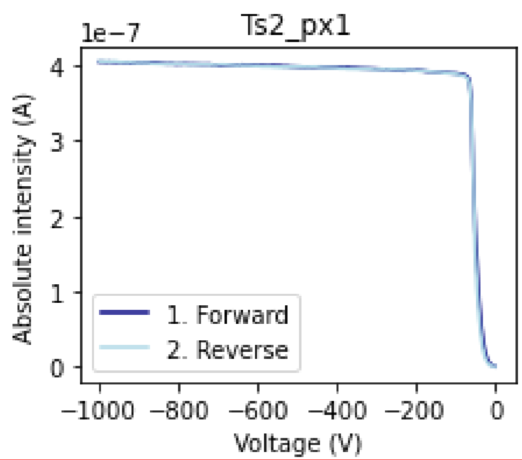
8keV	20keV	60keV
Estimated flux = $3.5\times10^{+5}$ photons.mm^{-2}.s^{-1}	Estimated flux = $8\times10^{+9}$ photons.mm^{-2}.s^{-1}	Estimated flux = $5\times10^{+7}$ photons.mm^{-2}.s^{-1}







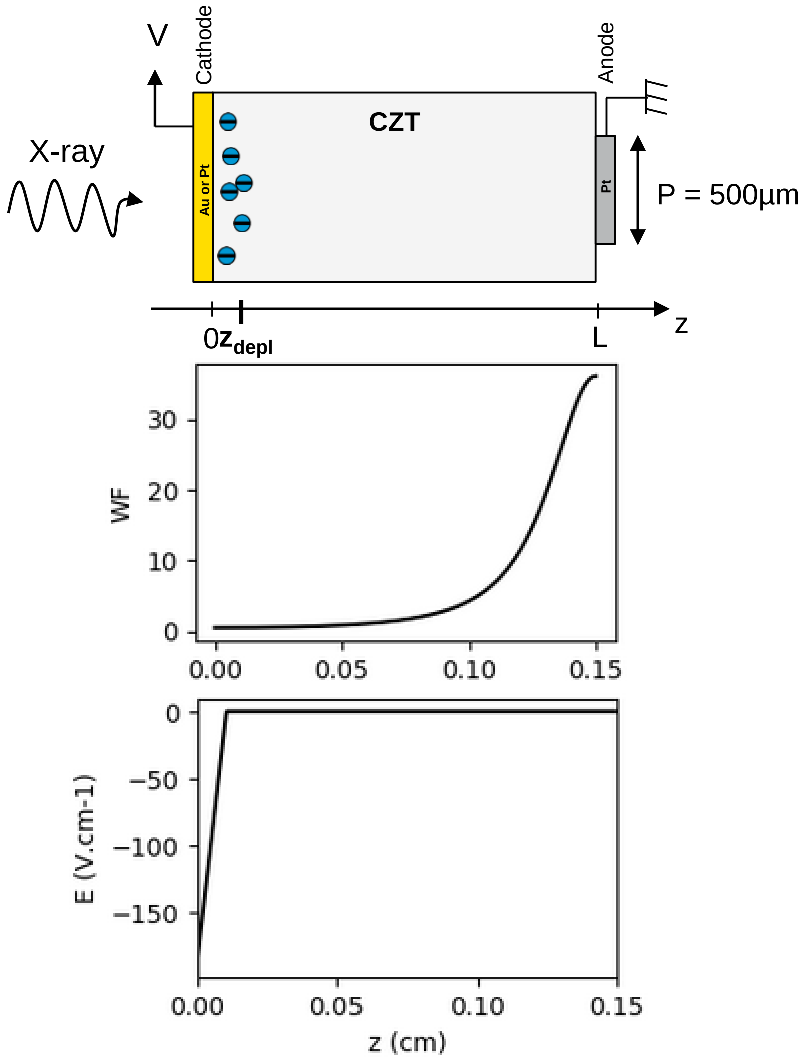




- V_{th} ⇘ when E_{ph} ⇗
- At 8keV, V_{th} ⇗ in reverse scan
- IV shape more squared when E_{ph} ⇗
- V_{depl} ⇘ when E_{ph} ⇗

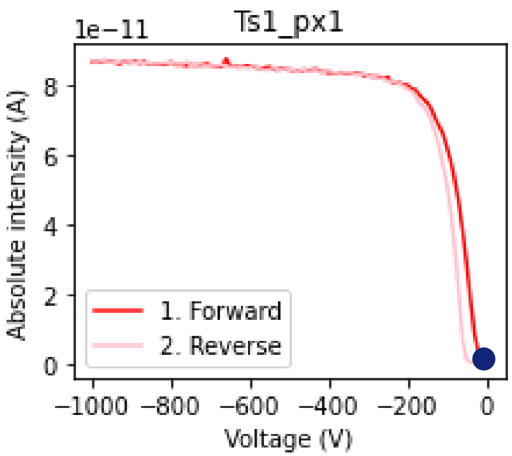
How to explain the differences observed with incident energy?

ANALYTICAL RAMO-BASED MODEL

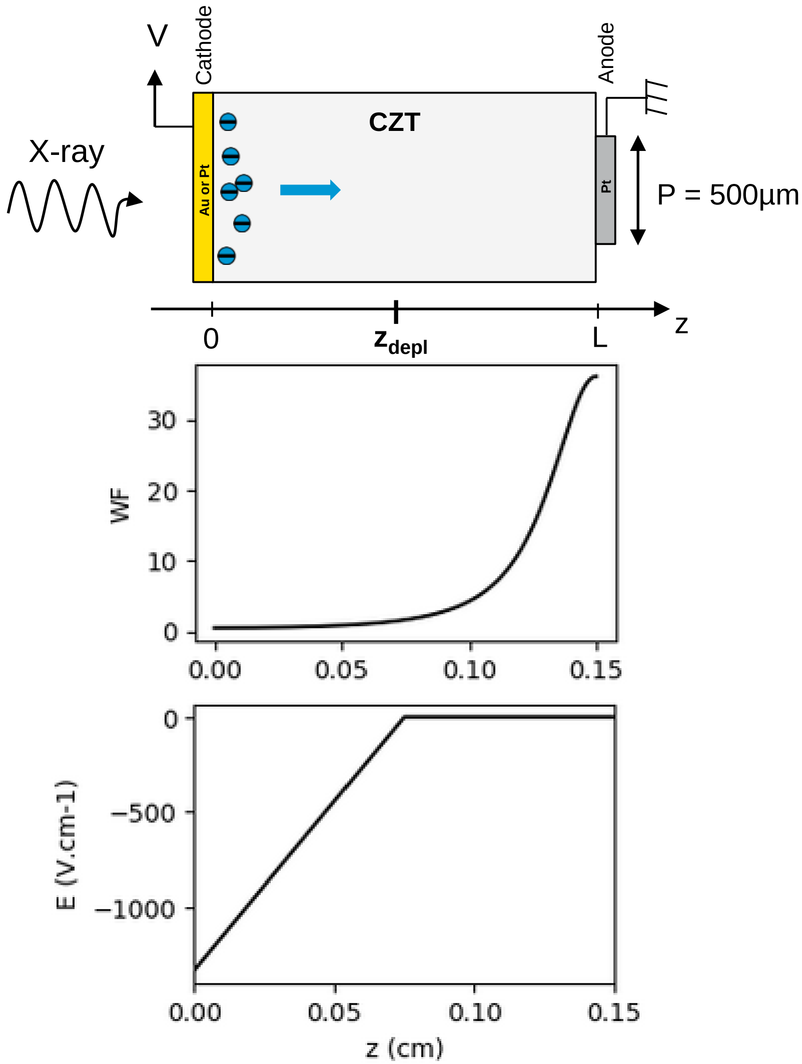


V = -1V

8keV

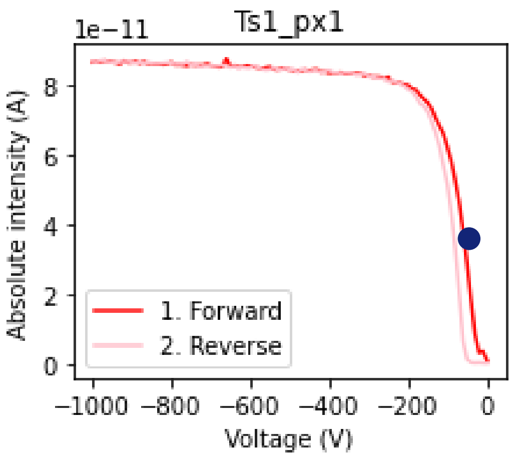


ANALYTICAL RAMO-BASED MODEL

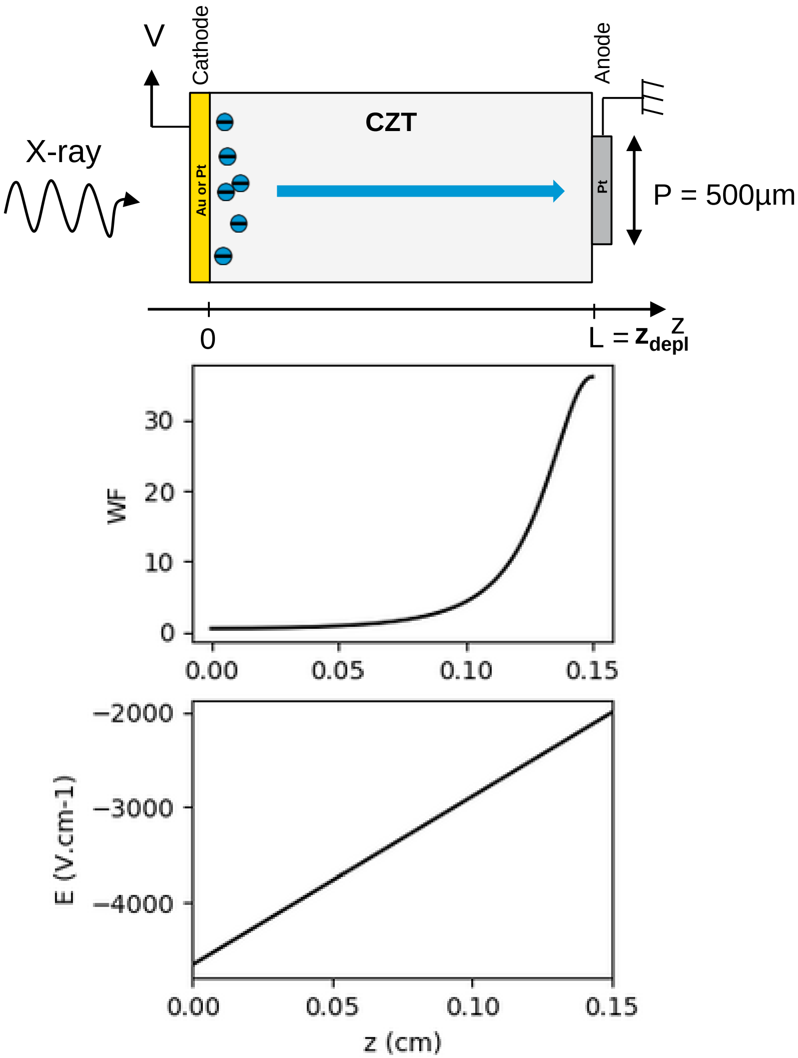


V = -50V

8keV

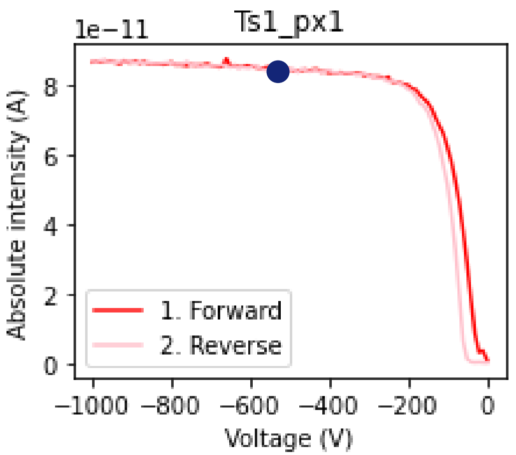


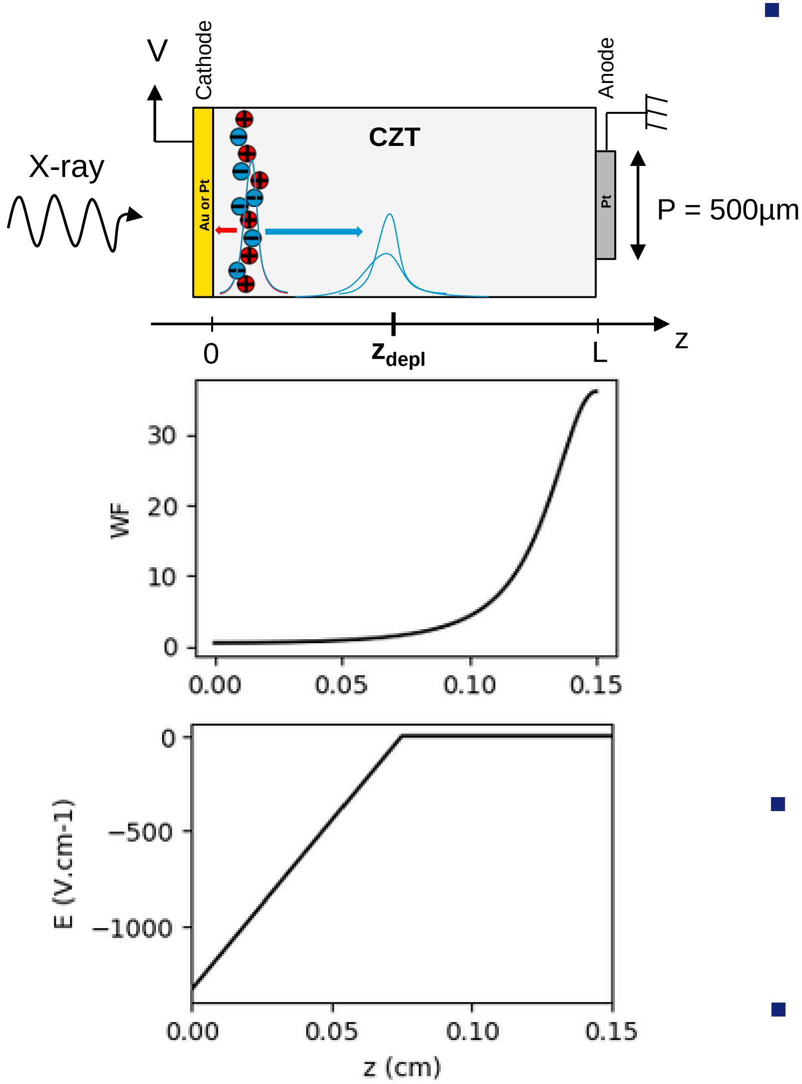
ANALYTICAL RAMO-BASED MODEL



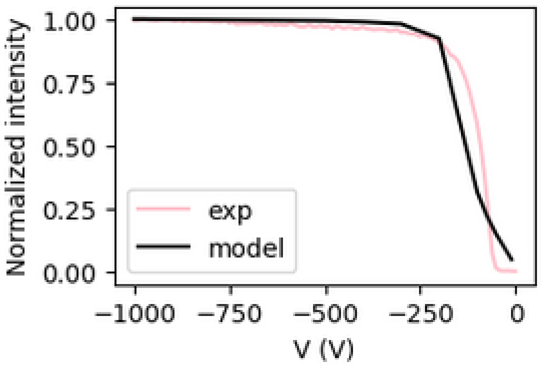
V = -500V

8keV





- **Analytical model principles**
  - Electrons and holes clouds are represented as Gaussians
  - Drift of both electrons and holes are considered
  - Free diffusion of electrons is considered
  - Diffusion of holes is not considered (if charges are created outside the depletion region holes are neglected)



- **Issues**
  - Voltage threshold is not explained
  - High µτ needed to fit experimental data
- **Further work needed**

OUTLOOK AND ONGOING WORK

- **Objectives**
  - Reduce the leakage current of the devices obtained with HF-CZT
  - Characterize the optimized devices
- **Context**
  - Characterization of 2 HF-CZT devices with optimized electrodes (Au/HF-CZT/Pt and Pt/HF-CZT/Pt) within the IMCZT collaboration
- **Results**
  - Significantly reduced leakage current (<100pA/mm^2 @-5kV/cm 20°C) compared with standard Redlen pixelated platinum electrode configuration.
  - Stability and repeatability demonstrated under X-ray fluxes up to 10^{+12}photons.mm^{-2}.s^{-1}
  - Linearity demonstrated for 10^{+7}-10^{+10}photons.mm^{-2}.s^{-1} flux range
  - Afterglow negligible in the seconds time range and stabilization time below 200ms.
- **Ongoing and future work**
  - Modelization of IV characteristics under X-ray irradiation as a function of incident energy
  - Finer afterglow characterization
  - Colleagues from Palermo university (L. Abbene and F. Principato) have been characterizing these samples (ITD model and gamma spectroscopy) and will be publishing soon so stay tuned.

Thank you for you attention !
Do you have questions?

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