



Science and
Technology
Facilities Council

Daresbury Laboratory

The CLARA Photocathode and Rb-Te R&D at Daresbury Laboratory

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21/09/2026

Photocathodes for Accelerator Science in Europe, Orsay, 2026

Outline

- The CLARA Photocathode
 - Cathode manufacture
 - RF conditioning in CLARA
 - Current performance
- Rubidium Telluride R&D
 - Motivation
 - Deposition process
 - QE and QE degradation comparison with Cs-Te
 - MTE and MTE degradation comparison with Cs-Te

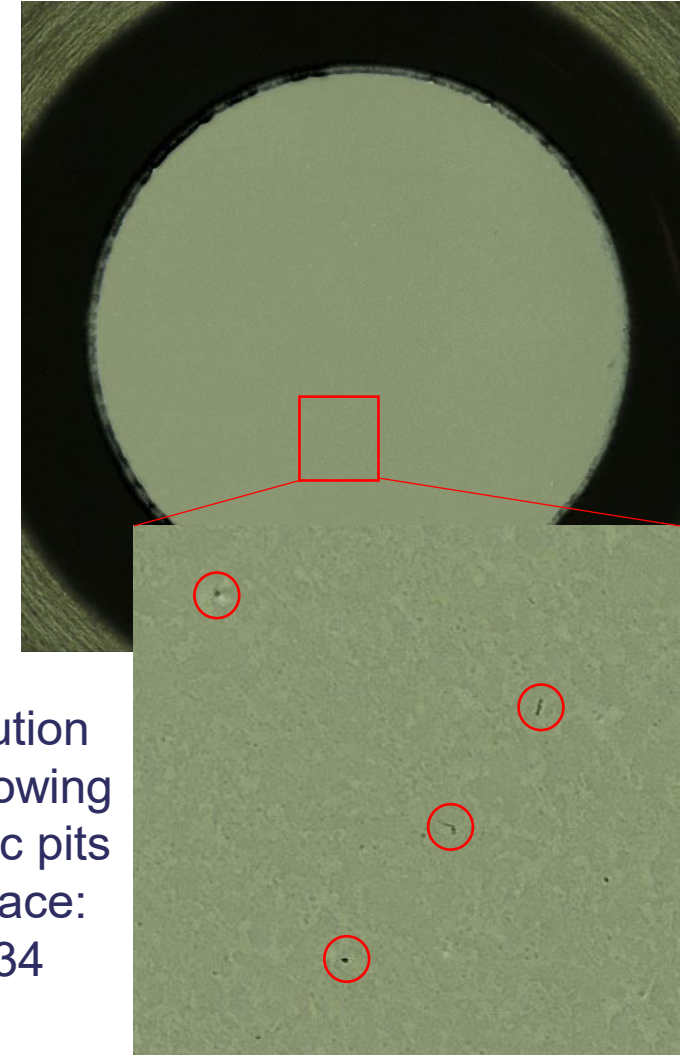
CLARA Caesium Telluride Cathode Production

- CLARA: 250 MeV 250 pC 100 Hz high brightness linear electron accelerator.
- Full details of the process presented at IPAC '26
 - H. Churn et al., DOI: [10.18429/JACoW-IPAC2026-THP2143](https://doi.org/10.18429/JACoW-IPAC2026-THP2143)
- Manufacture & Polishing
 - High purity, sintered molybdenum stock, INFN style plug.
 - Polished by DESY, Hamburg. EuXFEL polishing procedure.
 - Reasonable roughness but pitting present on surface.

White light
interferometry
roughness
measurements
post polishing

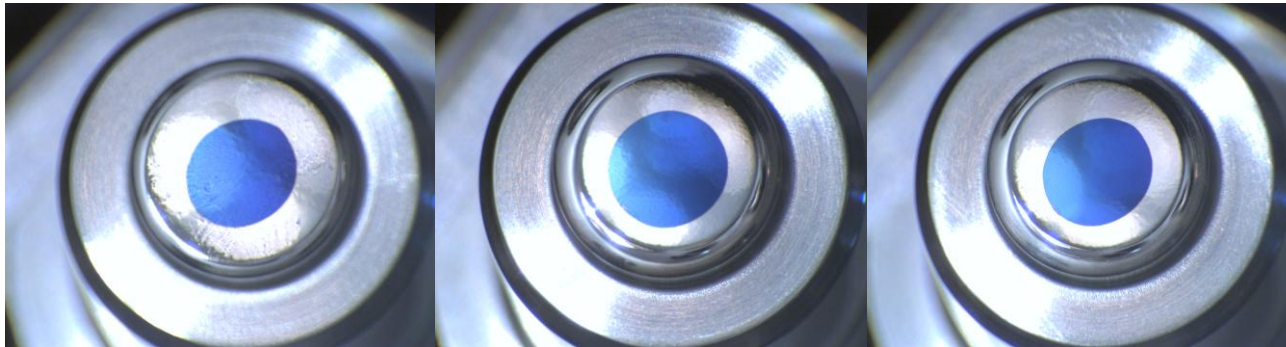
Photo-cathode	S_q [nm]		S_a [nm]	
	Av.	Std. Dev.	Av.	Std. Dev.
033	30.5	8.2	23.8	6.1
034	31.2	18.5	22.3	12.5
036	26.5	11.0	21.0	9.0

High resolution
images showing
microscopic pits
on the surface:
Cathode 034



CLARA Caesium Telluride Cathode Production

- Room temperature deposition.
- ~~10 nm~~ 20 nm* Te deposited according to QCM.
- Cs deposited from SAES Alkamax pills until photocurrent peaked.
- Immediate post deposition QE NOT precisely measured but estimated at ~25 %.

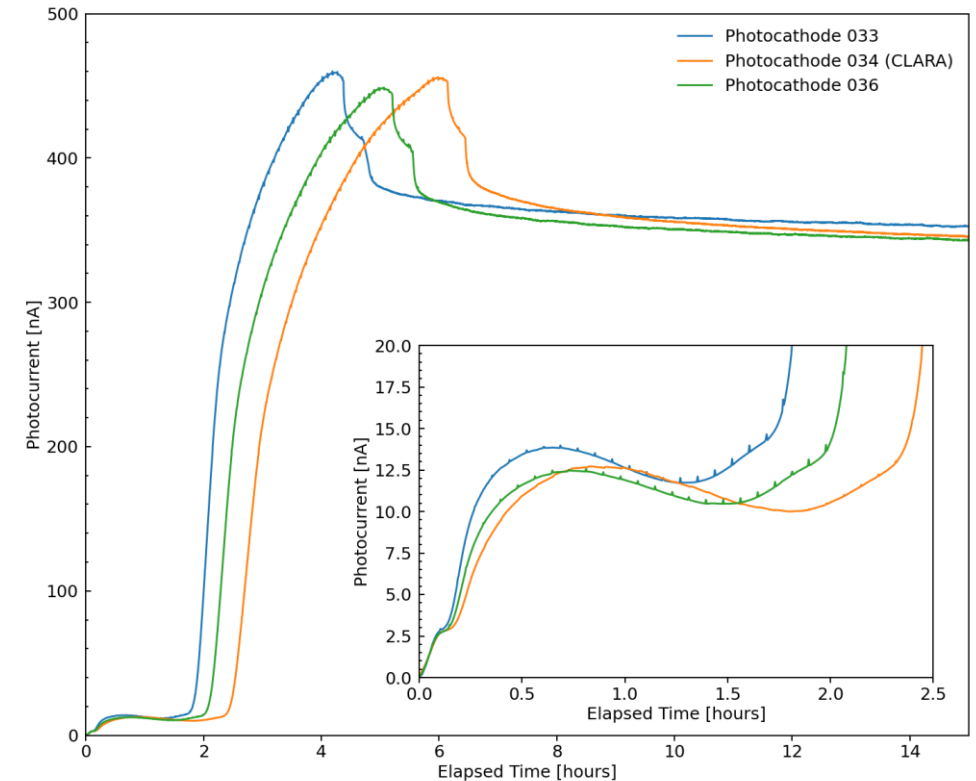


Cathode #033

Cathode #034

Cathode #036

Images taken post deposition



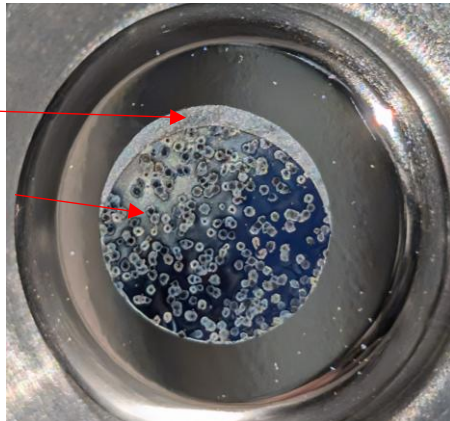
Photocurrent during Cs deposition

* Since IPAC we have discovered a fault in how our QCM was reporting data. Rates were x2 higher than originally thought.

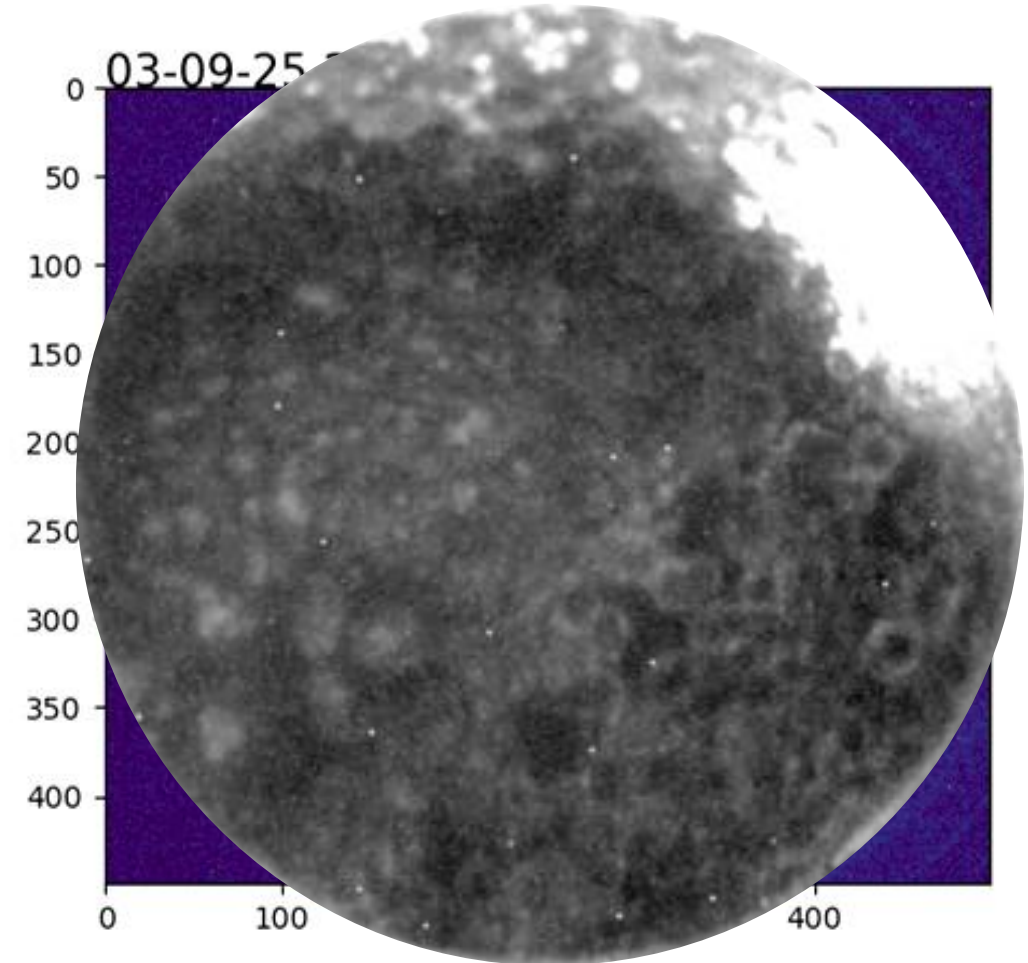
RF Conditioning the photocathode in CLARA

- Details presented at IPAC 2026 and P3 2025
 - L. Jones, CLARA Photocathodes: A Tale of Two-Three Cathodes, P3 2025
 - A. Pollard et al., DOI: [10.18429/JACoW-IPAC2026-TUP3075](https://doi.org/10.18429/JACoW-IPAC2026-TUP3075)
- 'Features' appear during RF conditioning.
- Quantitatively linked to RF breakdown events.
- Hypotheses: Caused by...
 - ...the micro-pits seen on the molybdenum substrate?
 - ...by dust on the cathode during loading?
 - ...embedded polishing particulate?
- Questions: are they physical, chemical, both?

- Tellurium has changed?
- Features about 0.25 mm across.



Cathode 036
after a failed
attempt at RF
conditioning in
CLARA

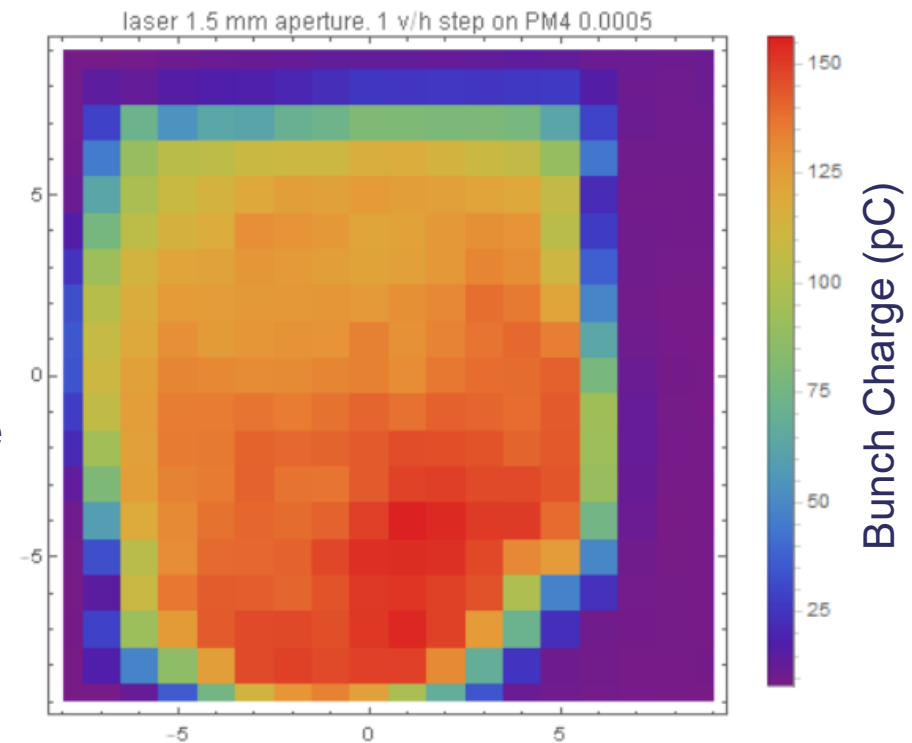


Cathode 034 during RF conditioning in CLARA

Cathode performance during CLARA Operation

- CLARA's highly successful friendly user run presented at IPAC 2026
 - M. Johnson et al., DOI: [10.18429/JACoW-IPAC2026-TUO2M05](https://doi.org/10.18429/JACoW-IPAC2026-TUO2M05) & Talk!
- 0.7 μm rad normalised emittance with a 250 pC 35 MeV/c beam.
- Acceptable dark current; ~ 100 pC with a 1.25 μs RF pulse and an 87 MV/m field.
- No evidence of 'features' in QE map...
 - ...but laser spot size is 0.6 mm
 - ...and features are ~ 0.25 mm

Charge map of Cathode
034 in CLARA shortly
after RF conditioning:
September 2025



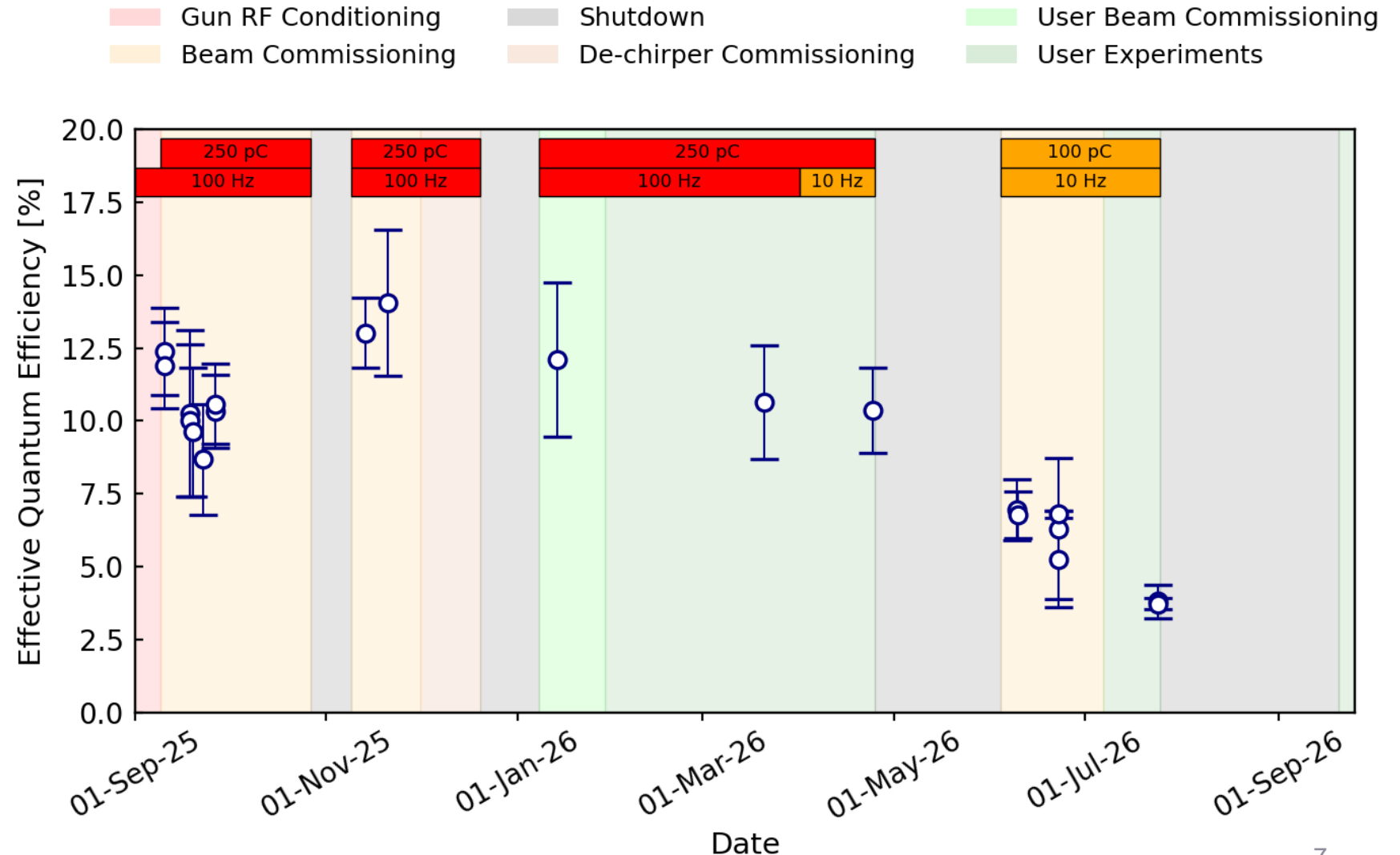
Cathode performance during CLARA Operation

Before May shutdown:

- QE looked like it was stable/very slowly decreasing at 11 %.

After May shutdown:

- Rate of QE decay appears to increase. But why?
- Currently investigating the corresponding vacuum and RF data.
- The QE post summer shutdown is...



Rubidium Telluride

With comparisons to caesium telluride

Preliminary results!

Rb-Te Motivation

- Limited literature.
- Some suggest no change in QE vs Cs-Te, others expect slightly lower QE.
- But in an accelerator:
 - Charge extracted more linked to field on the cathode.
 - QE needs to be high enough to:
 - a) Emit enough electrons for the given laser power, after any pulse shaping techniques.
 - b) Allow for degradation before needing to be changed.

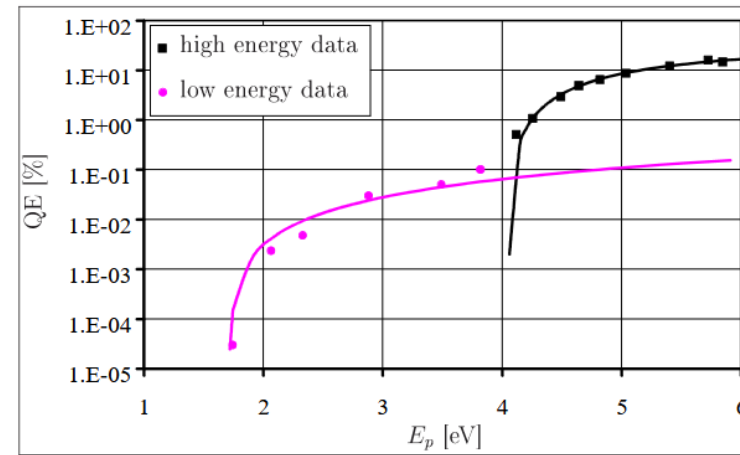


Figure 7.16: Quantum efficiency of a Rb_2Te cathode as a function of photon energy, after preparation

Full list of Rb-Te references in additional slides

iodide (Cs-I) with a window of LiF is necessary. Cs-I rejects even more of the middle and near ultraviolet as well as the visible wavelengths. Both of these photocathode materials will be discussed below.

Finally, in Fig. 1 there are shown for comparison two dashed lines representing examples of relatively narrow response photodetectors which operate not by photo-

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based on the desirability of being able to cesiate the photomultiplier dynodes to a limited extent, on the ready availability of pure cesium compounds, and on prior familiarity with evaporation of cesium compounds. The problems involved in using cesium in a

It should be mentioned that we have found **no major differences between rubidium and cesium telluride cathodes with respect to either quantum yield or rejection ratios**. Even though there is some problem caused by a reaction of the cesium with silver chloride seals, most manufacturers have preferred to work with Cs-Te rather than the Rb-Te. This choice is evidently

Photoemission from Cesium and Rubidium Tellurides

E. TAFT AND L. APKER
General Electric Research Laboratory, Schenectady, New York
(Received October 17, 1952)

REMARKS

This paper presents data only on Cs_2Te . Similar photoelectric experiments showed that Rb_2Te behaved in practically the same way. The fundamental photoemission and that resulting from excess Rb both had thresholds several tenths of 1 eV higher than did Cs_2Te , as one might expect. The maximum quantum yield from Rb_2Te samples was frequently 30 percent—just as high as from Cs_2Te . This is somewhat surprising. Rb_2Sb , for example, shows a distinctly lower yield than Cs_2Sb . It would be interesting to have optical data on Rb_2Te , we know only that in thick layers of uncertain stoichiometry it shows the same pale greenish tint as Cs_2Te .

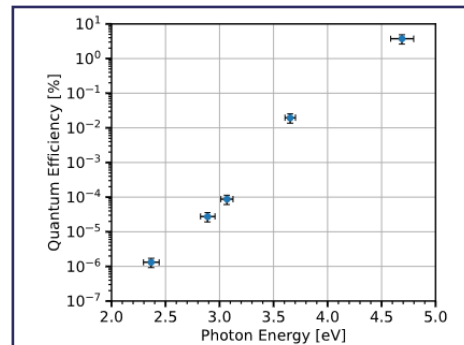


Figure 2: Measured quantum efficiency of the annealed RbTe photocathode at several wavelengths: 265, 340, 405, 430 and 525 nm. LED sources were used and calibrated using a Thorlabs PM400 power meter and sensor.

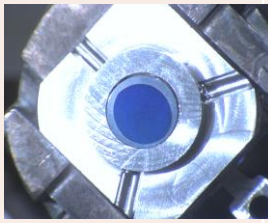
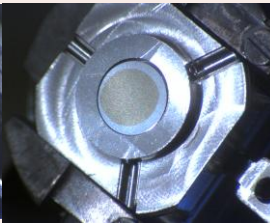
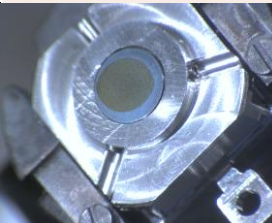
Photoelectric Properties of Rubidium Telluride Films

V. P. DENISOV AND A. I. KLIMIN

The electron affinity and photoelectronic work function are determined from the energy spectra of the photoelectrons, emitted for excitation of a rubidium telluride photocathode with a variable ratio of its components in the 230–260 nm wavelength region. For a TeRb film on tantalum, possessing a high quantum yield (up to 5.5% at 250 nm), they are equal to (0.4 ± 0.1) and (3.6 ± 0.2) eV, respectively.

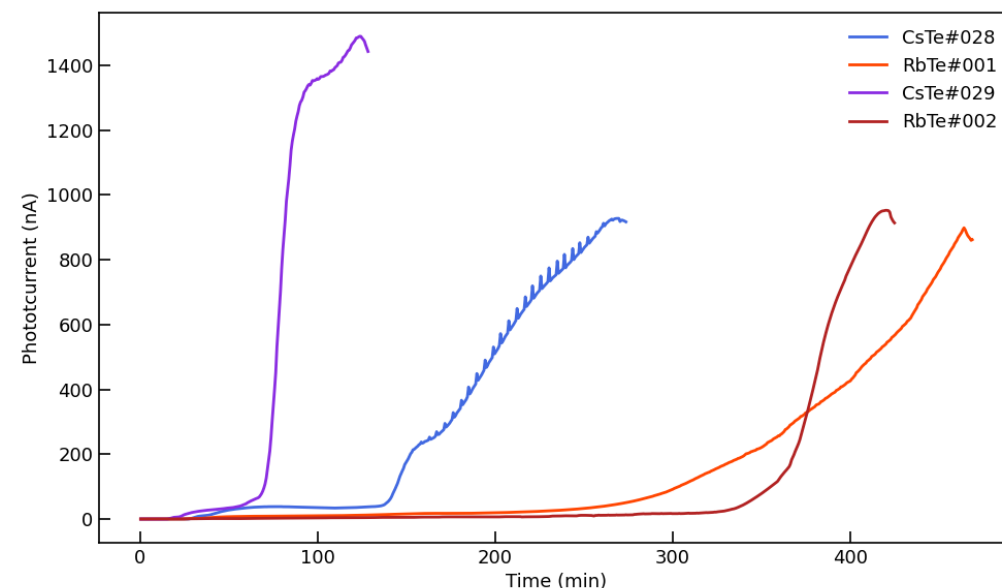
Could Rb-Te provide increased robustness and lower MTE in exchange for a moderate hit to QE?

Rb-Te (& Cs-Te) Depositions

Parameter	Order of deposition			
	Run #1		Run #2	
	CsTe#028	RbTe#001	CsTe#029	RbTe#002
Substrate Temperature	RT	RT	RT	RT
Tellurium thickness	20nm	10nm	10nm	10nm
Final photocurrent*	1007 nA	790 nA	1238 nA	797 nA
Final colour				

* Final photocurrent values are only comparable between runs – LED changes.

- 4 samples in 2 runs.
- **Colour:** Thickness seems more important than composition.
- RbTe#001: Deposition stopped before photocurrent decreased.



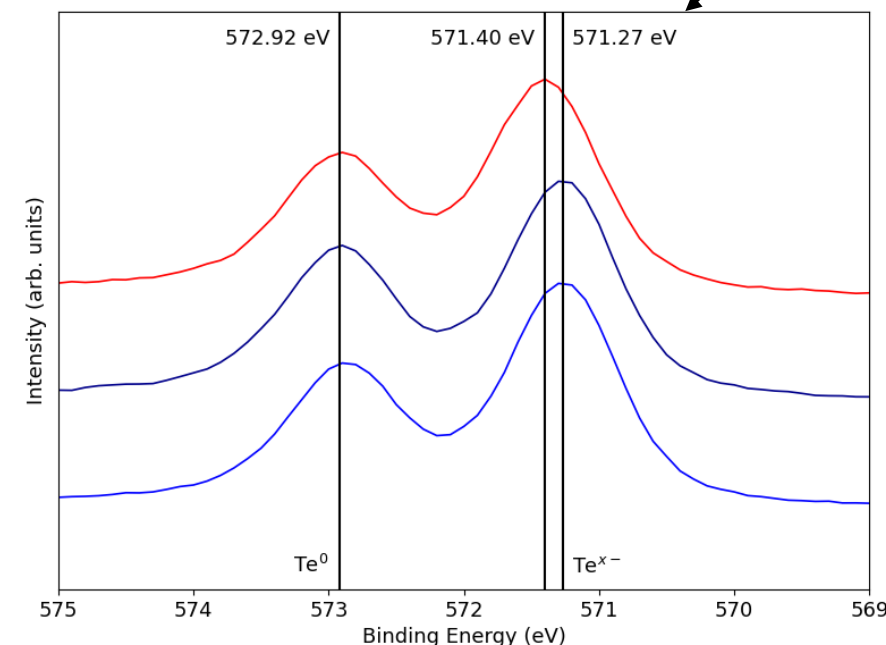
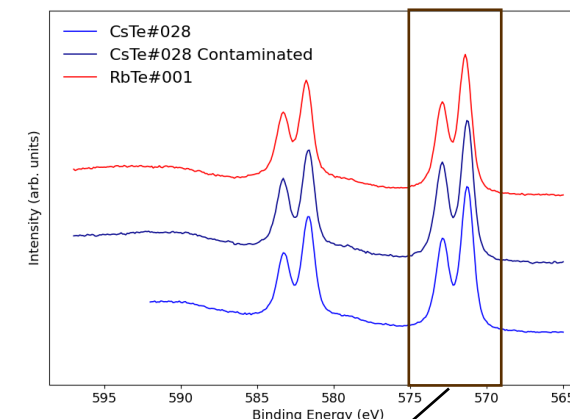
Photocurrent during alkali metal deposition

CsTe#028 and RbTe#001: QE and XPS

- CsTe#028 QE = 19.6%.
 - Fluorine contamination reduced it to 13.5% prior to additional measurements.
- RbTe#001 QE = 14.6%.

Element	Sample		
	CsTe#028 Post Dep	CsTe#028 Contaminated	RbTe#001 Post Dep
Tellurium (Te ⁰)	14.8 %	14.6 %	17.1 %
Telluride (Te ^{x-})	23.5 %	20.5 %	26.9 %
Caesium/Rubidium	59.6 %	57.5 %	56.0 %
Oxygen	2.1 %	3.5 %	-
Fluorine	-	3.9 %	-
Alkali : Te ^{x-} Ratio	~ 2.54 : 1	~ 2.80 : 1	~ 2.08 : 1
Alkali* : Te ^{x-} Ratio	~ 2.35 : 1	~ 2.27 : 1	~ 2.08 : 1
Te ⁰ : Te ^{x-} Ratio	~ 1 : 1.58	~ 1 : 1.41	~ 1 : 1.57

Tellurium core region scan

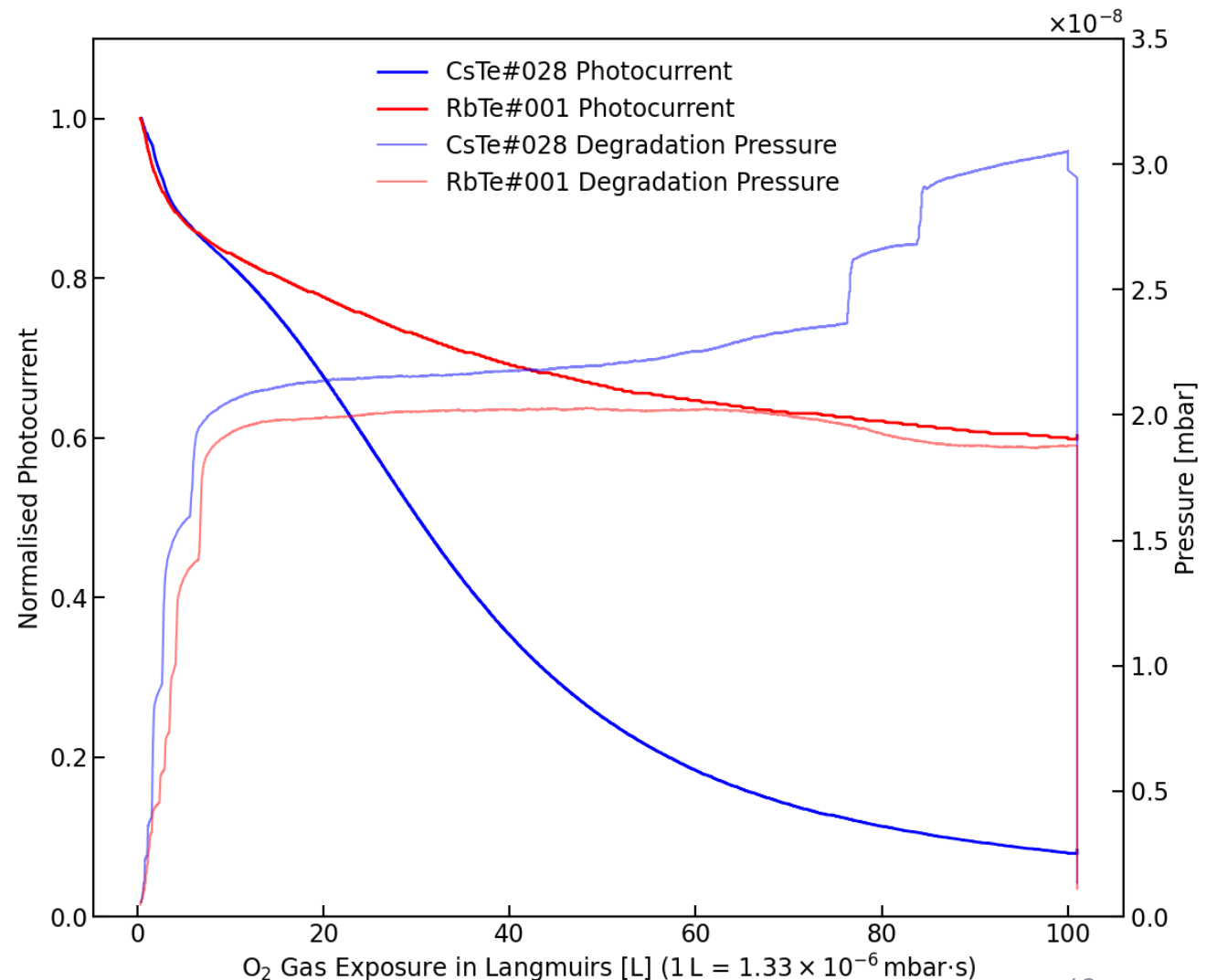


- ~ 0.13 eV greater shift of the telluride relative to the tellurium in Cs-Te vs Rb-Te.

CsTe#028 and RbTe#001: Degradation

- Base pressure $\sim 3 \times 10^{-10}$ mbar.
- 100 Langmuir oxygen exposure.
- RbTe#001: **40%** drop in photocurrent.
 - 14.3% $\rightarrow$ 8.5%
- CsTe#028: **92%** drop in photocurrent*.
 - 13.5% $\rightarrow$ 1.1%
- Some QE was recoverable upon heating for both samples.

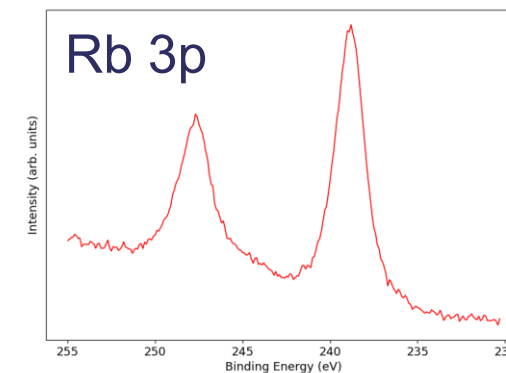
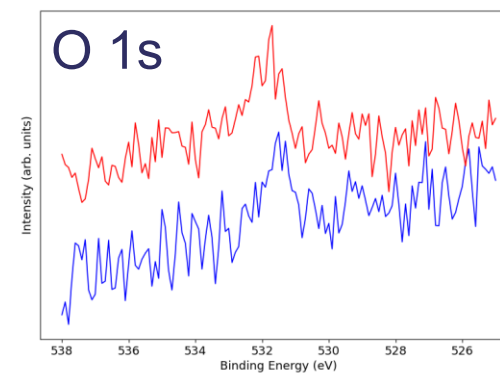
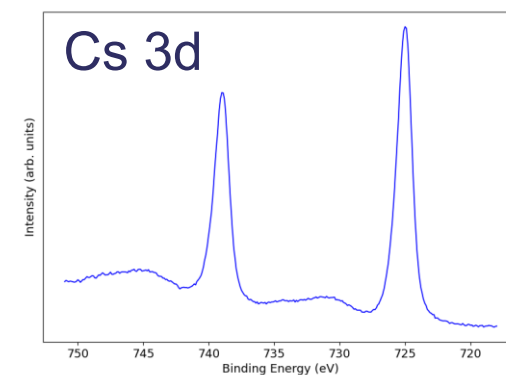
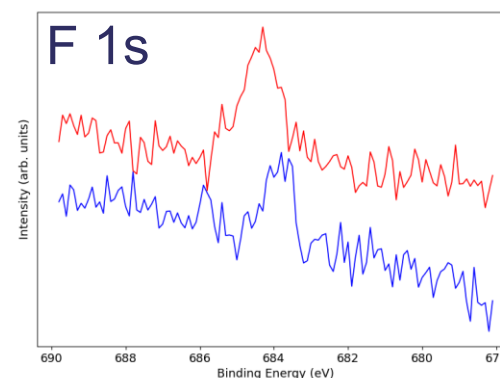
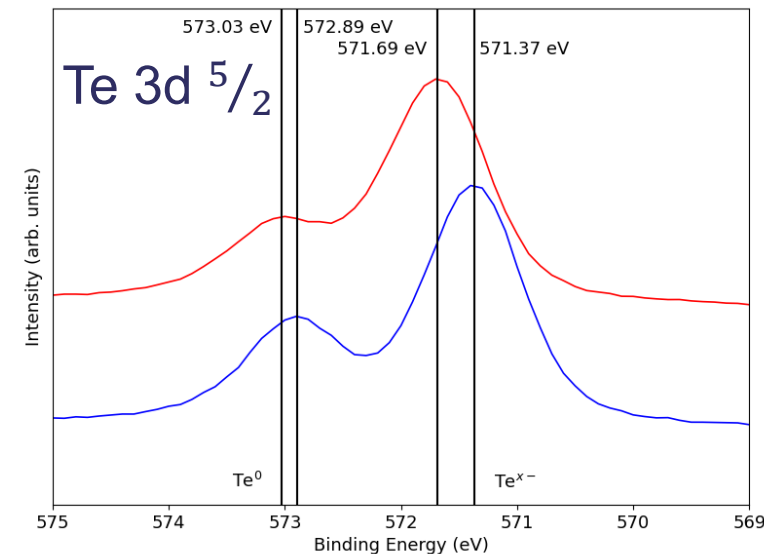
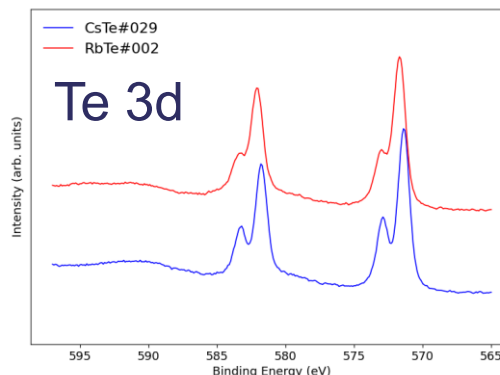
Degradation over 100 Langmuirs of oxygen exposure



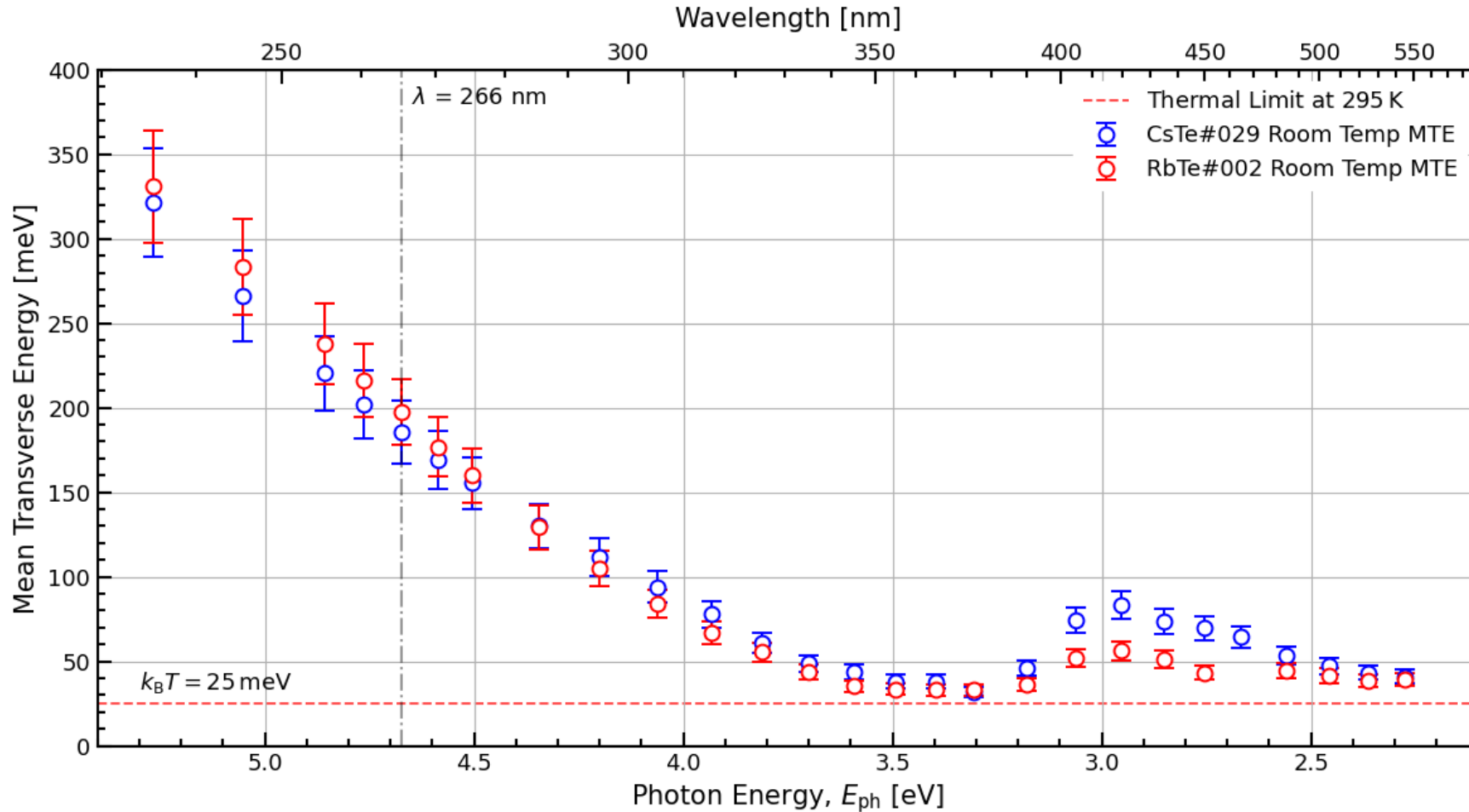
CsTe#029 and RbTe#002: QE and XPS

- CsTe#029 QE = 24.7%
- RbTe#002 QE = 16.7%

Element	Sample	
	CsTe#029 Post Dep	RbTe#002 Post Dep
Tellurium (Te^0)	10.9 %	9.7 %
Telluride (Te^{x-})	26.8 %	28.3 %
Caesium/Rubidium	60.2 %	57.3 %
Oxygen	1.1 %	1.8 %
Fluorine	1.0 %	3.0 %
Alkali : Te^{x-} Ratio	~ 2.25 : 1	~ 2.03 : 1
Alkali* : Te^{x-} Ratio	~ 2.13 : 1	~ 1.79 : 1
Te^0 : Te^{x-} Ratio	~ 1 : 2.46	~ 1 : 2.92

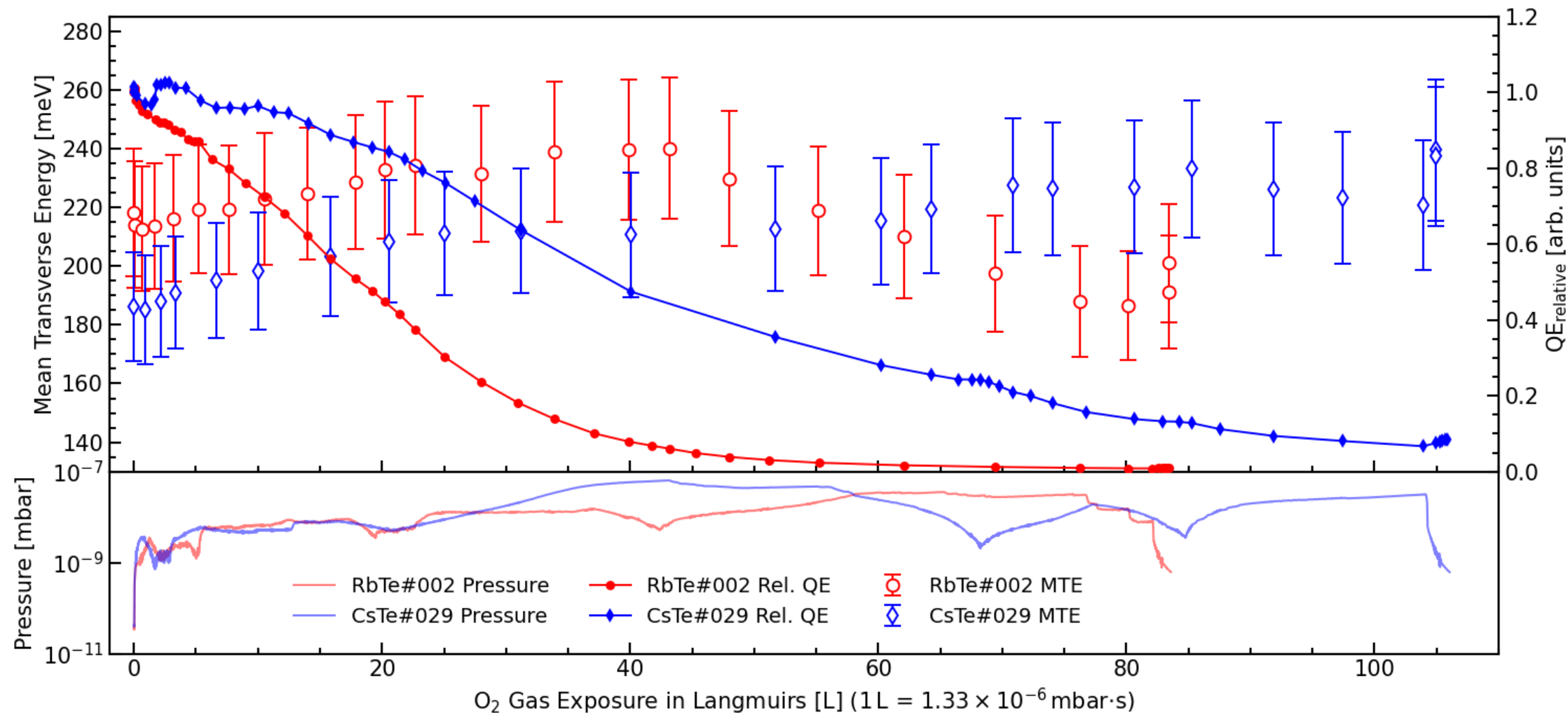


CsTe#029 and RbTe#002: MTE



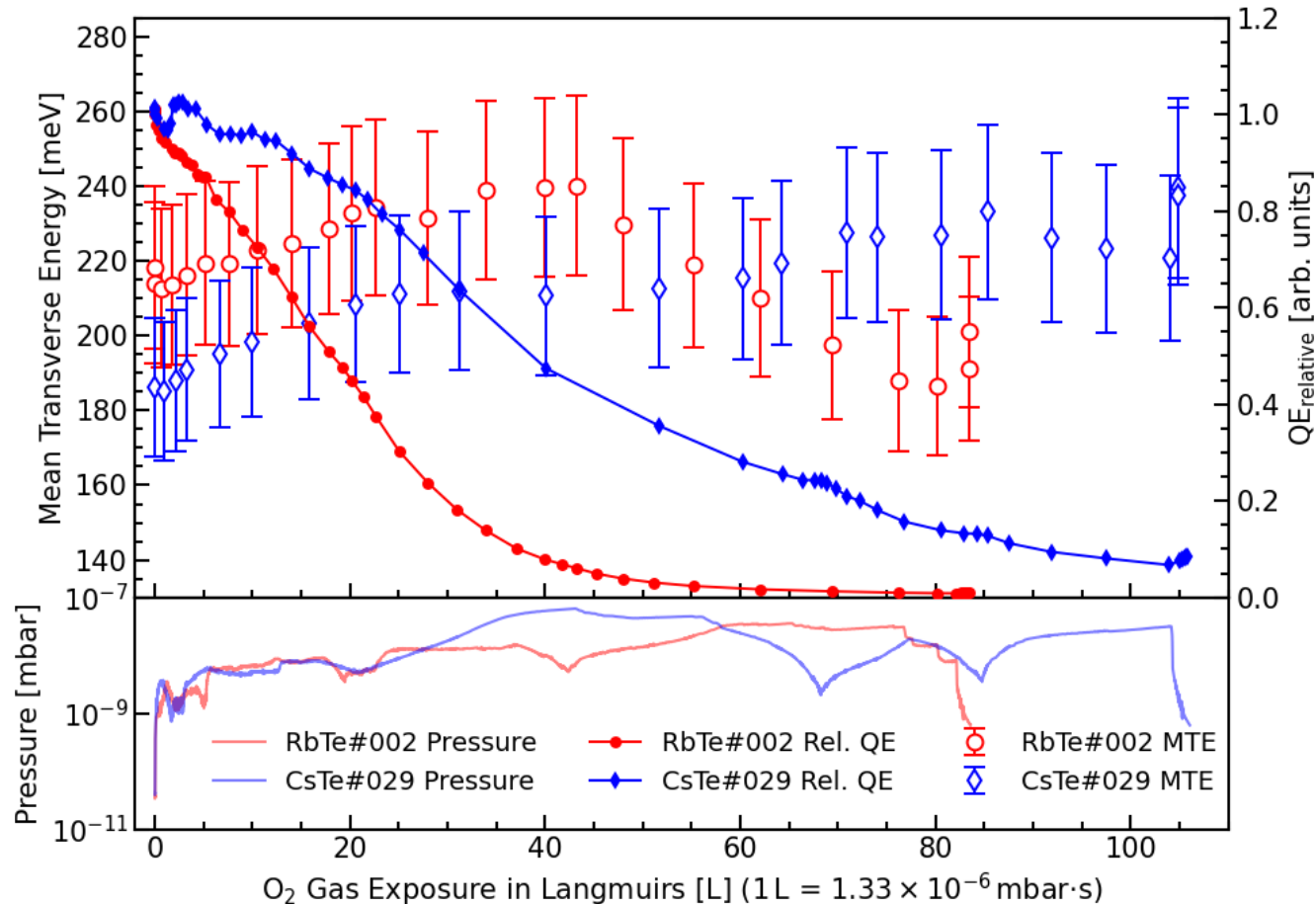
- MTE analysed in the TESS.
 - Jones et al. DOI: [10.1063/5.0109053](https://doi.org/10.1063/5.0109053)
- No noteworthy difference between the MTE of Rb-Te and Cs-Te.
- UV differences within error, slight divergence in the visible.

CsTe#029 and RbTe#002: MTE and Rel. QE Degradation at 266 nm



■ Base pressure ~ 3x10⁻¹¹ mbar.

CsTe#029 and RbTe#002: MTE and Rel. QE Degradation at 266 nm



- RbTe#002 degraded ~2x faster than CsTe#029.
 - Contradictory to direct QE data.
 - Cs-Te dropping ~90 % over 100 L is consistent.
- Starting RbTe#002 MTE higher than original 266 nm data.
 - Needs investigating.
- Consistent upward trend of the CsTe#029 MTE.
 - This matches previous data I have taken.
- RbTe#002 MTE trends upwards until QE nearly gone, then trends down.
 - Would CsTe#029 do the same if exposed to 200 L of oxygen?
- All changes modest when compared to error.

Conclusions and Caveats

Conclusions

- QE of Rb-Te approximately 0.1 lower than Cs-Te (25 % vs 15 %) **but still high!**
- Rb-Te more resistant to O₂ degradation!?
- Modest QE recovery possible with heating.
- MTE of Rb-Te and Cs-Te is the same within error at UV.
- MTE evolution under O₂ degradation differs between Cs-Te and Rb-Te.

More research required!

Caveats

- **Only two Rb-Te samples!!!**
- RbTe#001 was stopped pre photocurrent peak.
- Mild fluorine contamination might be influencing results.
- Simple room temperature sequential deposition recipe used. Results may vary with:
 - Optimised substrate temperatures
 - Different thicknesses
 - Multilayer or co-depositions
 - Epitaxy
- Inferred QE degradation (TESS) and direct QE degradation measurements disagree.

Summary

- Caesium telluride successfully running in CLARA.
- Features appear on the caesium telluride during RF conditioning.
- QE is trending downwards but remains sufficiently high.

- Rb-Te has a high QE, but less than Cs-Te.
- Yet may be more robust to O₂ degradation.
- Preliminary MTE measurements show no discernible difference.

Photocathode Team:

Hugh Churn, Saransh Malhotra, Tim Noakes & Lee Jones

Recent Past Members:

Chris Benjamin, Dominic Sterland & Felix Mildner

+ the wider CLARA team

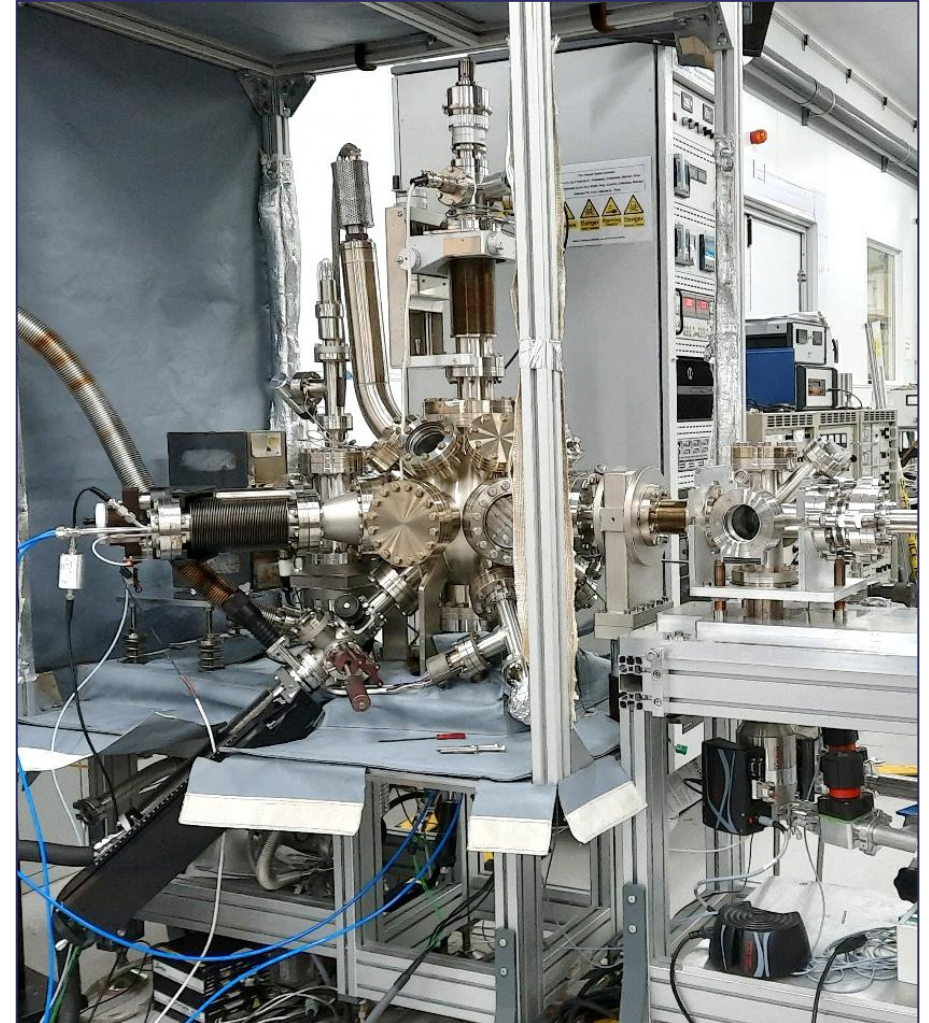
hugh.churn@stfc.ac.uk

Questions?

Extra Slides

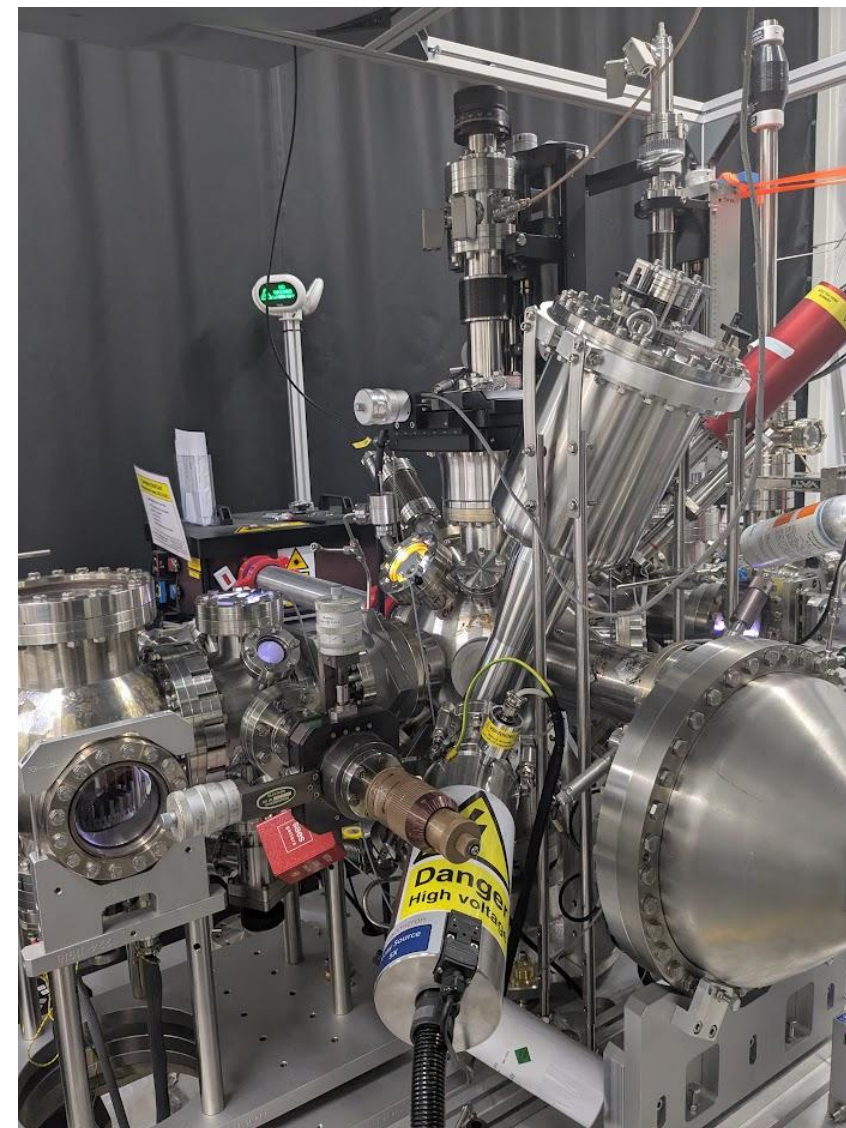
Alkali-metal Photocathode Preparation Facility (APPF)

- Can be swapped between Omicron flag samples and CLARA INFN plug cathodes.
- Low $\times 10^{-10}$ mbar base pressure.
- Tellurium deposition via thermal sublimation with optional cracker stage.
- Caesium deposited via Saes Alkamax pills. Thermal decomposition of caesium molybdate.
- Quartz crystal microbalance to measure deposition rate.
- Photocurrent monitored via 265 nm LED.
- Camera and internal halogen lighting takes images every 5 minutes.

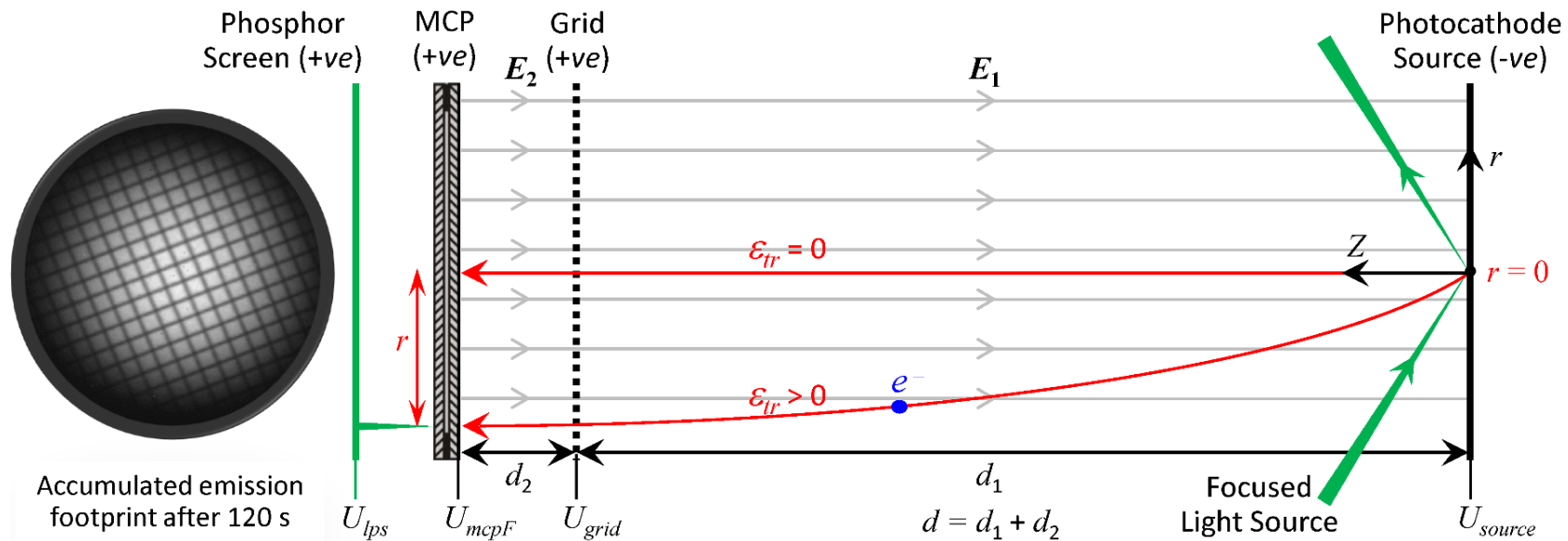


Multiprobe

- Surface analysis R&D on Omicron flag samples.
- Surface composition via X-ray Photoelectron Spectroscopy.
 - Monochromated aluminium X-Ray source.
 - Dual anode (Mg and Al) Un-monochromated X-Ray source.
 - Refurbished Thermo Alpha 110 hemispherical analyser.
- High precision QE measurement.
 - Pulsed 266 nm laser, high voltage anode and lock-in amplifier.
- Surface Topography.
 - Atomic Force Microscopy.
 - Scanning Tunnelling Microscopy.
- Modifiable to include ultraviolet photoelectron spectroscopy and low energy electron diffraction.
- Dedicated deposition chamber for further R&D.



Transverse Energy Spread Spectrometer (TESS)



- Laser-driven plasma broadband light source and monochromator provides incident light from deep UV to near infrared.
- Electrons are emitted from a tightly focussed spot on the cathode at very low currents to avoid space charge.
- Electrons are accelerated through a known distance and potential.
- Multichannel plate amplifies the signal then we image the fluorescence of a phosphor screen.
- ~100s exposure records all possible transverse energy components.
- Extremely low base pressure (3×10^{-11} mbar) and a piezoelectric leak valve allow for fine control of gas composition during experiments.

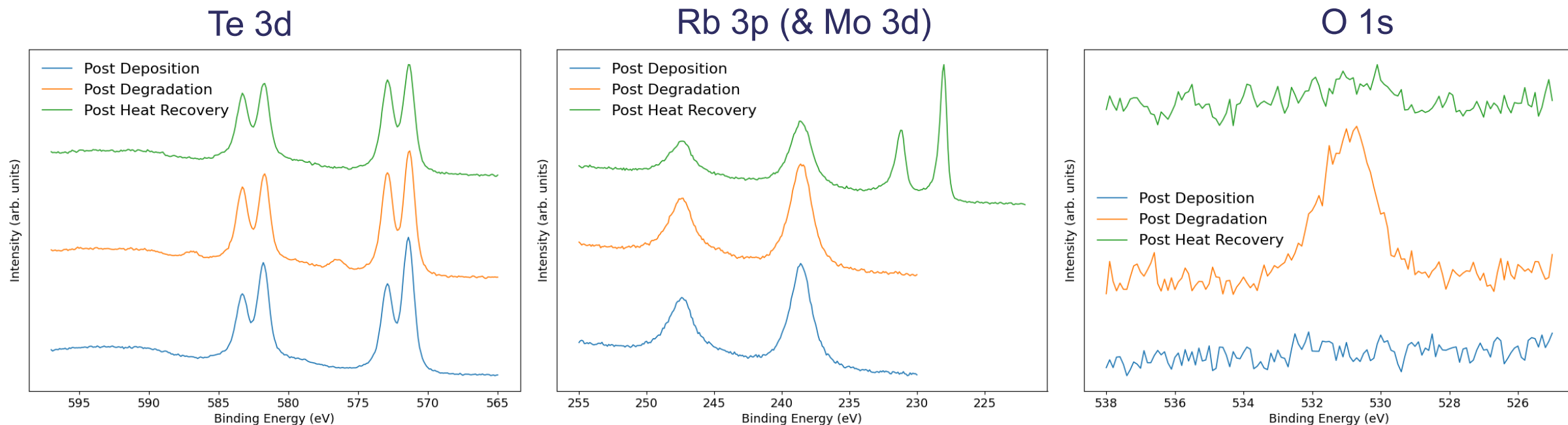
List of Rb-Te Sources

- V. Denisov and I. Klimin, “Photoelectric properties of rubidium telluride films”, *Radio Engineering and Electronic Physics*, vol. 23, Feb. 1978, p. 114-116. (1978)
- L. Dunkelman et al., “Spectrally Selective Photodetectors for the Middle and Vacuum Ultraviolet”, *Appl. Opt.* 1, 695-700 (1962)
- H. Trautner, “Spectral Response of Cesium Telluride and Rubidium Telluride Photocathodes for the Production of Highly Charged Electron Bunches”, PhD Thesis (2000)
- E. Taft and L. Apker, “Photoemission from Cesium and Rubidium Tellurides”, *Journal of the Optical Society of America* Vol. 43, Issue 2, pp. 81-83 (1953)
- M. Polyakova and D. Zernov, “The photoelectric and optical properties of the tellurium–rubidium photocathode”, *Radio Engineering and Electronic Physics*, 11, No. 6 (1966)
- C. Benjamin et al., “Rubidium telluride photocathodes for high quantum efficiency and low mean transverse energy accelerator applications”, *JACoW IPAC2024 (2024)*, WEPC71 (2024)
- X. Zhang et al., “Spectral response characteristics of transmission-mode alkali telluride photocathodes working from vacuum-ultraviolet to ultraviolet band”, *J. Vac. Sci. Technol. B* 35, 061202 (2017)

Not Rb-Te, but interesting:

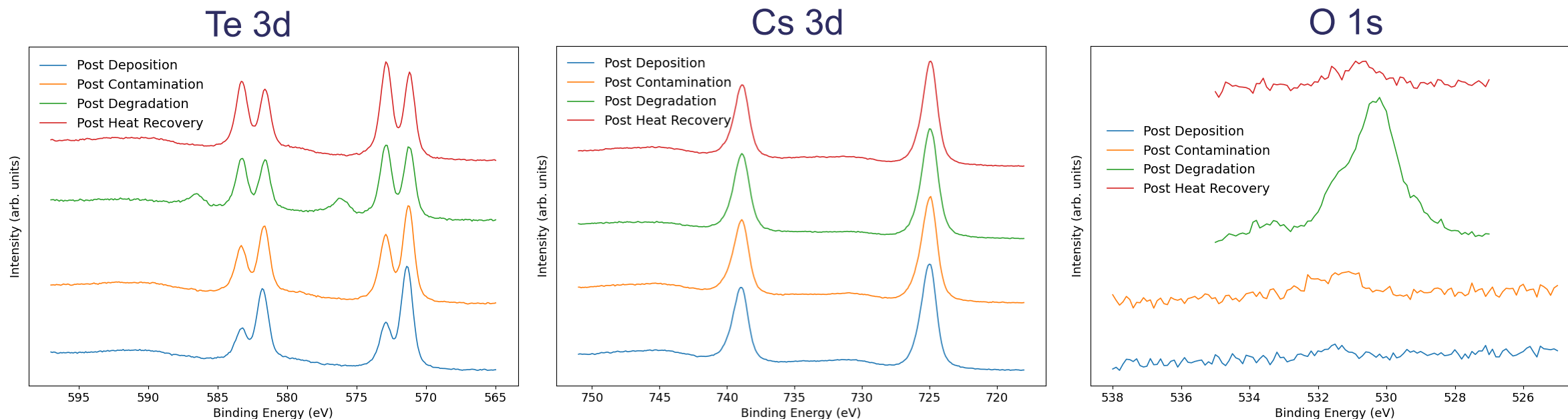
- L. Cultrera et al., “Rb based alkali antimonide high quantum efficiency photocathodes for bright electron beam sources and photon detection applications”, *J. Appl. Phys.* 121, 055306 (2017)
- D. Bisero et al., “K₂Te photocathode growth: A photoemission study”, *J. Appl. Phys.* 87, 543–548 (2000)

RbTe#001 Degradation XPS



- Heat Recovery: Progressively increased heating to ~12 W over ~2.5 hrs until photocurrent started to decrease.
- QE: 14.6 % → 8.5 % → 11.7 %
- Degradation increases tellurium, decreases telluride, small amount of tellurium oxide appears.
 - Oxygen pulls rubidium out of rubidium telluride into rubidium oxide?
- Sample thinner after heating, Mo 3d appears.
- Oxygen almost entirely removed by heating.

CsTe#028 Degradation XPS



- Heat Recovery: Progressively increased heating to ~8.5 W over ~3.5 hrs until photocurrent started to decrease.
- QE: 19.6 % → 13.5 % → 1.1 % → 2.9 %.
 - But no noticeable change after heat recovery on the lesser degraded spot at 5 % QE.
- Degradation increases tellurium, decreases telluride, small amount of tellurium oxide appears.
 - Oxygen pulls caesium out of caesium telluride into caesium oxide?
- No Mo 3d (or 3p) on survey to indicate thinning, but sample did start off thicker (20 nm of tellurium).
- Oxygen levels substantially lowered by heating.