Work Function and Quantum Efficiency Studies on Cesium Telluride

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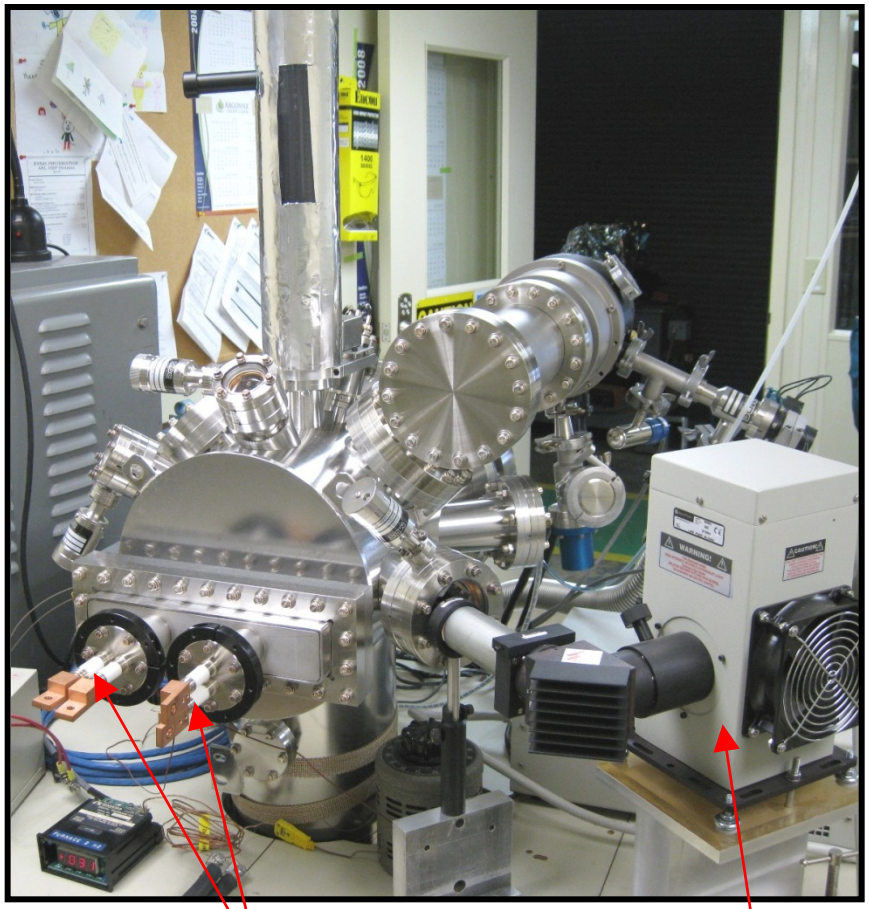
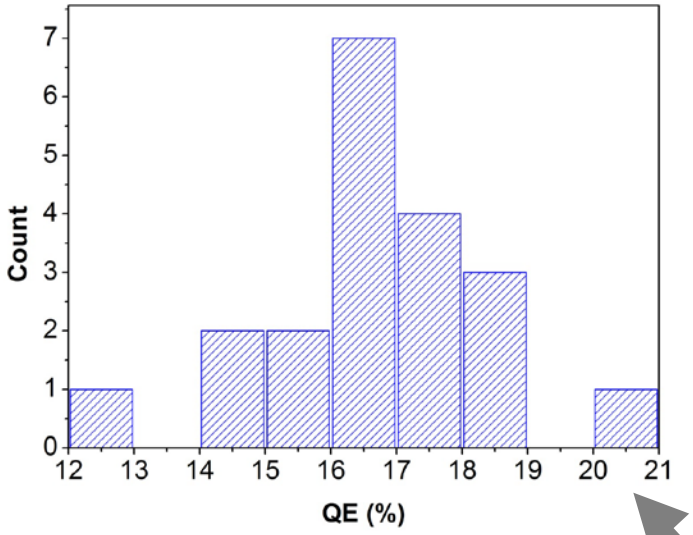
Motivation

- Argonne Wakefield Accelerator (AWA) upgrade requires production of electron bunch train consisting of 20 bunches, at 40 nC per bunch;
- This requires a high-QE photocathode (~1 %) – choose cesium telluride which has been shown to be robust in a photoinjector, and maintain QE > 1% for a considerable period of time;
- Perform studies on the QE and work function of cesium telluride to understand the properties of the photocathode – possibly improve on its performance;
- Results from this study may shed light on other high-QE photocathode, especially on the possible transient changes to the photocathode due to light exposure.

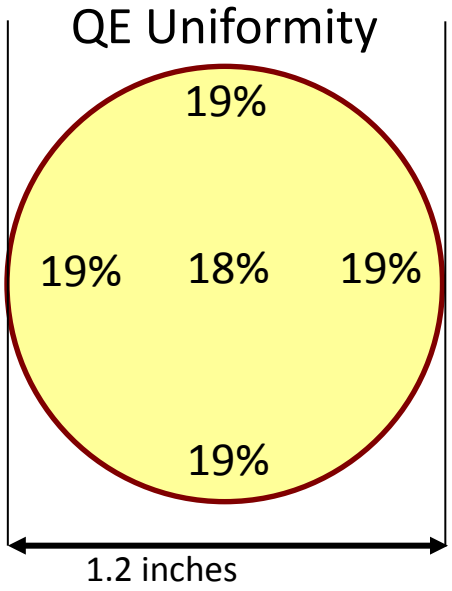
Cesium Telluride Production at the AWA

Photocathode Fabrication Chamber





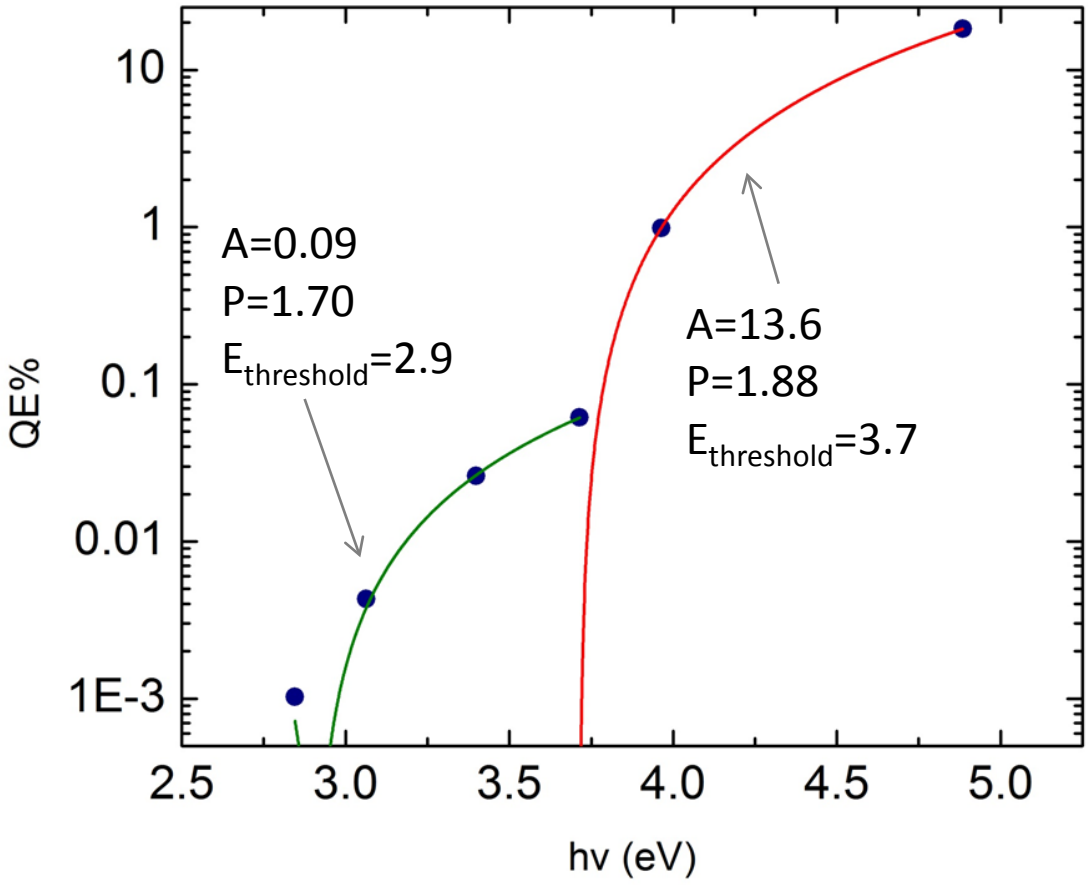
Peak QE histogram of photocathodes produced since 2010.



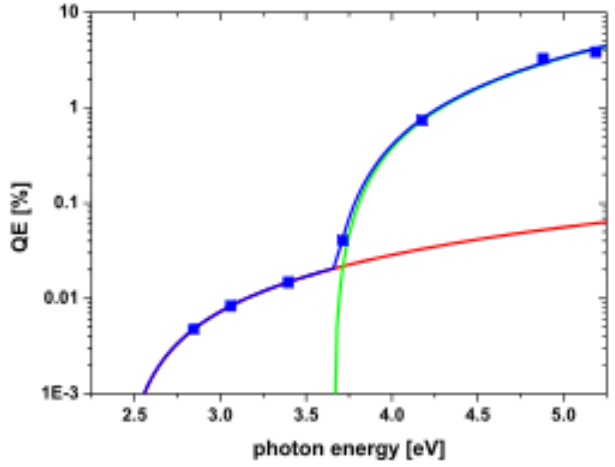
QE uniformity across the photocathode surface deposited on Mo plug. QE measurement error is ±1% absolute.

QE Scan at Various Photon Energies

Fit function: $QE \approx A(h\nu - E_{threshold})^P$



QE scan produces result similar to those previously published.



S.Lederer et al., Proc. EPAC08. 232-234.

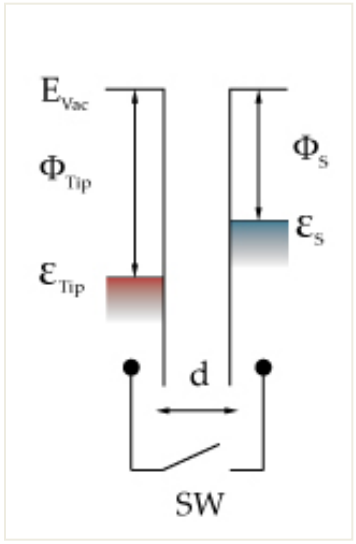
Work Function Measurement Using the Kelvin Probe

1. Two metal plates, different work functions ϕ_1 and ϕ_2
2. Upon contact, charge transfers and Fermi levels align:

   $\Delta\phi = |\phi_1 - \phi_2| = eV_{CPD}$
3. Apply a *backing* potential V_b. Vary until there is no electric field between plates
   - Null point-zero current crossing corresponds to the contact potential difference (CPD)

Important Note: For a semiconductor, the Kelvin probe method measures the Fermi Level with respect to the vacuum level, not the photoemission threshold. This is what we define as the "work function" for a semiconductor.

1.



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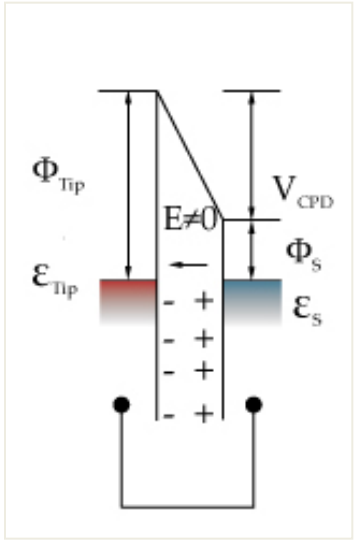

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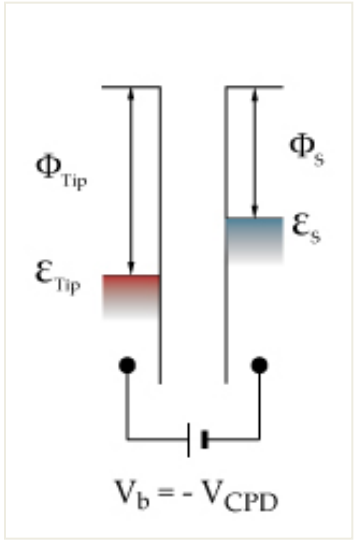
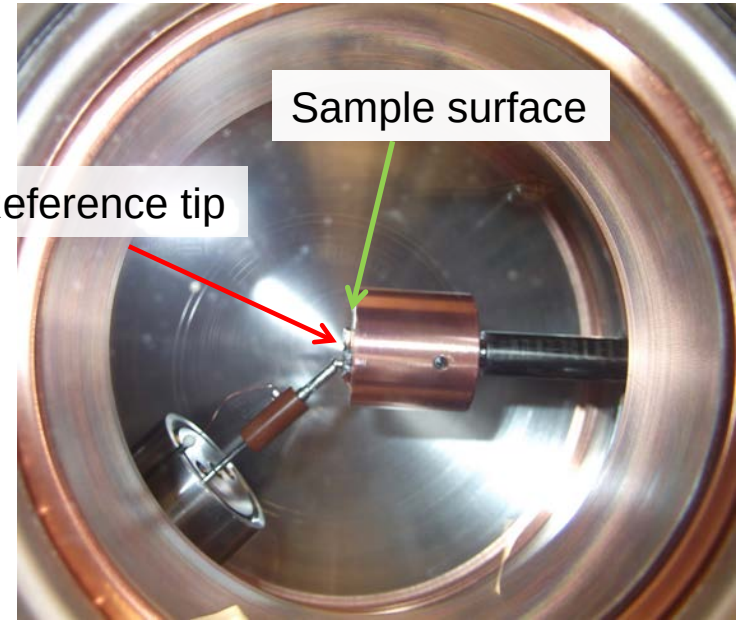
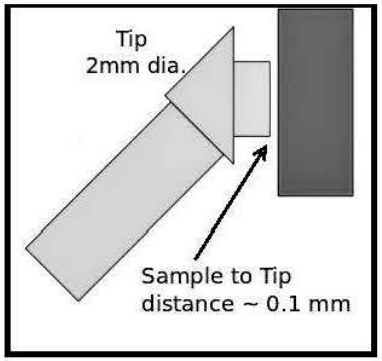


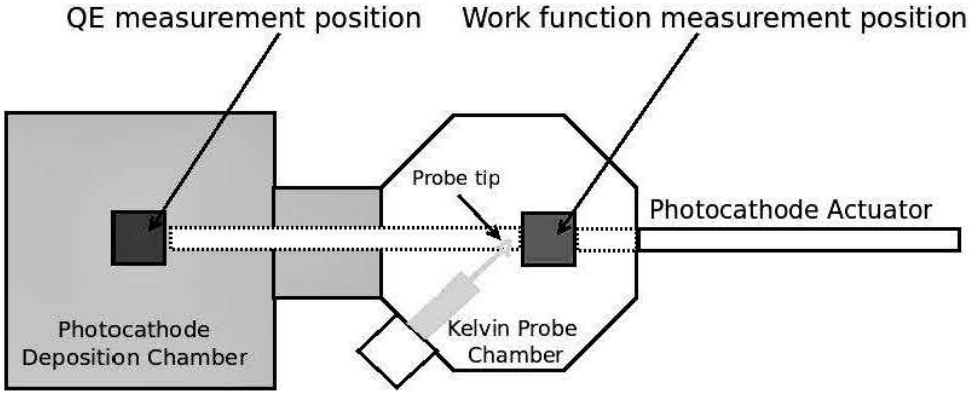
Experimental Setup

- The KP is inserted at a 45° angle with respect to the sample surface
- A customized 45° tip is used
- Tip Work Function calibrated value 4.6 ± 0.1 eV



Top View



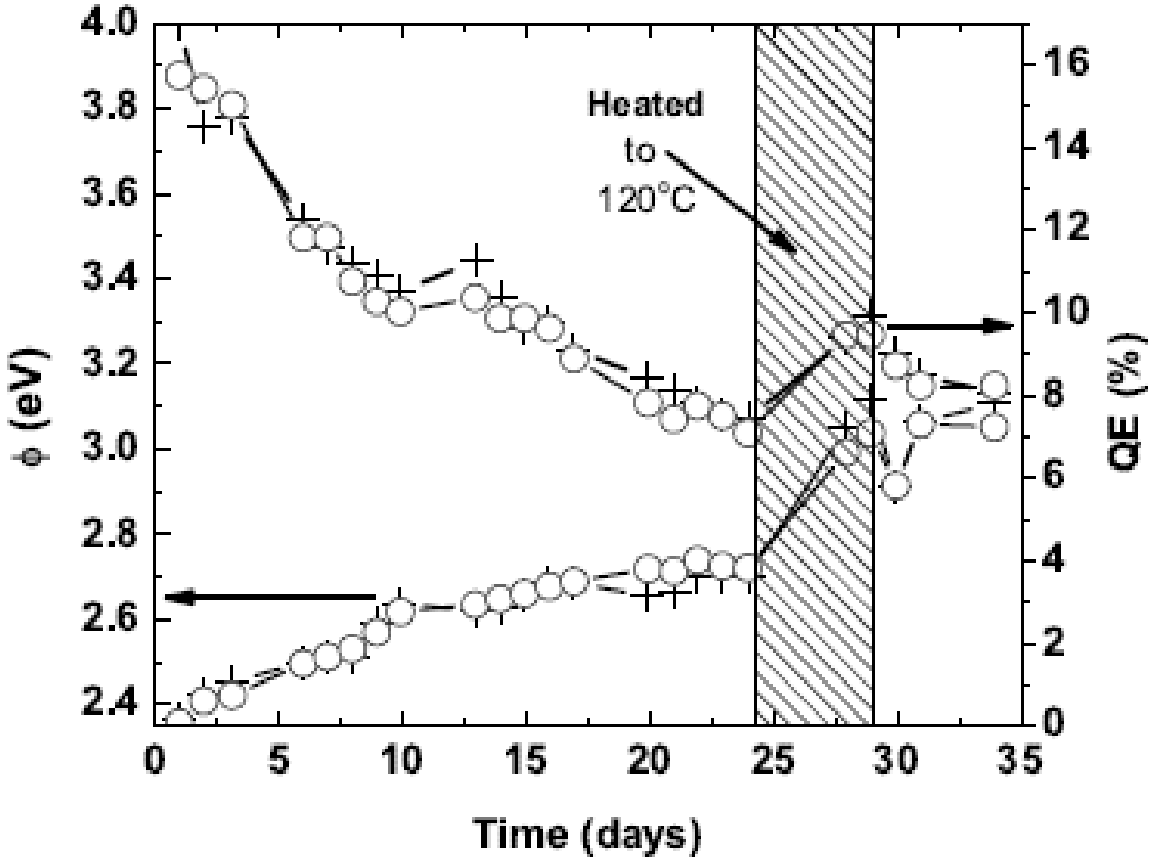


QE and Work Function Over Time

- QE declines with age.
- This corresponds to an increase in work function – consistent with previous data.
- We perform cathode rejuvenation by heating the photocathode at 120° C for ~4 days.
- **The Puzzle:**

  QE increases but work function ***does not track as expected.***

Aging effects at two different points on photocathode

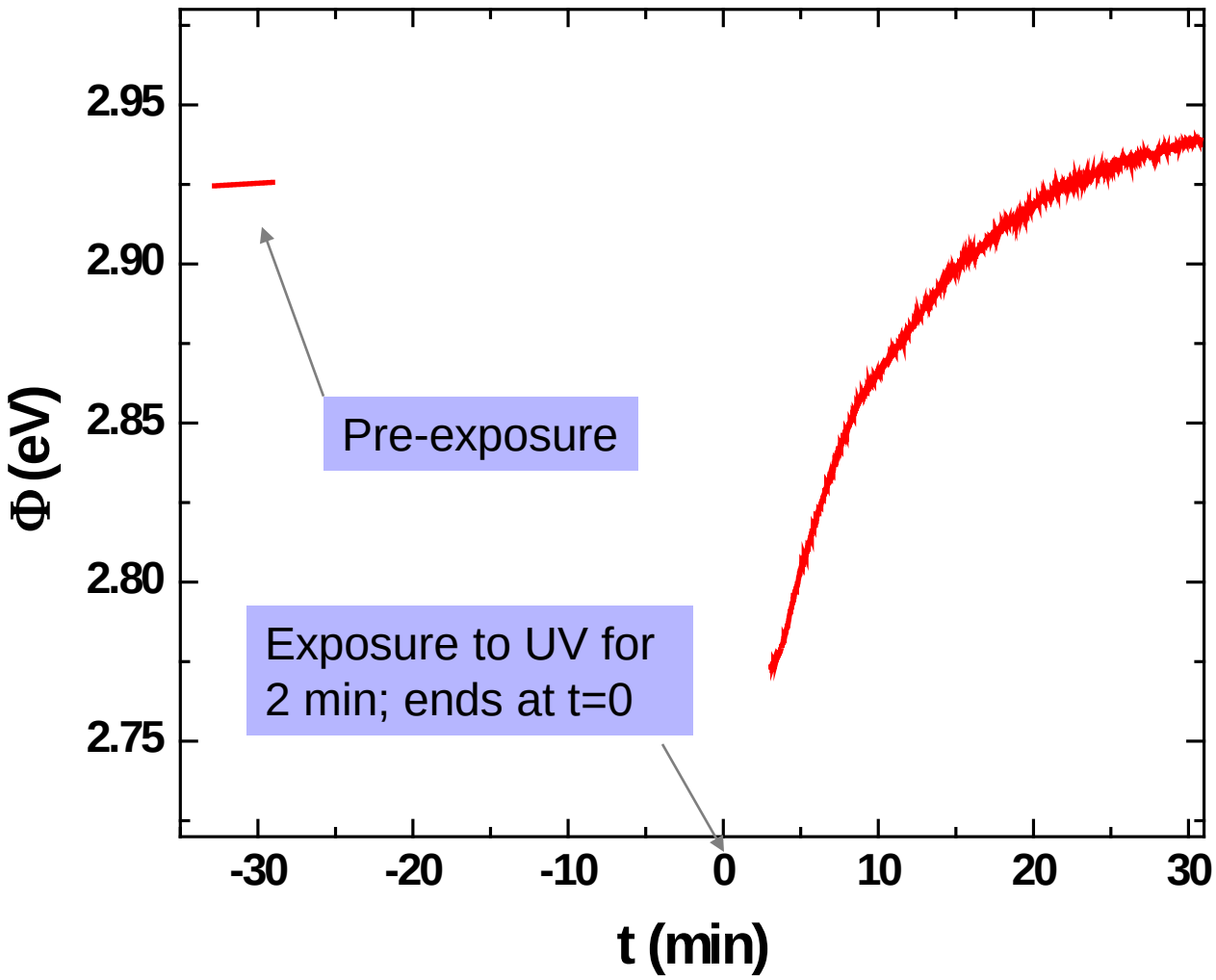


- Possible reason:

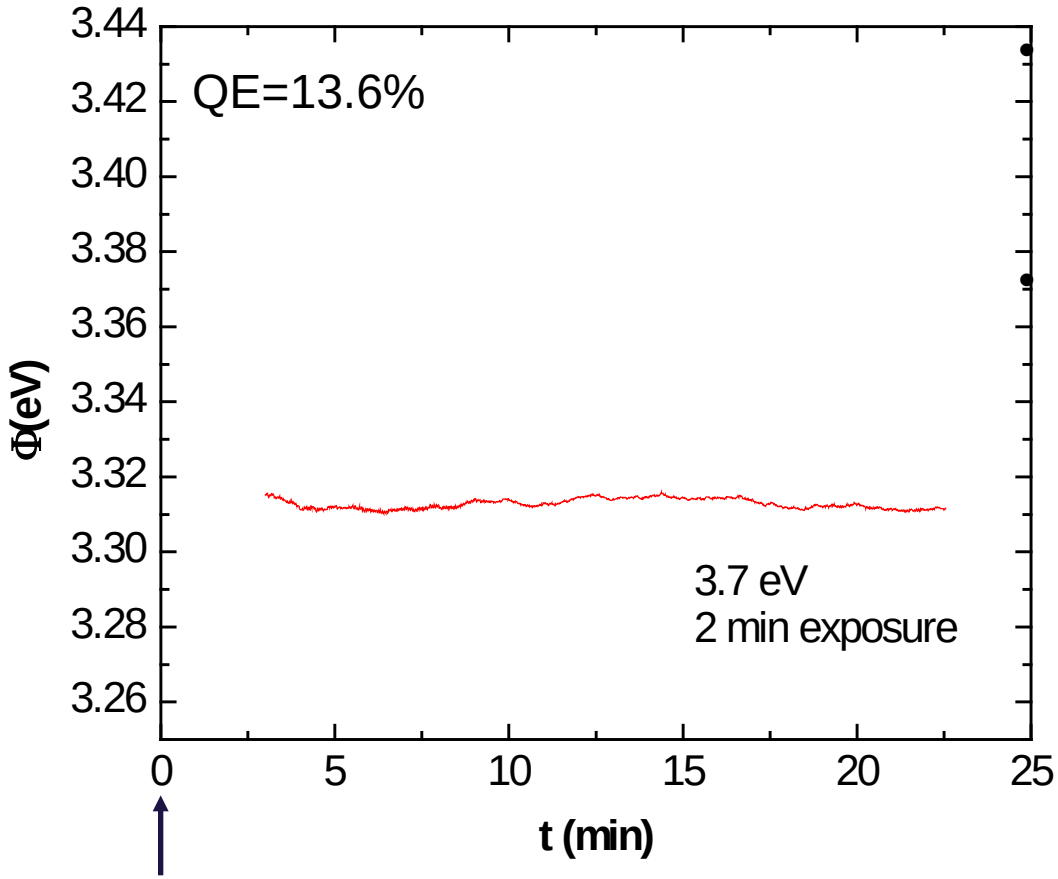
  As the photocathode ages, there is a change in chemistry. It may not be the same surface material as before. We will investigate this further.

Exposure to 4.9 eV Light

- UV exposure (4.9 eV) significantly reduces work function – this was unexpected
- Effect is temporary.
- What might this mean for the QE?
- Based on the fit,
  $\Delta\Phi$ ~150meV
  $\rightarrow \Delta QE \sim 2\%$



Exposure to 3.7 eV Light – No Significant Work Function Reduction



Both 3.7 eV and 4.9 eV are *above* photoemission threshold

Interestingly, diBona et al. reported that rejuvenation of QE only occurs with heating AND 4.9 eV UV exposure. Exposure to 3.7 eV did nothing*

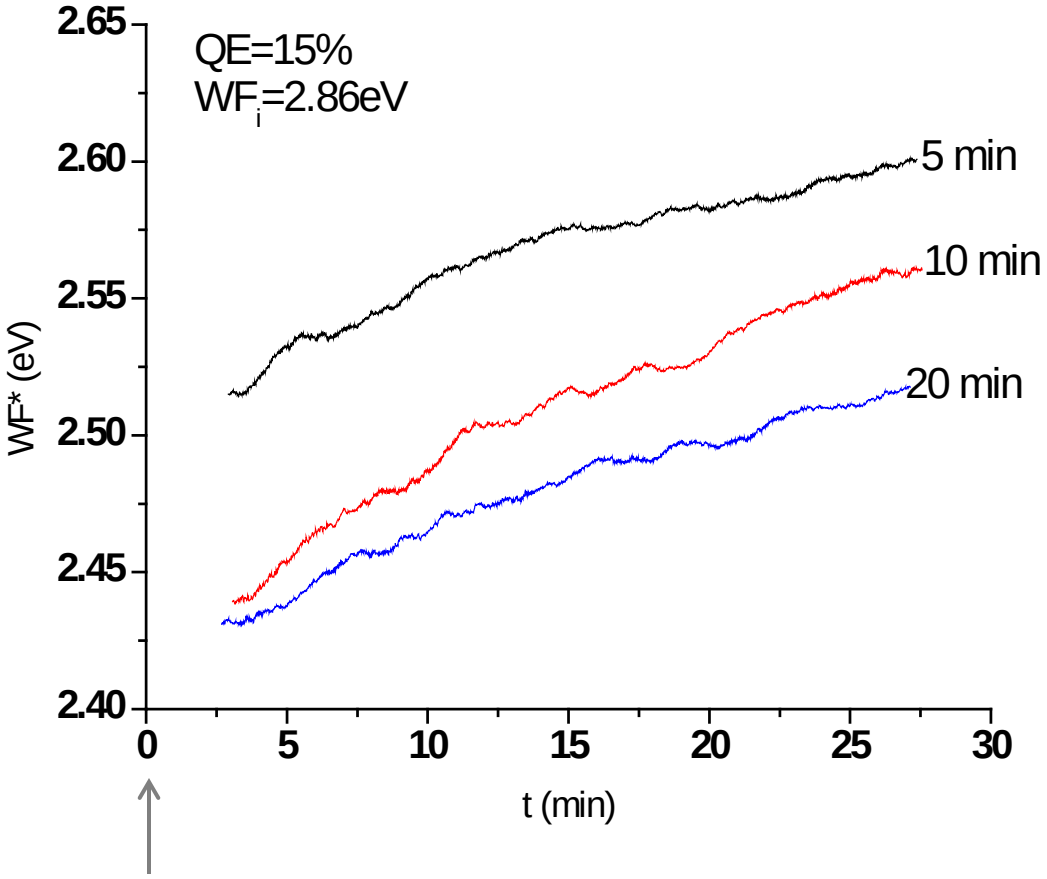
*References:
di Bona et al. J. Appl. Phys. 80, 3024 (1996)
Kong et al. NIMA 358,284 (1995)

Work Function Reduction With Exposure Time

- Longer exposure time → larger work function reduction (150-400 meV).
- Work function reduction maxed out after ~20 min exposure.

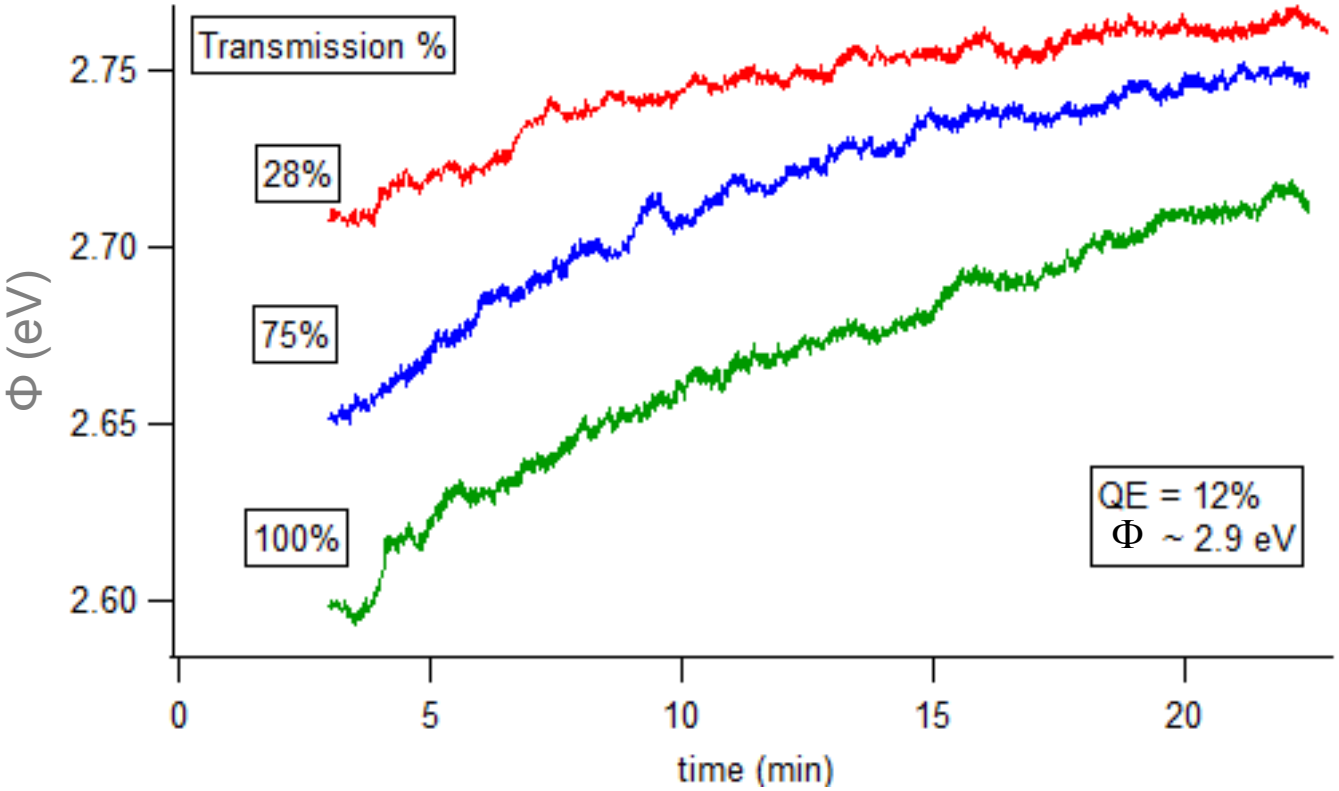
From the previous fit,
5 min exposure:
ΔΦ ~300meV
→ ΔQE ~ 6%

10-20 min exposure:
ΔΦ ~420meV
→ ΔQE ~ 7%



Work Function Reduction With Photon Intensity

- Filters were used to reduce intensity.
- Work function reduction increases with increasing UV light intensity.



Summary

- We have used the Kelvin probe technique to measure the work function of Cesium Telluride photocathodes produced in-house (total 6 cathodes studied).
- We observed a correlation between Quantum Efficiency and Work Function.
  - Cathode aging – QE and Φ vs. time behaves as expected before rejuvenation by heating.
  - Heating raises the QE without reducing Φ – further study is required.
- 4.9 eV UV light exposure temporarily reduces the work function. This effect is dependent on exposure time and intensity. 3.7 eV UV light did not produce this effect. *Further study is required – similar observation on ITO attributed to either charging effects or photochemistry.*

Measurement of the Contact Potential Difference

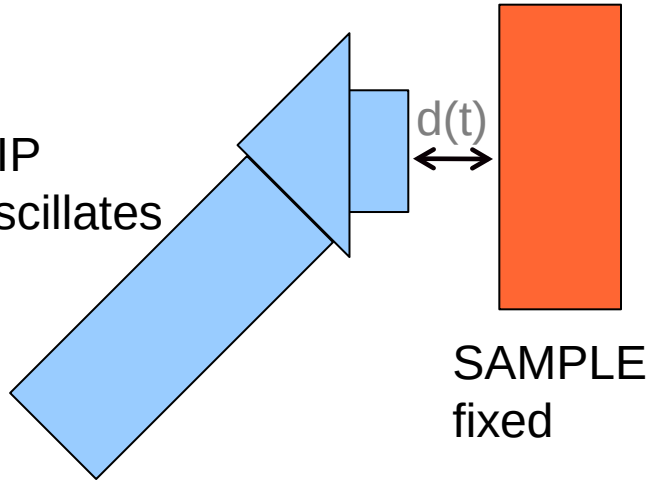
- In a Kelvin probe, tip and sample form a parallel plate capacitor

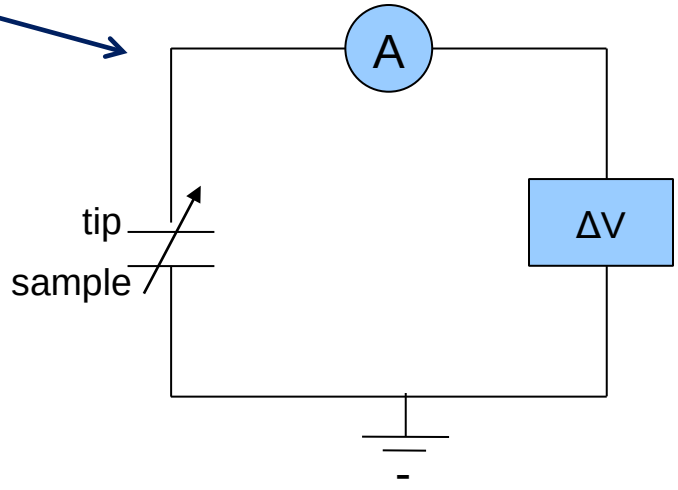
$$C = \varepsilon\varepsilon_0 \frac{A}{d}$$

- Vary the tip-to-sample distance sinusoidally

$$d(t) = d_0 + d_1 \sin(\omega t)$$

- This creates a circuit with variable capacitance





- The current in the circuit varies according to

$$i(t) = \frac{dQ}{dt} = \Delta V \frac{dC}{dt}$$

- Where

$$\Delta V = V_b + V_{CPD}$$