Lee Teng Project Proposal

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under the mentorship of
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1 Project Objective

The purpose of my project is to investigate the electron emission characteristics - the quantum efficiency and the work function - of Cesium Telluride photocathodes in different stages and methods of development. These photocathodes are the electron sources in use at the Argonne Wakefield Accelerator facility and optimizing their emission capabilities can increases their lifetimes for the accelerator. This study may even add to our overall understanding of the physics of photcathodes. We will primarily be focusing on how these properties evolve we form the the photocathode through the deposition of Cesium on the Tellurium substrate and the effects of rejuvenating (heating) the photocathode at different times after it is fully formed.

The figures of merit we associate with our photcathodes are their quantum efficiency and their work function. The quantum efficiency is the ratio of electrons released vs photons put in which we just measure in the formation chamber itself using a mercury lamp as our photon source and the work function is the energy difference between the Fermi energy. The Vacuum energy (or the energy to escape the Conduction Band) which we measure using a Kelvin Probe which we can attach to the deposition chamber and then use an actuator to reposition the sample for measurement. The formation and measurement of the photcathodes must all be done in ultrahigh vacuum, so I will also have to learn how to reach and sustain 10^{-10} Torr in our deposition chamber.

Our first objective will actually be looking at the effects of heating the photocathoode a day after it is fully formed. Previous studies [1] give early indicators that the quantum efficiency of these photcathodes decays significantly slower when subjected to heating at 120 C another day immediately after fabrication. With the Kelvin probe now functional, we want to now take work function measurements to see what effect this process incurs and how it correlates to the change in quantum efficiency; for metals the two properties are inversely related but this may or may not be the case for our CsTe sample.

The next endeavor is to get quantum efficiency and work function measurements while the deposition is occurring. All measurements heretofore have been done on the completed sample, but to better understand how the emission capabilities of our photcathodes develop we would like to see how the properties of the CsTe evolve as we build up, primarily, the Tellurium layer. We may also encounter false effects due to the start (measure) stop procedure now introduced and this impact, if significant, must be noted and corrected for.

These studies will further our understanding of CsTe photcathodes so that we may optimize their design and application.

2 Cesium Telluride

For new age accelerator technology large electron beam currents are often required. For example the Argonne Wakefield Accelerator(AWA) requires a high current primary beam to excite high gradient wakefields in the dielectric encased cavities (through Cherenkov radiation) so that a witness beam (which will actually be used for the experiments down the pipeline) can be accelerated by these wakefields. These primary electrons are sent into the beam line by the photoinjector and the source of these electronics is a photocathode. Photocathode devices work through the photoelectric effect in that when they are irradiated by light over some threshold frequency, they emit electrons. The new upgrade of the AWA wants to produce 64 bunch trains of primary electrons at 50nC each and it is designed to do this by splitting a 5 eV, 10 mJ laser into 64 separate pulses then delivering them in a delayed sequence to the photocathode. (see Fig 1.) However each pulse is thus significantly weaker, so the photocathode must be designed to emit a higher number of photoelectrons for a weaker input power or more electrons/sec out for less photons/second in - the ratio of the two is quantified by the quantum efficiency or QE. Calculations for the new upgrade show that a QE of above 1% is required - which is significantly higher than the $10^{-4\%}$ QE magnesium photcathodes (typical for a metal) that has heretofore been used by the AWA.

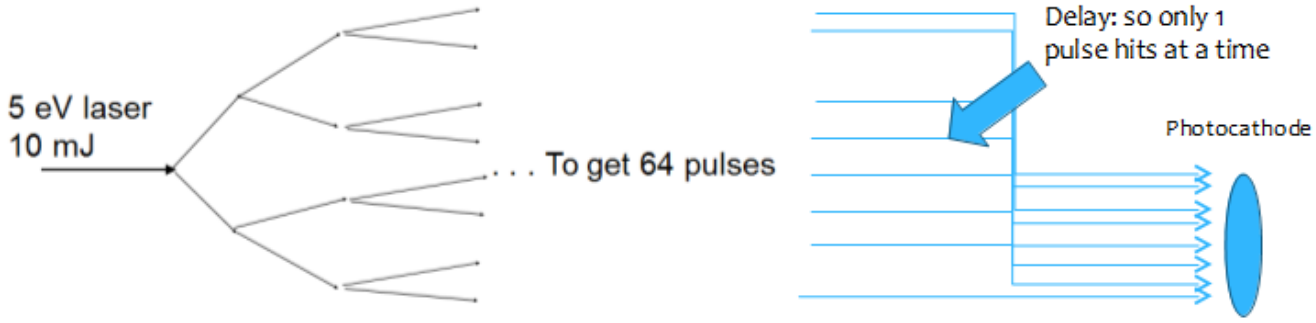

Figure 1: Shown is the equivalent circuit for the Kelvin probe setup with the tip - sample parallel plate configuration depicted as a variable capacitor, the applied ΔV as the backing potential, and an ammeter in series to measure the current.

Our group has shown that significantly higher QE can be attained with Cesium Telluride Photocathodes, which our results have shown to exhibit a typical initial QE around $10\% - 18\%$ (shown in Fig. 2) and are consistently above 1% in QE for at least a month - in fact they are still at 6%by then. These photcathodes do require a careful design process, spanning approximately 1 1/2 weeks and requiring ultrahigh vacuum systems (10^{-10}Torr). The end result is a bluish green film approximately 200 $\mathring{A}$ an 3.5 cm in diameter. This film is deposited on a Molbydenum plug - a Molybdenum doesn't react with Cesium as much as our normal copper substrates. This plug is polished down smooth to the .25 micron scale with liquid diamond - though with our new polisher table we can get this it down to .05 micron scale; the liquid diamond's complex crystalline structure allows it to smooth out the layers of molybdenum with getting embedded into the surface.
The fabrication process for these photcathodes first begins with 2 days of pumping - roughing pump to 10^{-4} Torr, turbo pump to 10^{-6} Torr and finally ion pump to 10^{-8}. and subsequently a 3 day bakeout at around 200 C. Then after cooling down the chamber, ultrahigh

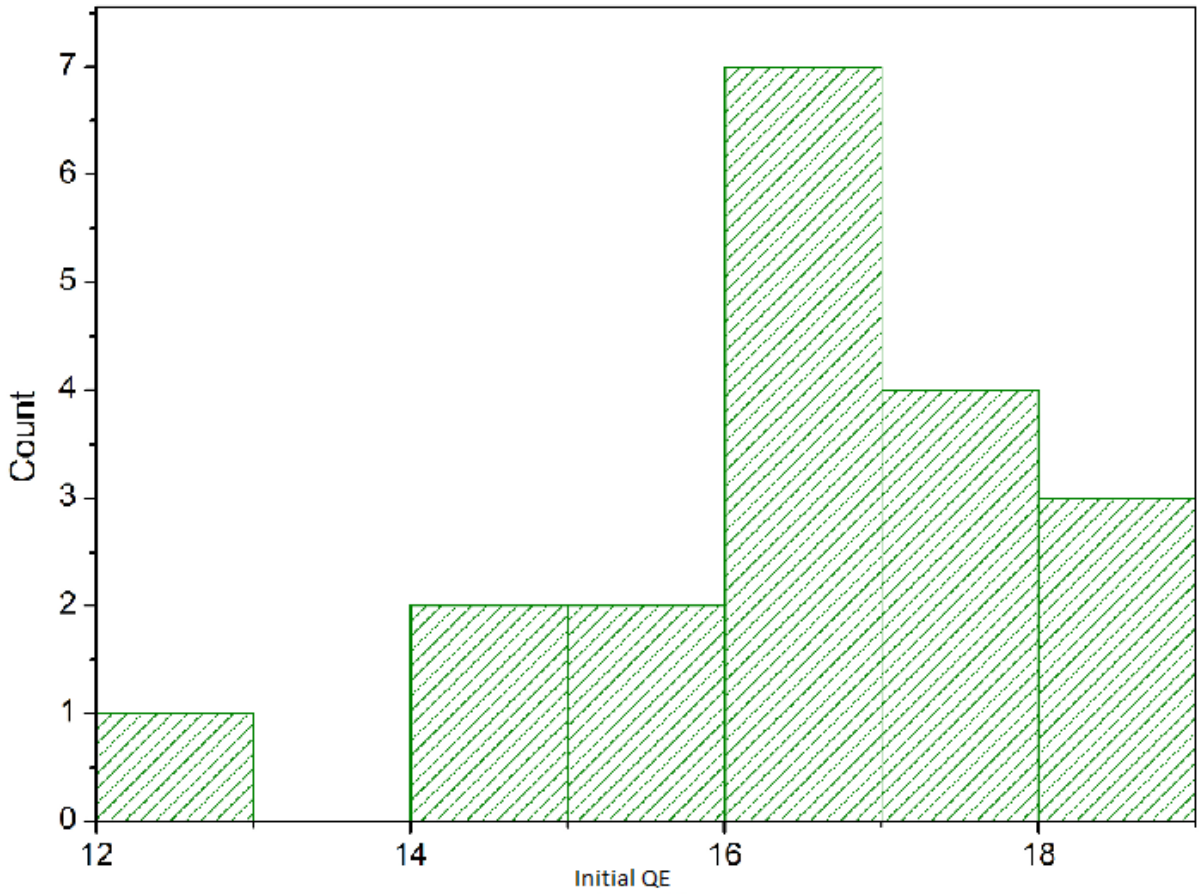

Figure 2: Spread of QE in all the photocathodes we fabricated

vacuum $10^{-}10$ is attained and we specifically heat up the plug to 120 C for deposition. A day later, with the plug still hot, we begin deposition. Deposition is evaporative for both the Cesium and Telurium. First the coil basket on which the tellurium chunk is placed is heated up to evaporate the tellurium and we us a thickness monitor near the plug to build up a the $200\mathring{A}$ layer - on the order of a 10 minute deposition. Then when the Tellurium deposition finished, we pass a current through the Cesium dispenser - which has Cesium bonded to a Chromate salt. While we deposit the Cesium, we intermittently check the QE and we continue deposition until the QE ceases to increase and plateaus (shown in Fig. 3). Afterwords we let the photocathode rest and reach equilibrium after about a day before moving the photocathode to the gun - this is done by attaching a cross chamber, which has its own vacuum pump, to the back of the deposition chamber and pulling the newly formed cathode out with an actuator into the cross. With the cross's pump continuously venting the chamber, we detach the cross and transfer it to the accelerator.

Though the primary purpose of this facility is to grow photcathodes for the AWA, during down times for the accelerator, the Yusof group does additional diagnostics to better understanding the physics behind the photocathode and improve its fabrication.

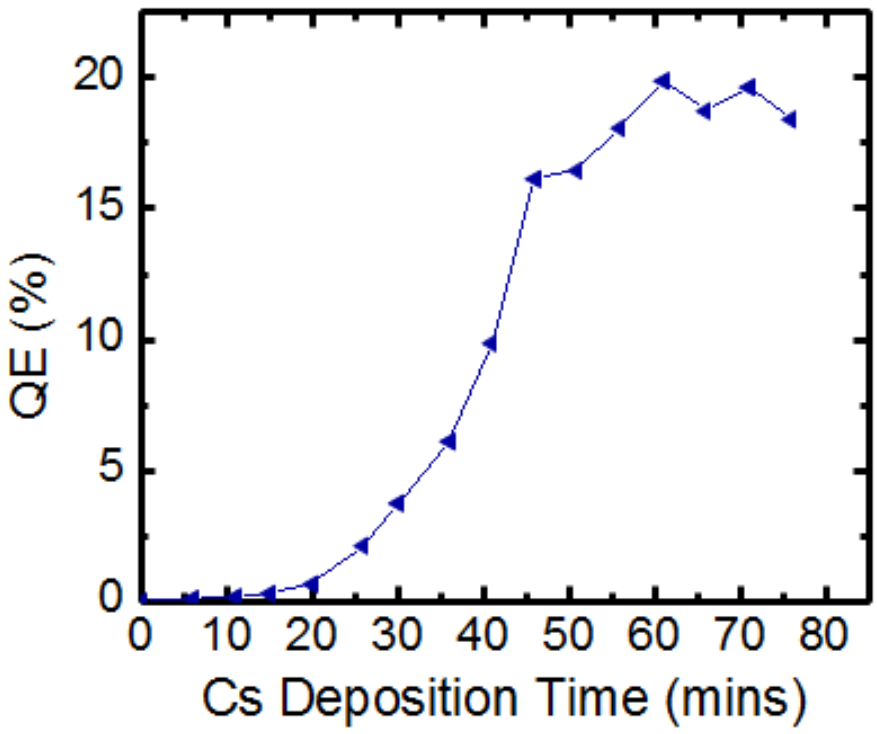

Figure 3: Typical Evolution of QE during cooking

3 New Diagnostic - Kelvin Probe Studies

The Kelvin probe is a non-contact method for determining the work function of a sample given the work function of the tip of the probe. The basic setup up is to place the two parallel to each other (as in a capacitive parallel plate configuration) and electrically linked the two through a common ground. This linkage will allow current to flow equalizing the Fermi levels of the tip and the sample (this is really only true for metals not semiconductors where there is a band gap but for simplicity in explaining the procedure we will just look at the metal case). If we then look at the definition of the work function

$$\Phi = E_{vacuum} - E_{Fermi} \tag{1}$$

where E refers to the energy of each of the levels. For both tip and the sample the Vacuum Energy level will be the same value, since the two aren't touching each other or anything else in the chamber. Thus the difference in work functions between the two is

$$\Delta\Phi_{sample-probe} = E_{Fermi:probe} - E_{Fermi:sample} \tag{2}$$

which translates to a potential difference called V_{cpd} between the probe and the sample when the are put in electrical contact.

$$v_{cpd} = \Delta\Phi_{sample-probe}/e \tag{3}$$

when e is the fundamental electric charge.
We can then instead of grounding the two, contact them across an element by which we can apply a known "backing potential" to cancel out some of the v_{cpd}, so that we have an equivalent circuit of a capacitor in series with a voltage source, and based on how much current is still flowing we can deduce the actual v_{cpd} (the steps are depicted in Fig 4).

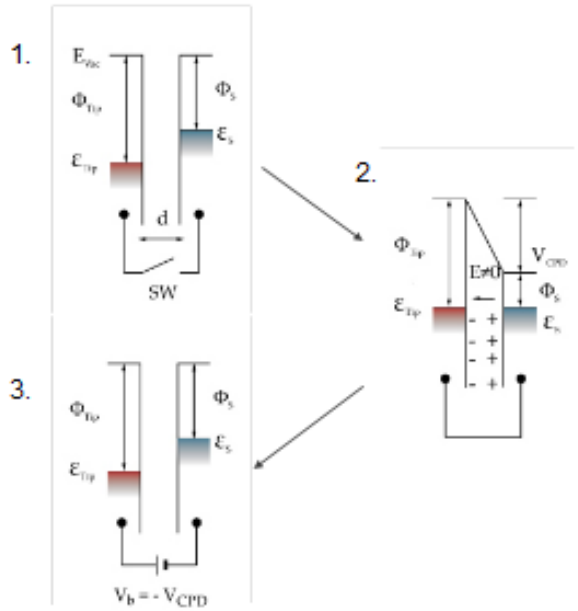

Figure 4: Block 1 - The tip and the sample are put in a parallel configuration, here the sample is the one on the right with the higher Fermi level. Block 2 - The two are then grounded and the Fermi levels work to equalize thus inducing the contact potential V_{cpd} across the configuration. Block 3 - Instead of grounding, a backing potential is applied to offset the contact potential and return the Fermi levels to their original states.

We must of course have a current to measure, and by definition

$$i_{cpd} = dQ/dt \tag{4}$$

and for a capacitive element

$$Q = Cv \rightarrow i_{=}vdC/dt + Cdv/dt \tag{5}$$

where

$$v = v_{cpd} - v_b \tag{6}$$

Then since we are choosing the applied backing voltage at some constant amount and the v_{cpd} is a constant physical property fo the material in the tip and the sample, the only thing we can vary to induce a current is by varying the capacitance of the setup. Since we have

a parallel plate geometry the easiest way to vary the capacitance is the vary the distance between the tip and the sample and the simplest way to do so is sinusoidally. Since C is inversely proportional to the distance between the plates we get

$$i = vd(A/(d_0 + d_1 sin(\omega t + \phi)))/dt = A\omega v d_1 cos(\omega t + \phi)/(d_0 + d_1 sin(\omega t + \phi))^2 \quad (7)$$

wit some arbitrary amplitude, frequency and phase. We see though there is a sinusoidal variance in the current with time, we still have a linear relation between i and v_b. So we can just look at at the peak to peak behavior and see.

$$i_{pp} = vB_{pp}(A, d_0, d_1, \omega) \quad (8)$$

where B is a constant peak to peak value of the time varying capacitance which we can arbitrate since we set all the parameters of the motion of the tip with respect to the sample. Then

$$v_b = v_{cpd} - i_{pp}/B_{pp}(A, d_0, d_1, \omega) \quad (9)$$

so we see that the v_{cpd} is the y-intercept of the v_b vs i_{pp} graph.
We can experimentally measure i_{pp} for multiple applied v_b and then from the best fit line to those points we can determine the y-intercept. Yet v_{cpd} is still just the potential difference between the tip and the sample and we want to specifically know the work function of the sample so we still need the work function of the tip. The method by which we can do this is to run the experiments with samples of a known work function. Since we apply v_b we know the direction for the potential drop and this must be opposite to the drop (or gain) from the capacitive element
sample. The equivalent circuit setup is depicted in Fig. 5.

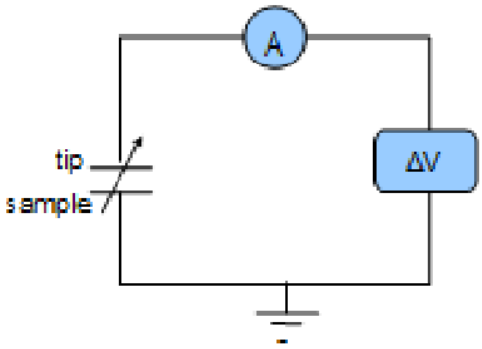

Figure 5: Shown is the equivalent circuit for the Kelvin probe setup with the tip - sample parallel plate configuration depicted as a variable capacitor, the applied ΔV as the backing potential, and an ammeter in series to measure the current.

4 Results

In our studies of QE and work function of these photcathodes, we are consistently seeing an inverse relationship between QE and work function and when we attempt to fit a power law of QE as a function of work function we get a power ranging from 2.5 to 4.2 as compared to the normal 2.0 for most metals,(an example is shown in Fig. 6). The spread in thfis power may imply that a power law fit may not be adequate or that there may not be a direct relation between the two for our photcathodes or semiconductors in general.

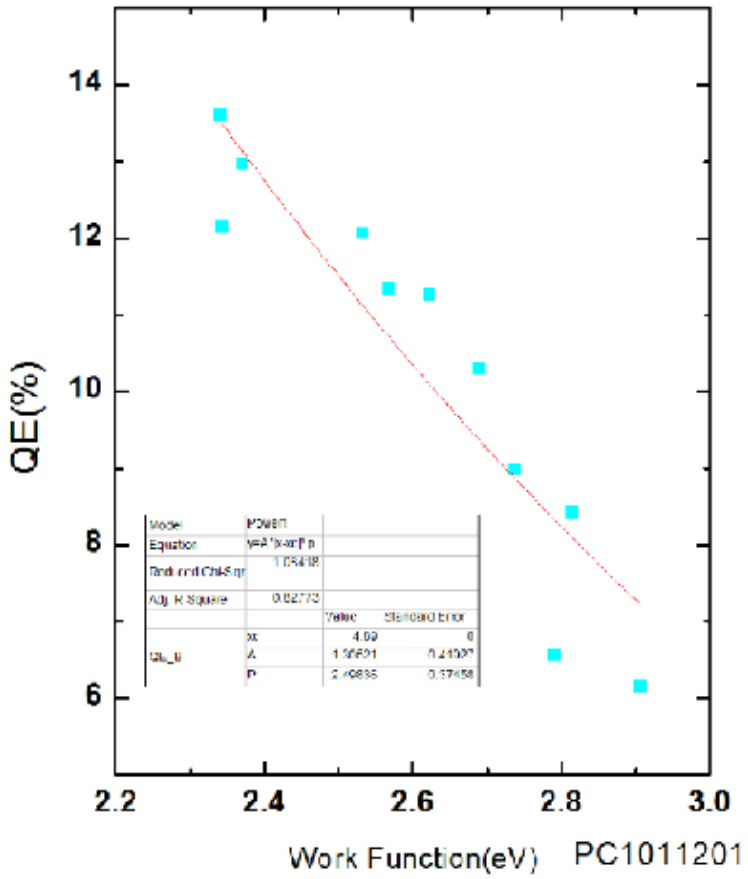

Figure 6: One plot of QE vs Work Function

For further analysis we tried and extra step in the fabrication process - heating the plug to 120 C for another 3 days but now a day after the formation of the photocathode. We find that this actually helps lessen the decay of the QE with the quantum efficiency after two weeks around 2% greater than photcathodes without the extra step (shown in Fig. 7). This result may hold some interesting clues about the arrangement of cesium in the telluride layer - as the extra heating step may be dispersing any clumping effects present.

5 Skills Acquired

Through this project I gained an understanding of the basic solid state physics that characterizes the behavior of our photcathodes and diagnostic devices. I also learned how to reach

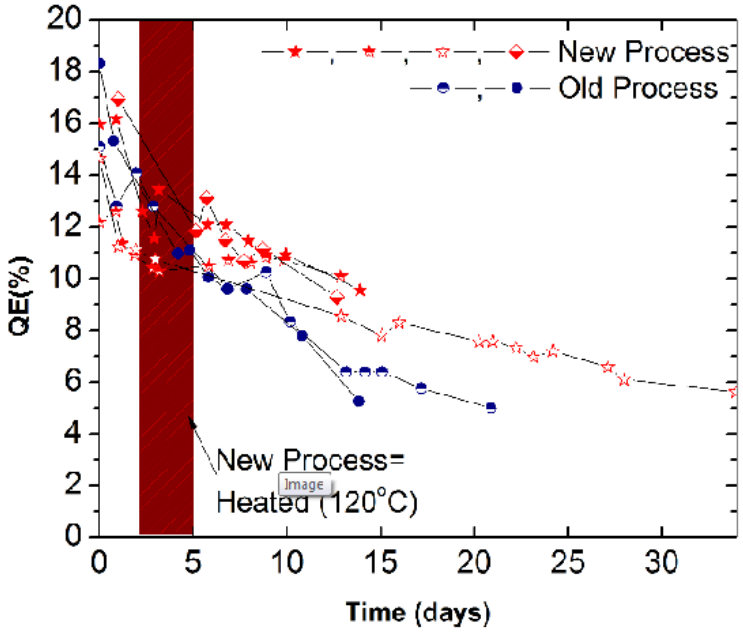

Figure 7: Evolution of QE over time (Blue: Standard recipie, Red: Additional Heating)

and maintain ultrahigh vacuum environments and clean and prep components to be placed in these environment. I gained the knowledge of how to fabricate a photocathode, operating a polishing table, pumping down a system and using evaporative deposition techniques. I learned a lot of specific skills for the project but also some very general techniques that are sure to be useful in future and my career in applied physics.

6 Acknowldgements

Thank you to my advisor Zikri Yusof for taking me on as a research assistant and teaching me so much about photcathodes, solid state physics and about the life of a physicist in general. Thanks to Eric Wisniewski and Daniel Velasquez for working with in the lab and teaching me so much along the way, I really enjoyed the experience. Finally, thank you to Linda Spentzouris and Eric Prebys and everyone who helped coordinate this internship to give me this opportunity.

References

[1] Z. Yusof, E. Wisniewski and L. Spentzouris (2012),DEVELOPMENT OF CESIUM TELLURIDE PHOTOCATHODES FOR AWA ACCELERATOR UPGRADE to be published in the proceedings of IPAC 2012