

DEVELOPMENT OF CESIUM TELLURIDE PHOTOCATHODES FOR AWA ACCELERATOR UPGRADE

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Abstract

Cesium telluride photocathodes have been fabricated for the Argonne Wakefield Accelerator (AWA) upgrade. The as-deposited photocathodes have consistently produced quantum efficiency values better than 10% with 254 nm light source and with variation of less than 5% over a circular area of 1.2 inches in diameter. We present various characterizations of the photocathode that have been performed, including rejuvenation, lifetime, and performance in the L-band AWA photoinjector.

INTRODUCTION

The Argonne Wakefield Accelerator (AWA) facility conducts advanced accelerator research studies for the next generation electron accelerators. The acceleration scheme focuses primarily on the generation of wakefields in dielectric structures using an electron bunch train to produce either high-gradient fields for particle acceleration, or high-power generation. Recent results have produced accelerating gradient of ~ 100 MV/m [1], and power generation of more than 30 MW at 7.8 GHz [2].

To achieve even higher gradients and power, the AWA facility is undergoing a significant upgrade with the construction of a new accelerator beamline. One of the requirements for the new accelerator is the generation of an electron bunch train consisting of up to 60 bunches, each with 50 nC charge. To achieve this, a high-quantum efficiency (QE) photocathode is required to produce such bunch train.

We have developed a photocathode deposition system to grow cesium telluride (Cs_2Te) photocathode for the new AWA accelerator. The system allows for a vacuum transfer of the photocathode to the new AWA photoinjector. We have also performed basic characterizations and studies of the properties of the photocathode to better understand its performance.

PHOTOCATHODE DEPOSITION SYSTEM

The photocathode deposition system consists of an ultra-high vacuum (UHV) chamber with a base pressure $\sim 2 \times 10^{-10}$ Torr., and a UHV transfer system that allows for a vacuum transfer of the photocathode into the AWA photoinjector. The photocathode deposition follows similar recipes developed previously [3,4]. The Cs and Te sources in the deposition chamber are evaporated thermally onto a Mo plug that is heated at 120 C. The Te deposition is monitored with a thickness monitor to a thickness of ~ 20 nm, while the Cs deposition subsequent

to the Te deposition is monitored via the photocurrent using 254 nm light from a Hg arc lamp. This photon wavelength is chosen since it closely matches the AWA laser that is used in the photoinjector.

The UHV transfer system consists of a long-stroke actuator that the Mo plug is attached to. During a cathode transfer, the actuator is pulled back to allow for the gate valve to be closed. It is then transferred to the back end of the new AWA photoinjector. UHV condition is maintained throughout the entire process.

PHOTOCATHODE CHARACTERISTICS

Figure 1 shows the distribution of photocathode QE for all the photocathodes we fabricated in a period of ~ 15 months. These were measured immediately after fabrication. As can be seen, the starting QE is routinely well above 10%, with a major portion having an starting QE of 16%-18%. A significant concern is the uniformity of the photocathode. The photocathode has an effective diameter of 1.2 inches, considerably larger than the typical Cs_2Te photocathode grown elsewhere. A scan of the QE distribution at 5 different points on the photocathode is shown in Figure 2. It reveals a uniformity that is better than 5%.

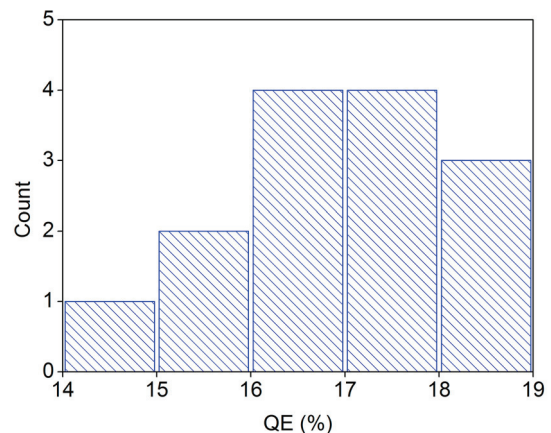


Figure 1: Distribution of QE on as-grown Cs_2Te photocathodes.

We have studied the aging of the photocathode in the UHV chamber. Figure 3 shows the evolution of the QE over a period of a more than 3 weeks. As can be seen, the QE drops quickly during the first few days, and then starts to level-off. While this is a typical behaviour for all of the photocathodes that we have grown, there is a variation in how quickly the QE drops and at what value it levels off.

On average, the QE tends to level off at $\sim 5\%$ over a period of about 1 month.

Figure 3 also shows a QE rejuvenation process. The photocathode was heated at 120 C in the UHV chamber over a period of ~ 3 days. There is a clear recovery of QE from $\sim 7\%$ to slightly above 10%. Again, while this behaviour is seen in all the photocathodes that have been subjected to this process, the amount of recovery can differ from one photocathode to another. On average, the heating process can recover the QE to about 50%-60% of the initial value. Similar QE rejuvenations have been reported elsewhere to varying degree of success [3,5]

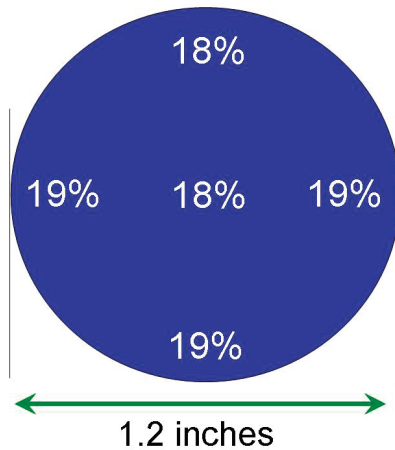


Figure 2: QE scan of photocathode surface. The uniformity is quite good.

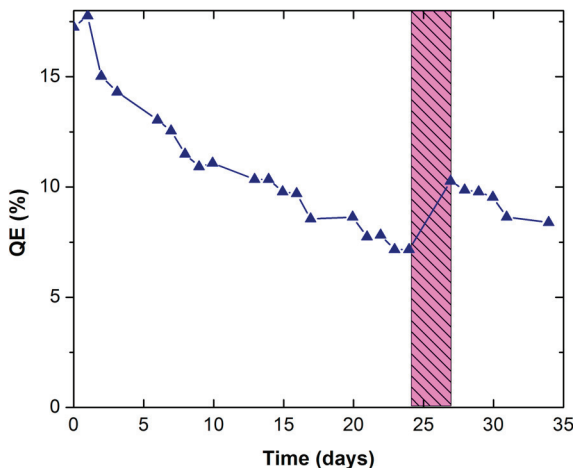


Figure 3: Aging of Cs₂Te in UHV chamber. The shaded region shows the heating process at 120 C. The horizontal axis is time in days after the end of photocathode fabrication.

We observe an interesting result from the heating process. While the QE does not recover fully to its initial value, the value of the QE does not appear to drop as quickly as before and may even plateau to a higher QE value. With that in mind, we subjected two newly-grown photocathodes to the same heating process. The photocathodes were characterized after growth and

allowed to cool down for a day. They were then reheated to 120 C for 2 days and then allowed to cool back to room temperature.

Fig. 4 shows two sets of photocathodes. Two photocathodes (blue) were treated normally after deposition, i.e. allowed to age in the UHV chamber without any further treatment. Two other photocathodes (red) have been subjected to the heating process one day after end of fabrication.

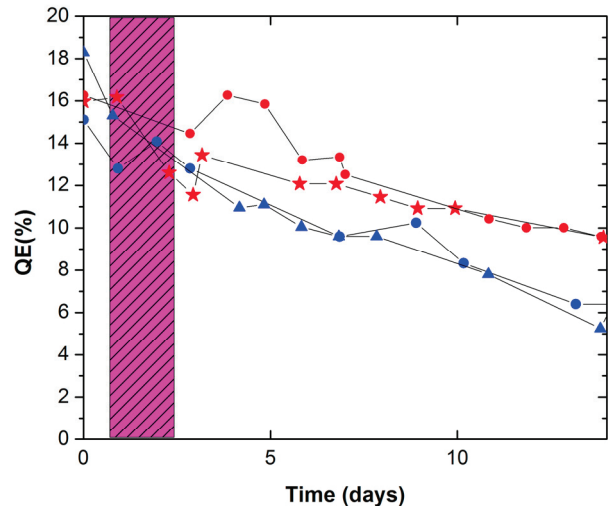


Figure 4: Comparison of photocathodes that were not treated to heating one day after fabrication (blue) to those that were heated at 120 C for 2 days (red). The photocathodes that were treated to the heating process show a slower drop in QE.

There is a clear observation that the photocathodes that were subjected to the heating process show a slower drop in QE over the same period of time when compared to the non-heated photocathodes. We also note that the slope of the QE decay, on average, is also smaller at a particular QE value for the heated photocathode. For example, at 12% QE, the heated photocathodes has a smaller slope than the non-heated photocathodes (we ignore the data immediately after heating since the values tend to fluctuate). This implies that the heated photocathodes appear to have a more “stable” QE over a longer period of time than the non-heated photocathodes. We are conducting further studies on this to investigate the reproducibility of this effect and to observe QE evolution over a longer period of time.

We note that in a study of the work function of Cs₂Te that we had conducted [6], the heating process for rejuvenation produces an unexpected change in the work function. While the heating increases QE of the photocathode, the work function also increases, defying the trend that is expected in terms of the inverse relationship between QE and work function for a metal or semiconductor. This suggests that the heating process may alter the stoichiometry or composition of the surface.

The ultimate test of the performance of this photocathode will be under the operating condition of the photoinjector. The photocathode will be subjected to a 1.3

GHz RF with a maximum gradient of ~80 MV/m. We intend to monitor the QE variation over time and dark current level from the photocathode.

SUMMARY

A photocathode fabrication system has been developed for the fabrication of Cs₂Te photocathode and is fully operational. The system allows for a UHV transfer of the photocathode from the deposition chamber to the AWA photoinjector. The QE of the as-deposited photocathode is consistently above 10% and shows a good uniformity over the large surface of the photocathode. Rejuvenation of QE via heating at 120 C shows limited recovery of QE to about 50%-60% of the initial value. However, subjecting the newly-formed photocathodes to similar heating process appears to produce photocathodes that show a lower decay rate in QE. Such a treatment has the potential to produce a more stable photocathode. Further studies on such a treatment are being carried out. Investigation on the performance of this photocathode in the AWA photoinjector will also be conducted.

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