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Cs_2Te PHOTOCATHODE PERFORMANCE IN THE AWA HIGH-CHARGE HIGH-GRADIENT DRIVE GUN

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Abstract

The unique high-charge L-band, 1.3 GHz, 1.5 cell gun for the new 75 MeV drive beam is in operation at the Argonne Wakefield Accelerator (AWA) facility (see M.E. Conde, this proceedings.) The high-field (> 80 MV/m) photoinjector has a large area, high QE Cesium telluride photocathode (diameter > 30 mm). The photocathode, a crucial component of the upgraded facility, is fabricated on-site. The photoinjector generates high-charge, short pulse, single bunches (Q > 100 nC) and long bunch-trains (Q > 600 nC) for wakefield experiments. The performance of the photocathode for the AWA drive gun is detailed. Quantum efficiency (QE) measurements indicate long, stable photocathode lifetime under demanding conditions.

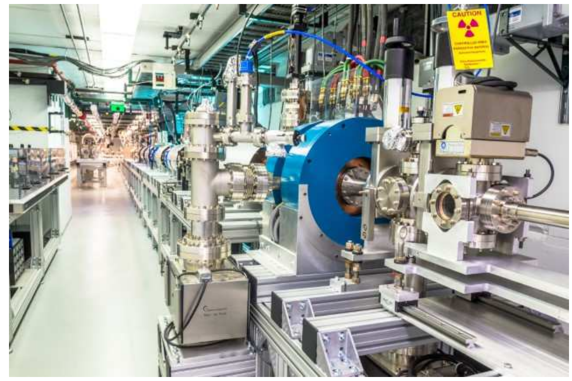

Figure 1: AWA upgrade: The new drive beam photocathode gun, looking in the direction of the beam. In the foreground is the cathode load-lock system.

THE ARGONNE WAKEFIELD ACCELERATOR (AWA) DRIVE PHOTOCATHODE GUN

The AWA L-band drive gun for the new 75 MeV drive linac has been commissioned and is operating. The 1.3 GHz photo-injector operates at high gradient (85 MV/m). The 31 mm dia. Cesium telluride photocathode, specifically designed for the production of high charge, is fabricated on-site. The photoinjector generates high-charge, short pulse, single bunches (Q > 100 nC) and long bunch-trains (Q > 600 nC) for wakefield experiments. A load-lock system was designed and built in-house for the required vacuum transport and installation of the cathode. The photocathode requirements at AWA were determined by the drive beam parameters. The AWA drive beam parameters are summarized in Table 1 [1].

Table 1: AWA Drive Beam Cathode Operating Parameters

Cathode peak RF field	>85 MV/m
RF pulse length	≈7.6 μs
Average dark current	<5 nC/RF pulse
QE%	>1%
QE lifetime	>1 month
Laser pulse width	1.5 – 8 ps FWHM
Single-bunch charge	100pC to >100nC
Multi-bunch mode:	• up to 50 nC/bunch • 2 to 32 bunches • bunch spacing = 770 ps • Max charge = 0.6 μC

PHOTOCATHODE FABRICATION

The method of fabrication used at AWA was based on and developed from methods published by researchers at LANL and INF and described in detail elsewhere [2, 3]. Using those sources for guidance, the AWA Cs_2Te photocathode is fabricated in a UHV chamber with a base pressure of 1.5×10^{-10} Torr.

The natural decline in QE of the photocathode while under UHV conditions can be reversed (up to a point) with a process referred to in the literature as rejuvenation. Previous studies on photocathode rejuvenation have shown a QE recovery up to about 60% of the original value [2, 4]. Two different rejuvenation methods have been reported. Reference [2] reported rejuvenation by heating the photocathode at 120-200°C for a period of several hours to a few days, while Ref. [4] reported that QE rejuvenation required simultaneous heating and illuminating with UV light.

Photocathodes have been rejuvenated at AWA many times, in most cases after the QE has dropped to about 5%. Rejuvenation was achieved by heating the photocathode in the deposition chamber at T=120°C for 1-3 days. The results have shown a minimum increase in QE of 60% above the QE measured just before heating. It was noted that the rejuvenated photocathodes also had a slower QE decay rate in the deposition chamber. This observation lead to applying the heating step immediately after fabrication in an attempt to retard QE decay. It was found that photocathodes formed with this post-deposition heating (annealing) step consistently showed improved QE lifetime. Figure 2 shows a comparison plot of QE lifetime for several photocathodes fabricated with and without the anneal. This plot indicates that QE decays

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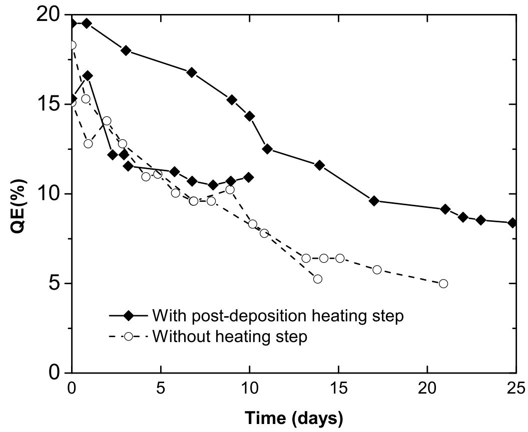

Figure 2: QE vs. time of four Cesium telluride photocathodes. After fabrication, two photocathodes (black diamonds) were heated for 2-3 days at 120° C. The result: the QE decay rate is significantly reduced.

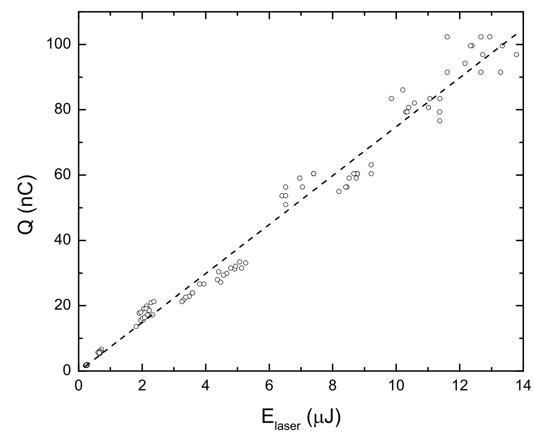

Figure 3: Shot-by-shot charge vs. laser energy data using a 22 mm laser spot on the Cs_2Te photocathode. The peak RF electric field on the cathode was 84 MV/m. The good linear fit indicates no space-charge effects. From the slope, QE>3%.

more slowly when the cathode is annealed [5]. The anneal is now a standard step of the fabrication process.

HIGH CHARGE GENERATION

In tests during commissioning, the AWA drive gun produced high charge electron bunches meeting the requirements. The laser spot on the cathode had a diameter of 22 mm (measured at the virtual cathode). A large spot, but not so large as to over-fill the cathode which could cause arcing and would also invalidate QE measurements. Varying the laser energy by using different combinations of neutral density filters, single-bunch beams with increasing charge were produced. The charge and laser energy were measured shot-by-shot, 10 shots at each laser setting. The results are plotted in Fig. 3. The spread is due to shot-to shot laser energy variation (jitter). 100 nC charge bunches were produced without adverse effects on the vacuum. There were no apparent space-charge effects, as indicated by the good linear fit of charge vs. laser energy. The gradient at the cathode was 84 MV/m. These measurements broke the record for high-charge bunch generation from Cs_2Te. (The previous record was a space-charge limited 50 nC at the TTF injector at PITZ [6]).

An important requirement of the AWA photoinjector is the production of high-charge bunch-trains. Bunch-trains are produced with a single laser pulse passed through a custom-built multi-splitter with adjustable delays between bunches. The multi-splitter can produce up to 32 bunches per train. In order to study a possible bunch-train charge position-dependence due to a limit on the charge that can be extracted within a given time frame, the first bunch-trains of four bunches were produced and the charge per-bunch carefully checked. The ICT integrates the total charge from all the bunches. The single-bunch charges can be measured one at a time with the ICT by blocking the other bunches. Low to high-charge bunch-trains were generated. In each case, the sum of the four single bunch charges measured by blocking the beam equalled the total charge of the train as measured at the ICT indicating that the QE has no bunch-train order-dependence in a four bunch, high-charge train. The QE measured for bunch number four was the same as the QE measured when generating bunches one, two, or three. The laser energy per bunch was unevenly divided by the beam-splitters. This is primarily due to a problem the polarization-sensitive beam splitters. As the laser energy was increased to produce high-charge bunch trains, the charge in bunch 3 and 4 did not follow the same ratios (see Fig. 4). However, this was not due to bunch-charge order dependence, but rather was a property of the laser energy transport through the multi-splitter and its polarization dependence. One important lesson learned was the overwhelming importance of laser profile quality (including polarization). Since these first measurements, laser profile improvements have been made with corresponding improvements in beam quality and bunch train charge uniformity.

PHOTOCATHODE PERFORMANCE SUMMARY

After initial RF conditioning to 88 MV/m, the QE stabilized at a solid 3.5%, 3.5 times the requirement. Single bunch and bunch-train QE phase scans were flat, an indication that there was no field enhancement of QE analogous to the Schottky effect observed in metal photocathodes. Data taken for bunch charge from 1 nC to 100 nC indicated that the high-charge beam is not space-charge limited. Bunch-train generation was successful up to total train-charge of 300 nC with no sign of QE degradation.

Twenty months after installation, the same photocathode is still operating, with QE now around 2% as illustrated in the plot in Fig. 5. Four pictures of the cathode showing changes to the surface over time as the cathode experienced the effects of the RF conditioning and UV laser are shown

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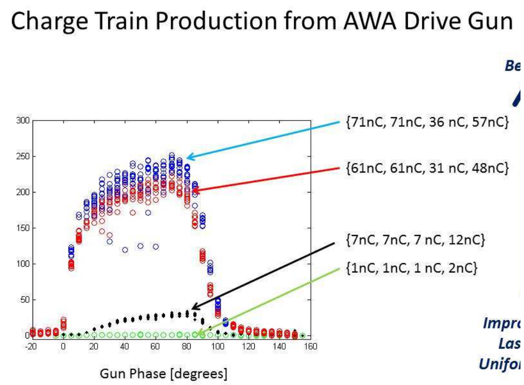

Figure 4: Summary plot of bunch-train generation at AWA (total charge per train). The maximum charge per train is a function of the laser profile quality. Individual charges sum to the total charge, indicating that there is no bunch-position QE dependence for the four bunch train.

in Fig. 6. There are an estimated 600 small (<0.5 mm) spots on the surface which developed during the course of RF conditioning and seem to have stopped accruing once the cathode was well-conditioned. The spots seem to be most likely due to arcing. It is not known if these spots represent real damage to the cathode thin film, ie. whether or not the cathode QE is dead in these spots. It is not even clear if the spots are in the thin film of the cathode or in the Molybdenum substrate. The spots, damaged or not, have not adversely affected the overall performance or the QE of the cathode.

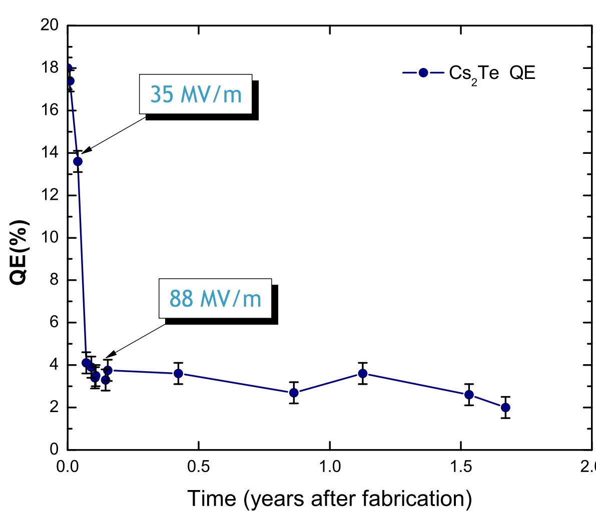

Figure 5: QE vs. time for the AWA drive gun photocathode installed in August 2013 and still operating today. The photocathode QE was initially about 18% in the deposition chamber and is currently about 2%.

CONCLUSION

The AWA photocathode program has succeeded in meeting the needs of the accelerator. The total charge delivered

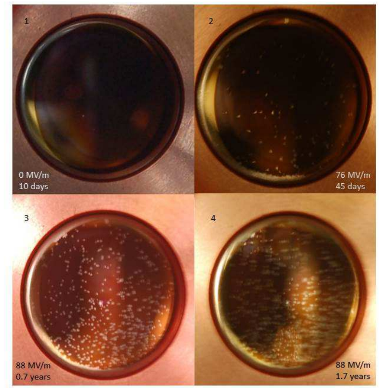

Figure 6: Pictures of the cathode 1) 8.26.2013 (shortly after installation) 2) 9.30.2013 3) 5.14.2014 4) 4.24.2015. An estimated 600 spots developed during RF conditioning. The photocathode QE is 2% after 1.7 years of operation.

(both single and multi-bunch), QE and the QE lifetime have both exceeded minimum requirements and expectations. The importance of controlling the parameters that influence the structure of the initial charge distribution will be addressed in future studies. Increased emphasis on laser profile quality improvements will continue to be pursued for the improvement of high-charge electron beam quality. (A laser relay imaging system was recently installed with promising results. See John Power, this proceedings). Laser pulse shaping will be explored. On the cathode side, improvements to the QE uniformity should be addressed to help improve the homogeneity of the charge distribution. Also, the nature of the spots on the cathode should be explored using a probe with a small laser spot rastered across the cathode may.

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