SUMMARY OF Cs_2Te PHOTOCATHODE PERFORMANCE AND IMPROVEMENTS IN THE HIGH-GRADIENT, HIGH-CHARGE AWA DRIVE GUN

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Abstract

The AWA L-band, high-charge photoinjector for the 70 MeV drive beamline has been operating for almost 3 years at the Argonne Wakefield Accelerator (AWA) facility. at Argonne National Laboratory (ANL). The gun operates at high-field (85 MV/m peak field on the cathode) and has a high quantum efficiency (QE) Cesium telluride photocathode with a large area (30 mm diameter). It produces high-charge, short pulse, single bunches (Q > 100 nC) as well as long bunch-trains (Q > 600 nC) for wakefield experiments (high peak current). During the first two years of operation, photocathode performance was evaluated and areas of improvement were identified. After study, consideration and consultation, steps were taken to improve the performance of the photocathode. So far, in total, three photocathodes have been fabricated on-site, installed and operated in the gun. Improvements made to the photocathode plug, vacuum system, and gun operation are detailed. The results include vastly improved conditioning times, better cathode performance, and QE above 4% for over 11 months.

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 method of fabrication used at AWA was based on and developed from methods published by researchers at LANL and INF-LASA and described in detail elsewhere [1, 2]. 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 and transported to the drive gun for installation in a UHV load-lock chamber.

The photoinjector generates high-charge, short pulse, single bunches (Q > 100 nC) and bunch-trains (Q > 450 nC) for wakefield (and other) experiments. The photocathode requirements at AWA were determined by the drive beam parameters. The AWA drive beam parameters are summarized in Table 1 [3].

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

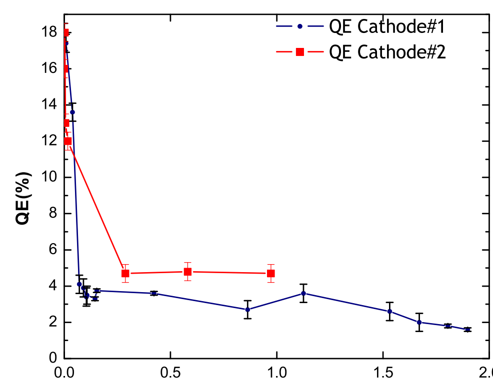

Figure 1: QE vs. time for the two AWA drive gun photocathodes installed since August 2013. QE drops sharply during RF conditioning to 88 MV/m and stabilizes to about 4% during subsequent operation.

PHOTOCATHODE PERFORMANCE SUMMARY

After initial RF conditioning to 88 MV/m, the QE of Cathode1 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

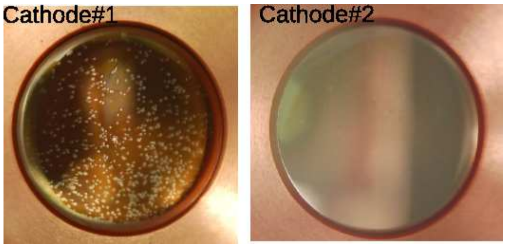

Figure 2: Pictures of Cathode1 (left) and Cathode2 (right) in the gun. On Cathode1, an estimated 600 spots developed, mostly during the month-long RF conditioning to 88 MV/m. Despite the appearance of the spots during RF conditioning, the photocathode performed fairly well for nearly 2 years of operation. However, the cathode started arcing uncontrollably and had to be replaced. Cathode2 is the replacement and has operated for 1 year with high QE, fast conditioning, and no arcing problem.

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 [4, 5].

Twenty-three months after installation, the same photocathode was still operating, with QE around 2% (see Fig. 1.) However, the cathode started arcing uncontrollably (the gun could no longer sustain RF) and the cathode had to be replaced (see Fig. 2).

A post-mortem of Cathode1 yielded the following. Pros: Lifetime 23 months with QE >= 1.5% Cons: 1. Slow conditioning (> 4 weeks) 2. Occasional arcing problems requiring re-conditioning (became more frequent in the last 3 months of operation). 3. End-of-life continuous arcing in the gap.

DIAGNOSIS

The problems were determined most likely due to the following:

1. Slow conditioning/spots/frequent breakdowns are thought to be related to the photocathode plug surface history of sandpaper polishing during the early testing stages. This has been found to introduce silicon impurities into the Mo surface and possible particulate contamination.
2. As the cathode aged, at times there were occasional arcing problems requiring re-conditioning. This and arcing in the gap as the cathode neared the end of its useful life seems to have occurred due to the enhanced field at sharp edges on the cathode near the spring.
3. White light interferometry performed on the used plug before and after removing the cathode film by wiping with alcohol showed that the spots are primarily damage to the thin film, rather than the Mo substrate.The difficult RF conditioning seemed to arise as emitters were processed on the cathode, blowing holes in the film.

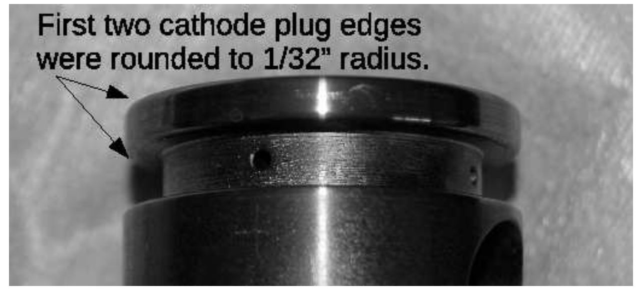

Figure 3: The rounded edges (radius 1/32 in.) eliminated the arcing in the gap.

ADDRESSING THE PROBLEMS

The problem of slow conditioning was addressed by carefully grinding the surface of the plug flat, removing 10s of microns of material to eliminate embedded Si particles. After this the plug was polished using polycrystalline diamond in stages from 6 micron down to 0.05 micron to a mirror finish.To address the possible problem of particulate contamination, an effort was made to clean particles out of the deposition chamber and the cathode plug was thoroughly ultrasonically cleaned after each polishing step.

The problem of arcing in the gap was solved by rounding the outer and inner plug edges (see Fig. 3.) This completely eliminated the arcing in the gap. From examination of the plug, it appeared that the inner edge was the problem, based on the evidence that copper from the gun had been deposited near that edge as a result of arcing. The original design included a radiused outer edge, but not the inner.

Immediately after removal, the Cathode1 plug surface was examined twice using white light interferometry (see Figs. 4 and 5). Initially, Sv=1505.79 nm, Sp=2041.89 nm. After wiping the surface with ethanol to remove the Cs2Te layer:Sv=606.308, Sp=231.332 nm. The Sv and Sp values correspond maximum valley depth and maximum peak height, respectively. Hence the maximum surface roughness was in the film. This indicated that the thin film sustained most of the damage and suggests that the visible spots are places that the cathode film was damaged during conditioning and arcing.

Unfortunately, it has not been possible to measure the thickness of the cathode. However, the values of Sp and Sv suggest an upper bound to the thickness of 2600 nm. A lower bound of 220 nm is set by the Te thickness which is monitored during the deposition.

Based on the different histories of Cathodes 1 and 2, it will be interesting to repeat the white light interferometry on Cathode2 and see if this type of damage has been eliminated (from the pictures taken in the gun this seems possible).

CONCLUSION

After the changes were made described above, the new cathode was installed. The improvements were phenomenal. Cathode2 was RF conditioned to 80 MV/m in just two hours and produced the first beam the same day.There has been

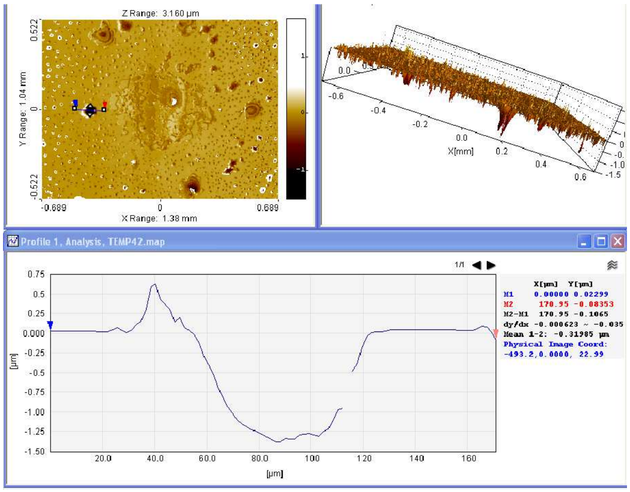

Figure 4: Cathode1 plug surface analyzed in the white light interferometer, before wiping off the surface. Micron scale pits and features.

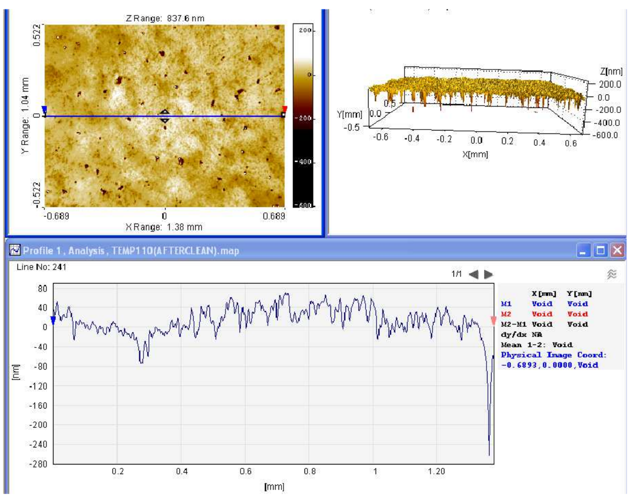

Figure 5: Cathode1 plug surface analyzed in the white light interferometer, after cleaning. Features are now on the order of 100s nm in scale. This suggests that the spots are places that the cathode film was damaged, in some cases removed down to the Mo surface.

no arcing in the gap with Cathode2. The QE is 4.7% after a year of high-charge operation. Few damage spots are evident (perhaps thanks to the smooth RF conditioning), see Fig. 2. In addition to the stated mechanical improvements, the gun operating protocol has changed: At startup, RF power is increased only while gun solenoids are off. Also, no RF pulsing while the solenoids fields are changing at low power to reduce chance of multi-pactor. A plan is in place to replace the cathode while performance is still high, probably in January 2017.

ACKNOWLEDGMENT

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory ("Argonne"). Argonne, a U.S.A. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S.A. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

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