STUDIES OF FIELD AND PHOTO-EMISSION IN A NEW SHORT-PULSE, HIGH-CHARGE Cs_2Te RF PHOTOCATHODE GUN

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Abstract

A new high-charge RF gun is now operating at the Argonne Wakefield Accelerator (AWA) facility at Argonne National Laboratory (ANL). The 1.5 cell 1.3 GHz gun uses a Cesium telluride photocathode driven with a 248 nm laser to provide short-pulse, high charge electron beams for the new 75 MeV drive beamline. The high-gradient RF gun (peak field on the cathode $>$ 80MV/m) is a key piece of the facility upgrade. The large Cs_2Te photocathode (diameter $>$ 30 mm) is fabricated in-house. The photo-injector generates high-charge, short pulse, single bunches (Q $>$ 100 nC) or bunch-trains (Q$>$1000 nC) for wakefield experiments, typically involving dielectric-loaded accelerating structures. Field-emitted dark current from the Cs_2Te cathode was measured during RF conditioning. Fowler-Nordheim plots of the data are presented and compared to similar measurements made using a copper cathode in the initial phase of conditioning. Results of quantum efficiency (QE) studies are presented with the cathode operating in both single and bunch-train modes.

EMISSION STUDY PLAN AND GOALS

The 1.5 cell, 1.3 GHz, AWA drive-gun is now operating, using high Quantum Efficiency (QE) Cs_2Te photocathodes fabricated in-house [1]. The photocathode requirements are QE greater than 1% with a lifetime of weeks to months while experiencing a very high gradient (80 MV/m) peak RF field on the cathode. The primary function of the gun is to provide high-charge, short-pulse electron beams to drive wakefield structures [2]. As part of the turn-on process, we are conducting field emission and photoemission studies in the gun.

Photocathode Field Emission Study

We measured and characterized field emission from two different photocathodes used during the two phases of RF conditioning. Copper was used for the initial gun conditioning, followed by Cs_2Te thin film on Molybdenum for planned high-charge operation. We hope to use the data to better understand the relative impact of different factors influencing the level of field emission and its possible mitigation.

Photoemission Study

We characterized photoemission from the Cs_2Te photocathode under various conditions. Using 2-10 ps, 248 nm wavelength laser pulses, we are studying photoemission at high gradient to optimize the performance of the photocathode and the gun. At the time of the writing of this paper, QE measurements of the photocathode in the gun have been made over a period of about 6 weeks.

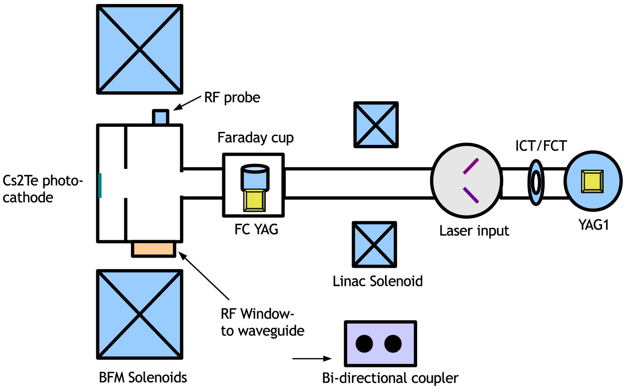

Figure 1: The L-band 1.5 cell photocathode gun with the relative positions of diagnostics to be used (cartoon - not to scale). The RF power input is measured near the RF window using a bi-directional coupler. The dark current is measured with a Faraday cup 58 cm from the cathode. The beam charge is measured using an Integrating Current Transformer (ICT). YAG(Ce) scintillating screens to image the beam and the dark current are available at two locations. In addition, an in-vacuum mirror at the Faraday cup location may be used to observe the photocathode and help to identify emission sites (not to scale).

EXPERIMENTAL SETUP

The beamline with the relative positions of diagnostics used for the experiments is depicted in a schematic shown in Fig. 1. RF power measurements were made using a dual-directional coupler connected in series in the waveguide just before the gun. The dark current was measured using a Faraday cup. The beam charge was measured using a Bergoz combination in-flange Integrating Current Transformer (ICT) and Fast Current Transformer (FCT).

ISBN 978-3-95450-138-0

YAG(Ce) scintillator screens were used to image the beam at two locations.

RF CONDITIONING AND FIELD EMISSION

RF conditioning of the gun was begun in 2011 but was interrupted by AWA upgrade expansion construction. To protect the both the gun and the cesium telluride cathode from effects of RF damage, the first round of conditioning took about 160 hours to reach 88 MV/m. The RF pulse length was 8 microseconds and repetition rates varied from 1 to 10 Hz. Next, the first Cs_2Te photocathode was installed and conditioned to 25 MV/m. Both photocathodes were used to produce electron beams, but progress was halted due to upgrade activities. Drive gun operation and the studies discussed herein resumed in summer 2013 and are on-going.

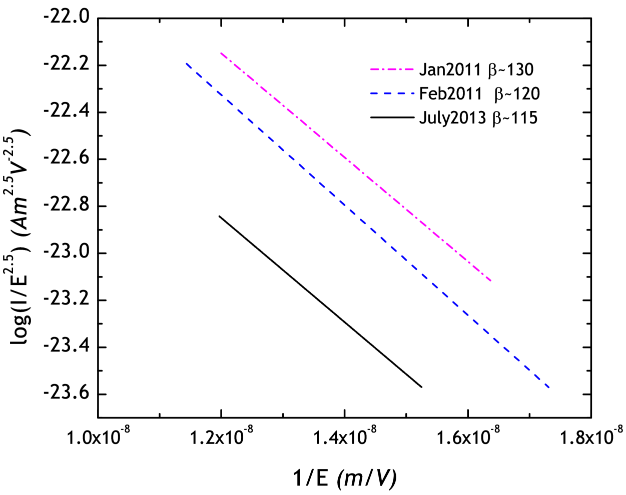

Figure 2: Initial RF conditioning was done with a copper photocathode. Linear fits of Fowler-Nordheim plots for the Cu cathode at several points in the conditioning process. The field enhancement factor (β) calculated from the slope of each fit indicate field enhancement in the gun with the Cu cathode is stable at about 120 after conditioning to 88 MV/m.

During conditioning, dark current data was taken with a Faraday cup located 58 cm from photocathode. The gun fields were measured using a diode at the bi-directional coupler in the waveguide near the RF window. Data from the copper cathode indicates a reasonable level of dark current and a field enhancement factor β=120.

Field emission from the cesium telluride photocathode was also measured with the Faraday cup during conditioning. Field emission from p-type semi-conductors has been shown to behave quite differently from metals and may result in non-linear Fowler-Nordheim plots [4]. As seen in Fig. 3 ,the preliminary results are suggestive of a field dependent, much lower β.

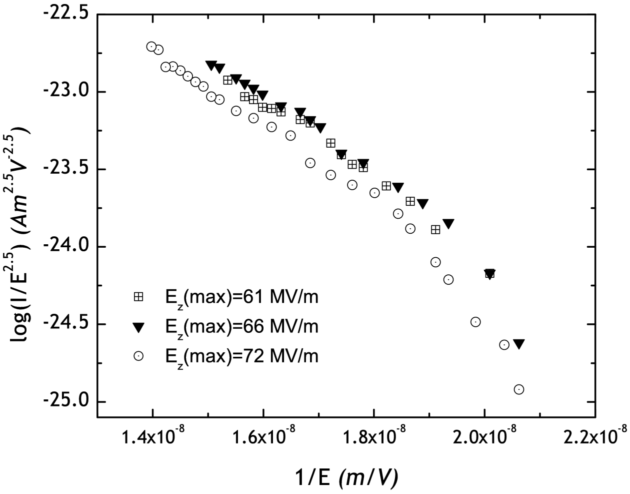

Figure 3: RF conditioning with Cs_2Te, a p-type semi-conductor thin-film photocathode. Three Fowler-Nordheim plots from data taken as conditioning proceeded appear non-linear, suggestive of β with a possible field dependence.

ONGOING PHOTOEMISSION STUDIES: PRELIMINARY RESULTS

Conditioning of the Cesium telluride cathode proceeded with some caution due to the vacuum requirement (low $10^{-}10$ torr). Arcing occurred fairly frequently as the field level was raised. The photocathode shows some small spots (about 0.5 mm in diameter), possibly indicating damage to the thin film from arcing during RF conditioning.

Once the photocathode was conditioned to about 30 MV/m, we began photoemission studies. Photoemission measurements were made using the experimental setup sketched in Figs. 1 and depend on laser power measurements concurrent with beam charge measurements in order to distinguish shot-to-shot variations in the laser or the QE. The diagnostics for the QE phase scan single bunch and bunch-train measurements [5] include the Bergoz in-flange ICT (to measure total charge) with FCT (to resolve individual bunches) described previously as well as a PD10-C OPHIR photodiode sensor with laser energy meter to measure laser power per pulse. We have been collecting data for QE lifetime studies on all the photocathodes we make for several years, but the data presented in this paper is from the first one operated for an extended period of time in the gun at high field. For a comparison, see Fig. 5

We performed QE-RF field dependence measurements by two methods: 1) by varying the peak RF power into the gun and 2) by varying the laser input phase with constant RF power. Plots of average QE values phase scans with 150 pC charge at several different RF field levels are plotted in Fig. 4. The QE remains relatively flat, showing little or no evidence of field enhancement. The laser photon energy at 5 eV is well above the photoemission threshold.

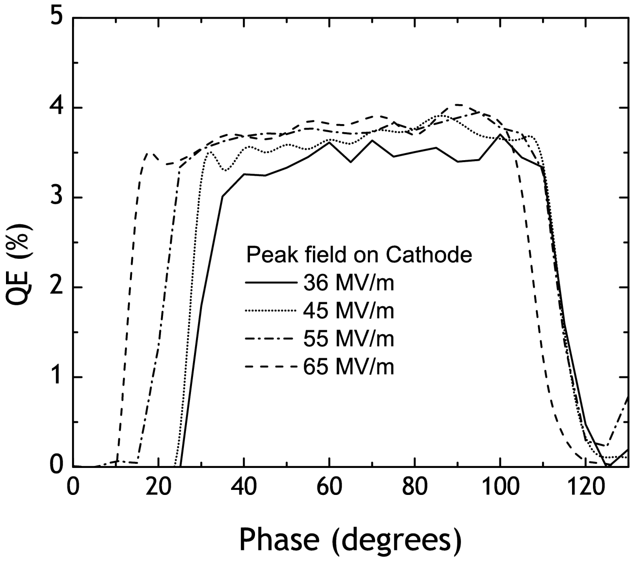

Figure 4: Averaged data from 4 phase scans at 36, 45, 55, and 65 MV/m. The scans are relatively flat showing little or no evidence of field enhancement.

Additional Studies and Analysis

The emission studies discussed here are broad in scope and continuing. For these reasons, only some of the highlights and preliminary results are presented. Additional work or data still to be analyzed includes: high charge phase scans, rastering the cathode with the laser to probe the spatial uniformity of QE, mapping the QE variations across the cathode and tracing them back to the deposition process or RF conditioning damage. Such a QE map may be of assistance in understanding variations in QE vs. laser spot size. Also planned are 1000 nC long bunch train QE measurements: generate from 4 to 32 bunches per train with 770 ps separation (1 RF period). The data will be analyzed for possible QE bunch-train position dependence.

SUMMARY

The first Cs_2Te photocathode is operating successfully at AWA in the new drive gun. In an effort to understand the performance limitations of the new gun and photocathode, photocathode emission studies will be conducted during conditioning and initial operation. RF conditioning of the Cesium telluride cathode has proceeded to 72 MV/m while maintaining QE at required levels. QE Phase scans using on-line laser energy and charge measurements indicate that the QE remains high after 1 month. Bunch train measurements have been performed, but the results are still being analyzed. The photocathode still in the gun shows a promising QE lifetime, plateauing near 4% in the gun after more than a month in the gun and over 6.6×10^{-10} RF pulses. Results from these studies will be analyzed and used to optimize the photocathode drive gun operation.

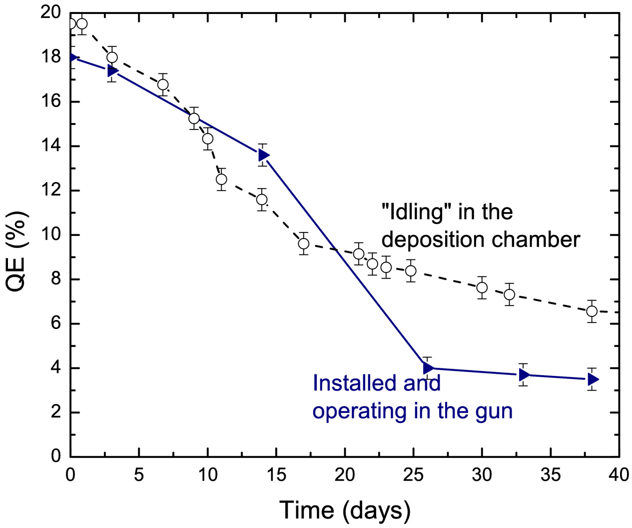

Figure 5: The QE for two photocathodes is plotted vs. time. The photocathode installed in the gun shows a promising QE lifetime, still near 4% in the gun after operating more than a month. Plotted for comparison is the QE lifetime of a photocathode “idling” in the deposition chamber.

ACKNOWLEDGMENTS

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (“Argonne”). Argonne, a U.S.Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S.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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