QE MEASUREMENTS OF A Nb-Pb SRF PHOTOINJECTOR

J. Smedley, T. Rao, J. Warren BNL, Upton, USA
P. Kneisel, TJNAF, Newport News, USA
J. Sekutowicz, J. Iversen, D. Klinke, D. Kostin, W. Möller, A. Muhs, DESY, Hamburg, Germany
P. Strzyżewski, A. Soltan INS, Swierk/Otwock, Poland

Abstract

We report recent progress in the development of a hybrid lead/niobium superconducting RF (SRF) photoinjector. The goal of this effort is to produce an injector with the SRF properties of a niobium cavity along with the superior quantum efficiency (QE) of a lead photocathode. A prototype hybrid injector, consisting of an all-niobium cavity arc-deposited with lead in the cathode region, has been constructed. We present the results of QE measurements on this cavity under RF field, and an arc-deposited cathode under DC bias at cryogenic temperatures.

INTRODUCTION

An injector capable of delivering moderate average current (~1 mA) along with significant peak current (~100 A) is needed for a variety of applications, including next-generation energy recovery linac based free electron lasers [1,2]. Superconducting cavity technology is uniquely suited to this task, as superconducting cavities are capable of supporting high accelerating gradients to minimize space charge problems at high peak currents, while avoiding the cooling issues inherent in high average current normal conducting RF injectors. A superconducting photoinjector has its own challenges – principally, how to introduce the photocathode into the superconducting cavity. An innovative solution to this has been developed by Forschungszentrum Rossendorf [3], utilizing an RF choke joint to allow a normal conducting cathode to be used in a superconducting cavity. We explore a second option – using the superconducting wall of the cavity as a photocathode. Previous work has demonstrated the feasibility of the concept by using the Nb back wall of the cavity itself as the photocathode. However, the low QE of Nb precludes this application [4]. For this reason, we concentrate on superconducting lead, which has been shown to provide roughly an order of magnitude higher QE compared to Nb [5] at room temperature with DC bias. The DC work investigated various methods of producing lead films on a niobium substrate, concluding that electroplating and arc-deposition were attractive candidates for lead film based cathodes in a photoinjector.

The first section of this paper will describe measurements of the QE of an arc-deposited lead cathode under DC bias at temperatures below the critical temperature for lead. The second section will describe QE measurements made on a ½ cell, 1.3 GHz SRF cavity with a 4 mm diameter spot of lead arc-deposited onto the center of the back wall. A second hybrid injector has been tested recently [6]. This ½ cell, 1.42 GHz cavity has a removable plug in the center of the back wall. The niobium plug was coated with lead via electroplating. The details of the RF measurements on both of these cavities are reported elsewhere [7].

LAYOUT

A cryostat in the Vertical Test Area (VTA) at Jefferson Lab was used for these measurements. The cryostat is set into the floor of the VTA – the bottom of the cryostat is almost 3 meters below the floor. A retractable radiation shield covers the cryostat. The internal volume radiation shield above the cryostat top flange is ~1 m^3. This space was used to house the photocathode laser and the transport optics. The cryostat is capable of cycling from room temperature to 2 K to room temperature in 8 hrs. The cryostat enclosure has RF sources for 0.7 to 2 GHz, as well as RF diagnostics.

Laser and Optical Layout

A KrF excimer laser (GAM EX5) was used to both laser clean the cathodes and extract photoelectrons. This laser is capable of producing ~6 mJ of 248 nm light per pulse, with a pulse duration of 5.3 ns FWHM and a variable pulse repetition frequency of 20-250 Hz. The laser and the transport optics were mounted on a breadboard bolted to the cryostat top flange. The beam path on the breadboard was folded to allow 1:1 relay imaging of an iris onto the cathode using a 1.5 m lens. The optical path length was almost 6 m, 3 m prior to the lens, and 3 m from the lens to the cathode in the cryostat. The transport efficiency was 55% through three turning mirrors, lens, and the input flange of the cryostat.

Laser Cleaning

Higher energy from the excimer laser was used to improve the QE of the cathodes by driving off surface contaminants, for both DC and RF cathodes. Previous work on lead has established an optimum energy density of ~0.2 mJ/mm^2 for cleaning lead to maximize the QE while avoiding damage to the coating [5]. Laser cleaning was performed with the full beam area, resulting in a cleaned area on the cathode of 5x4 mm^2. The cathode was irradiated for 200 seconds (30k shots at 150 Hz).

DC Measurements

The DC measurements used a vacuum cube mounted at the bottom of the laser transport tube (near the bottom of the cryostat). This cube contained a cathode and anode with a separation of 1 mm. The anode consisted of a mesh with 40 lines/in which could be biased to 1 kV, providing a 1 MV/m field on the cathode. The cathode was a niobium rod 9 mm in diameter and 8 mm long arc-deposited with ~1 µm of lead. The cathode was connected to a picoammeter (Keithley 6485), allowing the photocurrent to be measured. The optical transmission of the anode mesh was 90%.

RF Measurements

For RF cavity measurements, the cavity was initially mounted with the sealed end of the cavity up, as shown in Figure 1. This orientation was used to prevent debris from falling on the cavity during testing.

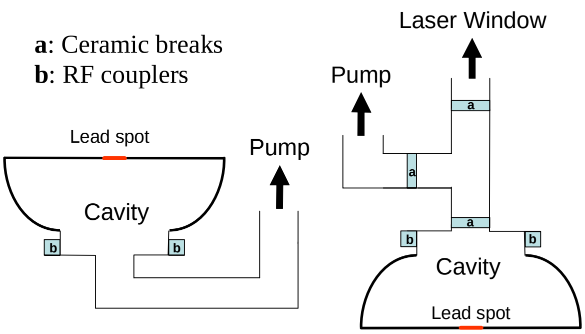

Figure 1: (left) Cavity orientation for RF measurements (right) Cavity orientation for QE measurements

For QE measurements in the RF cavity, the cavity was mounted with the exit iris up to allow the laser to hit the cavity back wall. In this orientation, the cavity was electrically isolated from the laser tranport tube with a ceramic break. DC isolators were used on the RF input and pickup cables. The outer wall of the cavity was connected via an electrical feedthrough on the top flange of the cryostat to the picoammeter, allowing the current leaving the cavity to be monitored. The last 1.5 m of the laser transport tube was isolated from ground as well. This allowed a DC bias of 1 kV to be used on the tube, to prevent secondary electron emission from the tube from reaching the cavity.

DC MEASUREMENTS

The QE of an arc-deposited lead cathode was measured at 295 K (Figure 2). The cathode was subsequently laser cleaned with an energy density of 0.15 mJ/mm^2 and the QE measured, again at 295 K. The QE was measured as the system was cooled, both above and below lead's critical temperature of 7.9 K [8]. The cathode was laser cleaned while cold, and the QE was measured again.

The QE did not change appreciably at cryogenic temperatures. The slight reduction in QE from 295 K to 8.8 K is likely caused by cryopumping onto the cathode: the QE is restored by laser cleaning while the cathode is cold. The QE of this arc-deposited cathode was significantly lower than previous arc-deposited cathodes measured in similar conditions [5]. To understand this difference, a scanning electron microscope was used to image the cathode after the measurement. Figure 3 shows the pre- (3a) and post- (3b) laser-cleaning surfaces of this arc-deposited cathode, along with the surface of a previous arc-deposited cathode (3c) after similar cleaning. This cathode shows significant gaps in lead coverage of the niobium substrate, both before and especially after laser cleaning. In particular, after laser cleaning, portions of the cathode have only 50% coverage of lead. This likely contributes to the lower measured QE for this cathode compared to previous arc-deposited cathode, which had no gaps in lead coverage.

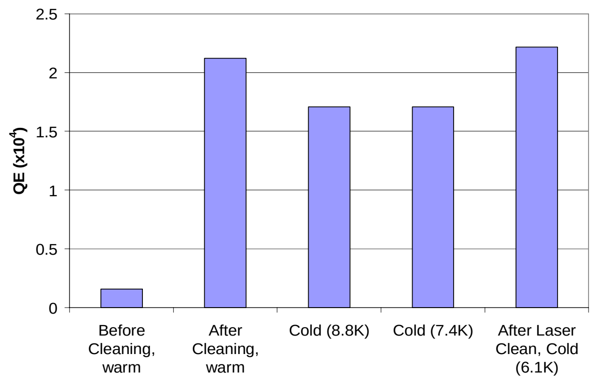

Figure 2: DC QE results

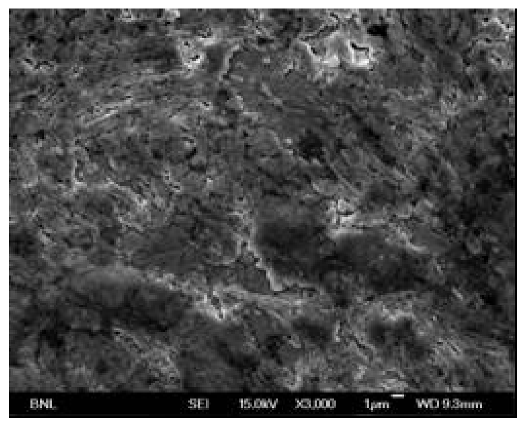

Figure 3a: Arc-deposited lead on niobium, before laser cleaning. Some patches of exposed niobium.

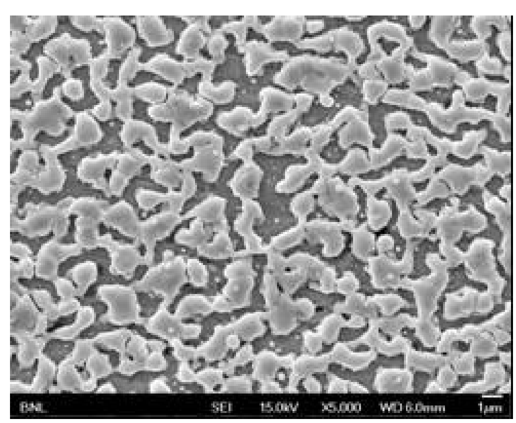

Figure 3b: Arc-deposited lead on niobium, after laser cleaning. Dark areas are exposed niobium.

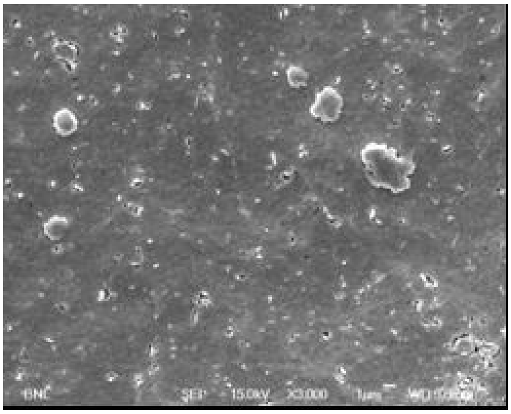

Figure 3c: previous arc-deposited lead on niobium, after laser cleaning [5]. No exposed niobium.

RF CAVITY MEASUREMENTS

A 4 mm diameter spot was plated onto the back wall of the 1.3 GHz niobium ½ cell via arc deposition. It should be noted that this deposition was done at the same time as the cathode used in the DC measurements, and may suffer from similar surface irregularities. The RF performance of this cavity is the subject of a related paper [7]. In brief, the Q_0 prior to lead coating was 10^{10} at 2 K, and the peak field was 40 MV/m. After lead coating, these values were largely unchanged. The RF performance degraded significantly when the cathode was mounted right-side up for the QE measurements. In this configuration, significant conditioning was required to reach 4.5 MV/m, and the Q_0 at low field was only 10^9. This degradation was likely caused by debris falling from the laser transport tube onto the cavity surface.

The current was measured leaving the RF cavity, in a manner similar to that used for the DC cathode. In this case, the entire cavity was electrically isolated and connected to ground through the picoammeter. A correction factor is required to account for the fact that the laser pulse duration of 5.3 ns covers many RF cycles at 1.3 GHz. A simulation was performed using ASTRA to determine the fraction of the electrons that could escape the cavity as a function of the peak electric field. The results are shown in fig. 4.

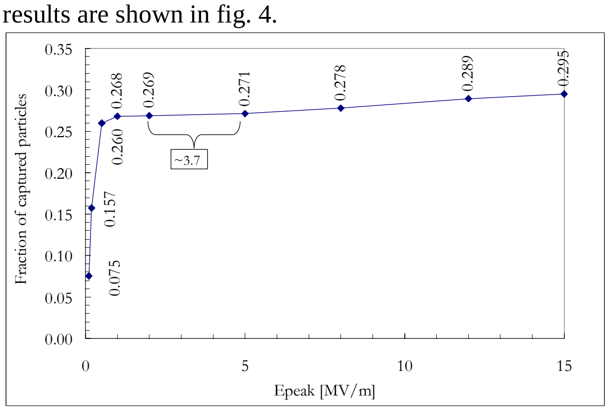

Figure 4: Fraction of photoelectrons which escape the cavity

Figure 5 shows the QE of the hybrid cavity after laser cleaning with an energy density of 0.17 mJ/mm^2. The laser was running with a repetition rate of 150 Hz and a pulse energy of 1.2 µJ on the cathode (0.18 mW). The calculated QE includes the correction factor from fig. 4. Also shown is the dark current with a Fowler-Nordheim fit.

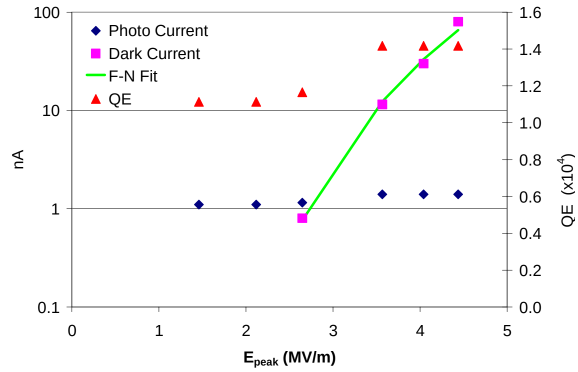

Figure 5: QE for hybrid Pb/Nb cavity

Figure 6 demonstrates the linear dependence of the photocurrent on laser pulse energy. The 3 mm diameter laser spot was scanned across the surface of the lead spot, confirming that emission came predominately from the lead coated spot - the photocurrent from the niobium area was at least a factor of ten lower than the lead spot.

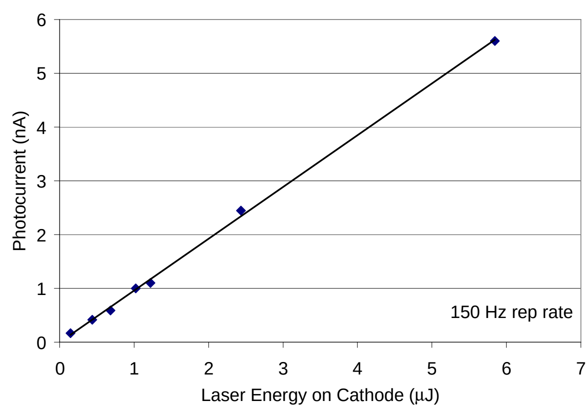

Figure 6: Linearity of photocurrent

CONCLUSIONS

QE measurements have been made for lead photocathodes in both DC and RF fields at cryogenic temperatures. The DC measurements demonstrate that the QE of lead does not change from room temperature to below its critical temperature. The QE measured for the lead cathode in a niobium SRF photoinjector was comparable to the DC value. Both the DC and RF QE values were a factor of three lower than previously measured arc-deposited lead cathodes at 248 nm. Poor coverage of the niobium by the lead film may contribute to this discrepancy. The lead coating does not significantly impact the RF performance of the cavity [7].

ACKNOWLEDGMENT

We would like to express our gratitude to colleagues at BNL, DESY, INS and TJNAF from whom we received technical support.

This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges, a world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for the United States Government purposes.

REFERENCES

[1] J. Sekutowicz et al., Phys. Rev. ST Accel. Beams **8**, 010701 (2005)

[2] F. Gabriel et al., Nucl. Instr. and Meth. in Phys. Res. **B 161-163**, 1143 (2000)

[3] D. Janssen et al., Nucl. Instr. and Meth. in Phys. Res. **A 507**, 314 (2003)

[4] T. Srinivasan-Rao et al., "Design, Construction and Status of All Niobium Superconducting Photoinjector at BNL", 2003 Particle Accelerator Conference (PAC'03), IEEE # 03CH37423C, p. 93 (2004)

[5] J. Smedley et al., "Progress on Lead Photocathodes for Superconducting Injectors", Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee, 2598 (2005).

[6] J. Smedley et al., "Photoemission Tests of a Pb/Nb Superconducting Photoinjector", to be presented at PAC 07, Albuquerque, NM, June 24-30 2007

[7] J. Sekutowicz et al., "Status of Nb-Pb Superconducting RF-Gun Cavities", to be presented at PAC 07, Albuquerque, NM, June 24-30 2007

[8] P. Schmuser, Superconductivity, desy.de/~pschmues