ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI059

FABRICATION OF ALKALI ANTIMONIDE PHOTOCATHODE FOR SRF GUN

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Abstract

The first alkali antimonide photocathode was prepared and inserted into the BNL 704 MHz SRF gun. An excimer laser cleaning system was installed in a cathode deposition chamber and the cleaning technique developed previously was used in the first cathode preparation. We also demonstrated that oxidized cathode can be removed by exposing it to the same excimer laser. In this paper, we show the set up of the incorporated laser cleaning system and the QE enhancement of alkali antimony photocathode. The vacuum evolution at transport cart and QE measurement system are also discussed.

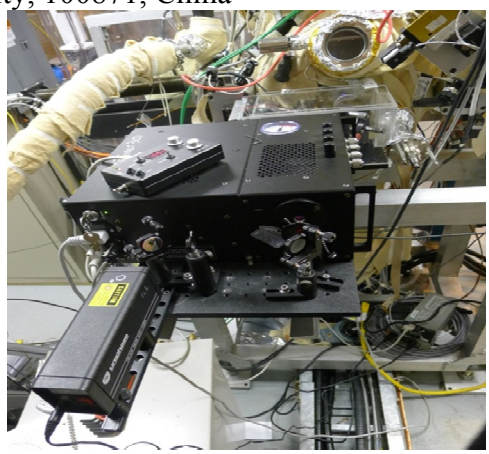
INTRODUCTION

The first beam test of the 704 MHz SRF gun will be a milestone for the high current ERL R&D and LEReC projects at BNL. The 704 MHz SRF gun is designed to accept an alkali antimonide photocathode as the electron source. In this design, the cathode is prepared in a separate deposition chamber and then transferred to the gun inside a cathode transport cart [1]. Hence, in order to meet this milestone, the contaminant sensitive cathode needs to be fabricated in the deposition chamber, transported through a UHV load-lock system, inserted into the gun and conditioned to minimize the dark current at the desired gun field.

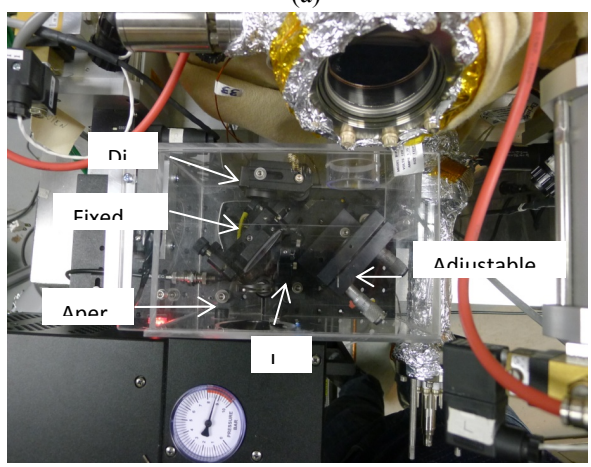
The design of the cathode stalk precludes us from using thermal process to clean the substrate prior to cathode fabrication and to remove the spent cathode. In the last year, we developed a technique of using excimer laser to enhance the photoemission of multi-alkali photocathode and remove used cathode layer. In the following sections, we describe the adaptation of this technique, fabrication of Cs_3Sb cathodes, the insertion process and vacuum evolution during the transport.

DESCRIPTION OF THE CATHODE PREPARATION SYSTEM

The multi-alkali deposition system was described in detail in a previous proceeding [2]. The laser and optical system for substrate cleaning is shown in Figure 1. It was designed so that it can be well aligned in a laser controlled area and moved to cathode deposition area.



(a)



(b)

Figure 1: (a) Excimer laser and alignment He-Ne laser; (b) Excimer laser beam optics and diode detector.

There is a fused silica viewport on the deposition chamber that transmits UV beam into the chamber. A focusing lens in the optical transport system is used to adjust the beam spot size on the cathode from 1.5 mm^2 up to 4 mm by 5 mm. Leakage light from one of the mirrors is used to monitor the laser power during laser scanning to clean the entire substrate. Multiple apertures in the beam path were used to monitor the beam alignment while transferring the laser system. The UV laser beam is fully enclosed by a plexiglass box to bring it down to the Class II laser level in the cathode deposition room.

*Work supported by Brookhaven Science associates, LLC under Contracts No.DE-AC02-98CH10886 with the U.S. DOE
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Cs_3Sb CATHODE GROWTH PROCEDURE

Currently, the cathode substrate is copper. For first beam test, a Cs_3Sb cathode was fabricated instead of K_2CsSb as planned due to the uncertainty in establishing the potassium layer thickness and because Cs_3Sb is more reproducible and has higher QE than K_2CsSb. The following procedure was used to form the cathode layer:

- Set up the excimer laser for cleaning the substrate.
- Laser scans the entire substrate area.
- Heat up the copper stalk to 80°C.
- Evaporate 100 nm thick Sb layer on the substrate by measuring the thickness using a crystal monitor.
- Increase the substrate temperature to 140°C.
- Evaporate Cs while monitoring photocurrent. Stop Cs evaporation when the QE plateaus.
- Quickly reduce the substrate temperature to 25°C.
- Move the cathode stalk into the transport cart once the photocurrent is stable.

THE ROLES OF EXCIMER LASER IN CATHODE PREPARATION

Excimer Laser Enhances Cathode Photoemission

Enhancement of photoemission due to excimer laser exposure was demonstrated on Mo and Ta in our previous tests [3]. We also successfully applied this method on Si, Cu and Ti substrates with the same laser parameters. The QE enhancement ranges from 50% to 300% depending on the substrate's initial condition. The higher the substrate contamination, the larger is the QE enhancement. We also proved that with an optimized laser pulse energy density, the substrate surface finishing does not change.

Table 1: Comparison of QE before and after exposure to a 248 nm laser beam for various materials.

Material	QE_ laser exposed (%)	QE_laser unexposed (%)
Mo	6	4
Cu	0.25	<0.1
Ta	6	3.5
Ti	4.4	1.6
Si	8	5.5

Table 1 shows QE improvement due to excimer laser exposure for the various materials. The metal substrates were cleaned using identical UHV procedure and the silicon sample was etched with piranha solution prior to installation in the vacuum chamber.

In the first cathode fabrication, we exposed a 4 mm by 4 mm area of the copper substrate to the UV laser. The exposed area has 30 times higher QE than the rest of substrate. To avoid this large QE variation on the cathode surface, for the second cathode we exposed to entire substrate surface to the UV laser and got relatively uniform photoemission over the cathode area.

Excimer Laser Removes Old Cathode Layer

The first cathode was exposed to ambient air in a vacuum accident. Our 704 MHz cathode stalk also functions as choke joint for the SRF cavity, and hence is difficult to replace. As the QE of the cathode in operation degrades beyond acceptable value, growing new cathode layers over this spent layer will not only degrade the QE but may also increase the risk of introducing flaked cathode material into the SRF gun. Conventional heat cleaning to remove the spent layer is not possible in this system due to the large mass of the cathode stalk.

Mechanical polishing can be another option to remove this cathode layer. That approach would necessitate removal of the stalk from the vacuum chamber and mechanical polishing out the old layer from the cathode. This would then be followed by numerous steps, including particulate removal, stalk re-alignment and vacuum chamber baking before the new cathode can be grown on the substrate. Total process would have taken more than one month.

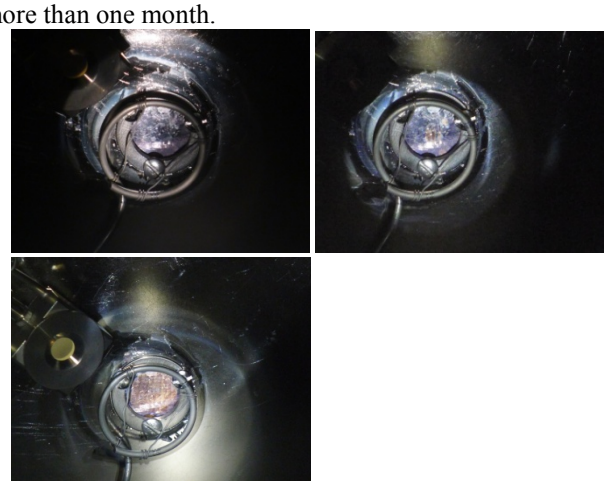

Figure 2 a) before exposure to excimer laser; b) small area exposed, cathode layer has been removed exposing copper substrate; c) entire cathode layer was removed and copper substrate is fully exposed. The ring on the top of the cathode is anode.

By irradiating the exposed cathode with a 248 nm beam, we were able to remove the contaminated layer in just two days that included preparing laser, aligning the optics and cathode removal. Figure 2 shows the evolution of contaminated cathode layer during the removal process. The optimal laser energy density for cathode removal and substrate cleaning is 2.5 mJ/mm^2 The laser spot size on the cathode substrate is 2.5 mm by 2 mm. A cathode area of 320 mm^2 was scanned with step size matched for 50% overlap in laser spot size. Total of 200 spots on the cathode were illuminated with a dwell time of 30 seconds/spot. The entire process lasted 7 hours. The chamber vacuum increased from $2*10^{-10}$ torr to $7*10^{-10}$ torr during laser scan but recovered within a few seconds once the laser illumination was stopped. In order to keep the laser energy density constant, the laser was filled with

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fresh KrF gas just before moving to cathode area. The laser output power can be changed by adjusting the discharge power of the laser. A diode was placed to monitor the leakage light from a mirror and hence the energy density on the cathode. The initial laser energy density was 2.5 mJ/mm^2. After 7 hours operation, power had decayed by 15%, which was compensated by increasing the discharge power to the laser maintaining energy density fluctuation on the cathode to be less than 0.1mJ/mm^2. The second cathode was fabricated using the recipe described above, resulting in a QE of 0.25%, which was higher than the QE of first cathode. It indicates the oxidized cathode layer was totally removed and the substrate was not harmed. The QE is lower than the published value due to the interaction between the copper substrate and antimony prior to formation of Cs_3Sb [4].

CATHODE TRANSPORT AND INSERTION INTO THE GUN

The cathode was retracted into the transport cart and moved to the gun. The load lock ports were protected to preserve particulate-free environment. A cold finger had been incorporated in the transport system to keep the contaminants reaching the cathode surface while the load lock system was baked. Figure 3 shows vacuum evolution of the transport cart and load lock system over a period of 20 days.

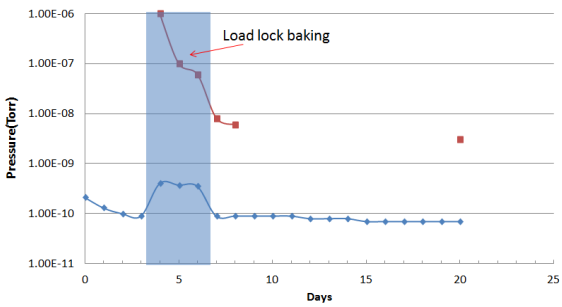

Figure 3: Vacuum evolution when cathode in transport cart. The red curve is the pressure in the load lock section and blue curve is in the cathode section. The blue shaded area shows the period when the load lock section was baked and the cathode was protected by a LN_2 shield.

The cathode vacuum was in the 10^{-11} torr scale except during the three days when the load lock section was baking, when it increased the pressure to low-10^{-10} torr. Such vacuum would preserve the cathode QE for several weeks with minimal decay. The cathode stayed attached to the gun but valved off from it for about 22 days waiting for the gun to be ready.

With the present arrangement, we are only capable of measuring the cathode QE in the preparation chamber and in the gun. We have designed a QE measurement system which can be incorporated into the transport cart. It consists of a laser pointer, linear translator and a mirror anode. The mirror anode performs two functions: 1) it reflects the 532 nm beam from a laser pointer mounted outside the vacuum envelope to illuminate the cathode, 2) with a small positive bias, acts as an anode to collect the charge leaving the photocathode upon laser illumination. The translator allows the insertion of the mirror/anode in front of the cathode for QE measurement. With this device, we will have capability to study the QE evolution in cathode transport cart as well as the effects of RF conditioning of the gun.

CONCLUSION

The two alkali antimonide cathodes were grown for the 704 MHz SRF gun. The first cathode was inadvertently exposed to atmosphere and the second one is being tested in the gun now. With this cathode, a gap voltage of 1.4 MV in pulsed mode and 1.2 MV in CW mode have been reached. We designed and built a compact excimer laser cathode cleaning system, which performed very well in both cleaning the cathode substrate and removing entire contaminated cathode layer. The QE of the second cathode is better than QE of the first one. The vacuum during transporting the cathode is good to preserve the cathode quality. We also designed an in-situ QE measurement device that can be added on to the transport cart to study the QE evolution.

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