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PROGRESS ON GROWING A MULTI-ALKALI PHOTOCATHODE FOR ERL AT BNL

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Abstract

K_2CsSb is a robust photocathode capable of generating electron beams with high peak, high average current and low thermal emittance. During the last two years, a great improvement in the design and fabrication of a reliable deposition system suitable for K_2CsSb cathode growth and its insertion into BNL high current ERL SRF gun has been achieved. A standard procedure for the growth of multi-alkali cathodes combined with another procedure to transport these cathodes into the SRF gun was developed. The first cathode is planned to be grown on a copper insert and mounted into the 704 MHz gun. In this article, we will describe the progress of cathode growth and transport for ERL project. In particular, effect of excimer laser exposure and the cathode growth on Ta will be included.

INTRODUCTION

The multi-alkali photocathode is considered to be suitable for high current applications due to its high quantum efficiency at visible wavelengths. The photocathode of choice for BNL-ERL photo-injector is K_2CsSb due to its capability to generate high average current and low emittance electron beams. The 704 MHz SRF photoinjector is built for testing ERL concept up to 500 mA high average current. A multi-alkali photocathode deposition system for this gun was built by Advanced Energy Systems (AES) [1]. In last two years, we assembled entire system and grew several cathodes to find the optimal cathode preparation parameters. We also tested the transport cart and insertion of the cathode plug through the load-lock system. 0.2% QE was obtained from a K_2CsSb cathode grown on the copper substrate. Currently, the gun is being conditioned for CW SRF operation with a copper cathode plug and the vacuum in both the deposition chamber and the transport cart is maintained in low 10^{-10} torr range. The cathode will be deposited on this plug soon after the conditioning. The first cathode test in the gun is scheduled for November.

DESCRIPTION OF THE DEPOSITION SYSTEM

The K_2CsSb deposition system consists of a main deposition chamber and three source chambers attached to the main chamber but isolated from each other and the main chamber through gate valves. The main chamber is equipped with two view ports, an RGA, a quartz crystal monitor, anode, resistive heater and load-lock port. Ion pumps integrated with NEG pumps maintain the vacuum in low-10^{-10} torr scale. Each of the source chambers has one ion pump keeping the vacuum in mid-10^{-10} torr range. Bellows coupled manipulator can move the sources into the deposition chamber and locate them in front of the substrate. We use Alvatec Alkali metal source of type S and 99.999% purity pellets antimony source. The alkali sources are evaporated by resistive heating of the source container and the Sb is evaporated by heating a boat which holds the crucible containing Sb pellets. Each alkali arm contains two Cs or K sources to increase the evaporation area and cathode uniformity. To protect the sides of the cathode plug from being coated with the cathode material, an aperture is placed between the substrate and the source to limit the deposition area to a 0.75 inches diameter. The substrate can be heated or cooled by flowing dry N_2 gas through a pipe in contact with the stalk. With the same pipe, the stalk is maintained at LN_2 temperature when in the SRF gun. The stalk can be heated up to 200 °C and maintained at optimal temperature for evaporation. To determine the initial quantum efficiency, the cathode is irradiated with a low power CW laser. Emitted electrons are collected at the anode in front of the cathode. The whole deposition system is placed in a class 10,000 clean room shown in Figure 1. The load lock connection port is inside a class 100 clean room to avoid accumulation of the particulates in section that comes in contact with the SRF gun.

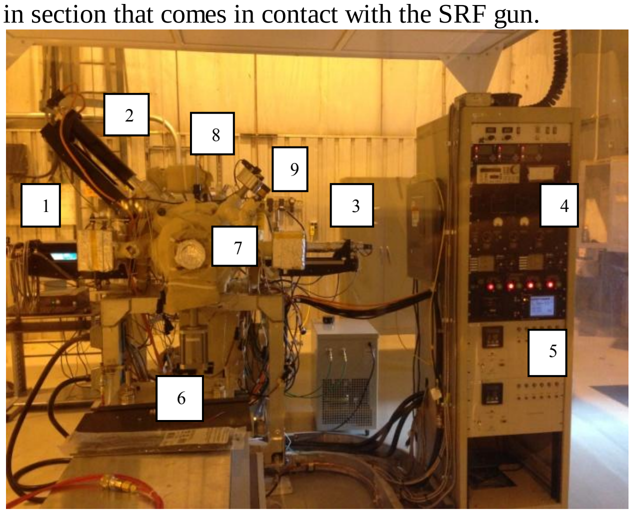

Figure 1: The picture of ERL-deposition system: 1 – K source; 2 – Sb source; 3 – Cs source; 4 – control system for valves and source; 5 – power supply for baking; 6 – table for supporting cathode transport cart; 7 – load lock port; 8 – heater; 9 – crystal monitor.

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We use a specially designed transport cart to transfer the cathode between the deposition system and the SRF gun. The cathode substrate is an integral part of a grooved choke joint structure mounted inside the transport cart as shown on Figure 2c. The diameter of the copper stalk is 1 inch. The transport cart consists of a bellow manipulator and an intermediate section, which is connected to either the deposition system or the gun. The vacuum plenum of the cart is made up by two ion pumps and one TSP. During baking of the intermediate section prior to transferring the cathode, the cathode is protected from the gas load by a cold shield near the isolating valve. The QE of K_2CsSb cathode will be preserved for a few weeks in the low 10^{-10} torr vacuum achieved in the load-lock. Two identical transport carts have been fabricated to allow the gun to be tested with one cathode while the second is being prepared. The transport cart is shown in Figure 2a. Currently, the transport cart is attached to the gun for RF condition, see Figure 2b.

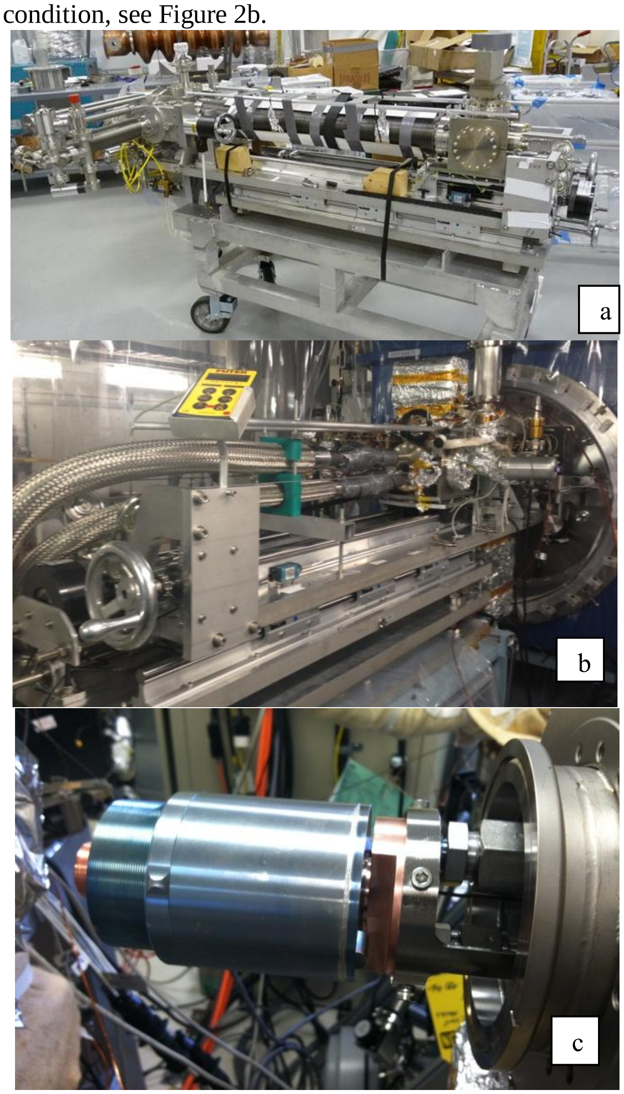

Figure 2: Photographs of the cathode and transport cart: a) The cathode transport cart; b) The transport cart attached to the gun and the cathode stalk inserted. Two line attached to the manipulator are for cooling the cathode in the gun. Same port will be used for heating the substrate during cathode preparation; c) The cathode stalk mounted on the transport cart.

STANDARD CATHODE GROWTH PROCEDURE

- Heat up the stalk to 100°C.
- Evaporate Sb layer to a thickness of 10 nm. The thickness is measured by a crystal monitor.
- Increase the substrate temperature to 140°C.
- Evaporate K layer to 20 nm while monitoring the photocurrent change. Stop evaporation when photocurrent reaches maximum amplitude.
- Decrease the temperature.
- Evaporate Cs when temperature goes to 130□ C, while monitoring photocurrent. Cs evaporation is stopped when the QE plateaus.

SELECTION OF CATHODE SUBSTRATE

In the first gun tests with electron beam, we will use K_2CsSb photocathode grown on the copper stalk. Because copper atoms easily diffuse into K_2CsSb crystal, the QE of a single layer cathode is usually lower than pure K_2CsSb crystal. Typically, the QE of K_2CsSb on copper cathode would be around 0.1% to 0.2% following the standard growth procedure. We have grown a single K_2CsSb layer on the copper substrate in this deposition system several times. The best QE was 0.2%. Additional K_2CsSb layers reduce the probability of copper atoms diffusing into emission surface, thereby increasing the overall QE But the thicker layer may result in flaking of the cathode material, which is detrimental to SRF operation. It is shown that high QE K_2CsSb cathode can be grown on Si [2], however, the large dielectric loss of Si in CW SRF environment precludes its use in an SRF gun. To find the suitable metal substrate for the 704 MHz gun, we compared the performance of the cathode on two substrates, Mo and Ta, chosen for compatibility of their mechanical, thermal and electrical properties with the SRF gun. Both samples were from Goodfellow with better than 99.9% purity. The samples' thickness is 0.5 mm. The Mo sample has an optical quality surface finish. The Ta samples with different surface finishes were tested for QE. One Ta sample was polished by 9 um polishing compound with Metadi No 40-6543 diamond suspension from Beuhler. Another identical Ta sample was not polished. No *in situ* cleaning was performed on any of these samples and *ex situ* cleaning consists of only typical ultrasonic cleaning and rinsing with acetone prior to insertion in the vacuum chamber. We found the cathodes on polished and unpolished Ta substrates to have nearly the same spectral response. Also, QE of both cathodes is similar with a value of 2.53%. Then, with the same procedure, we obtained a 3% QE with Mo substrate. The operating life time of the cathodes on all these substrates, measured using a low power 532 nm laser beam was comparable. Therefore, both Mo and Ta are suitable substrates for growing K_2CsSb cathode. The next step was incorporating the substrate material in our pre-existing cathode stalk, to be inserted into SRF gun. We sputtered a Mo layer with different thicknesses onto a 1 inch diameter polished copper stalk. However, none of the Mo layers adhere to the copper well and easily flaked off raising concerns over its operation in SRF gun. Then, AES, Inc. brazed a 0.006" thick Ta foil on the copper stalk. The braze material is under the entire surface of the Ta foil. The Ta attached to the stalk well, as shown on the left hand side of Figure 3. We measured the particles generation and electrical contact for the Ta-Cu brazed sample before and after cooling down to LN_2 temperature. Four-point resistance measurement shows that the resistance between Ta and Cu did not change after the cool down cycle. In a class 100 clean room, we immersed a particulate free Ta-Cu brazed sample into LN_2 and after cooling cycle, we compared the particle count with another identical sample which did not undergo the thermal cycling. We found the particle counts of both samples are comparable. There was no fracture in either Ta or braze material after cooling cycle. Therefore, we chose the Ta-Cu brazed stalk for the 704 MHz SRF gun test. This stalk is currently under procurement.

Figure 3: Left – the dummy brazed Ta-Cu sample; Right – the polished copper cathode stalk with the choke joint section.

NON-THERMAL SUBSTRATE CLEANING AND CATHODE REMOVAL

While operating in an electron gun, the K_2CsSb cathodes have limited charge life time. Usually, new cathode layers are grown over the used layer. However, after a few evaporations, the collective layer becomes thick enough to flake and contaminate the gun environment. For an SRF gun, non superconducting material contaminations will lead to field quenching or field emission. Heating the substrate to 800˚C may remove the old layers but is not suitable for the 704 MHz gun stalk due to significant engineering problem associated with the design of the heavy cathode plug. We have demonstrated that 248 nm excimer laser can totally remove the K_2CsSb cathode and preserve the substrate roughness [3]. We grew a cathode following the standard procedure described above. The excimer laser beam size is 3.5 mm^2. A collinear green laser with spot size smaller than that of the UV laser was used to measure the change in QE. We found that with excimer laser energy density of 3.5 mJ/mm^2 and repetition rate higher than 30 Hz, the cathode photocurrent decreases to background within 10 seconds. Figure 4 shows the regions exposed to the excimer laser, appearing visibly different. We used EDX to measure the elements present on the surface. In the EDX spectrum, we found the Sb, K, Cs signals were completely eliminated in laser exposed areas.

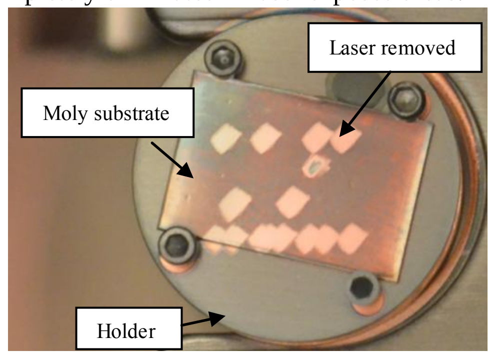

Figure 4: Excimer laser radiated K_2CsSb cathode sample. The rectangular regions are exposed to the laser. The cathode material in these regions is removed.

This technique can be used to address three issues associated with multi-alkali cathodes in high current photoinjectors. For instance, i) once the QE of the cathode decays below the design value, by irradiating it with the UV laser, we can clean substrate and remove the cathode simultaneously prior to fabricating the new cathode on the same substrate without any degradation of the UHV system. ii) Enhance the photoemission. We fabricated cathode with a stable 6% QE on a laser exposed Ta substrate. iii) In a photo-injector, by exposing the cathode to the UV laser, the cathode area could be exactly matched to the electron beam size, the halo electron beam generated either by the halo of the laser or the scattered laser beam can be completely eliminated, thereby improving the electron beam quality and reducing the beam loss induced pressure increase.

CONCLUSION

The cathode deposition system for the 704 MHz gun is ready for use. The photocathodes were grown on the copper cathode stalk a few times and a reasonable QE was obtained. The transport cart with the cathode stalk was pumped down to low 10^{-10} torr and tested in the SRF gun. We developed a new technique to remove the K_2CsSb cathode material by an excimer laser.

REFERENCE

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