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RESEARCH ON ALKALI ANTIMONIDE PHOTOCATHODE FABRICATION RECIPE AT PKU

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Abstract

Low emittance, high QE and long lifetime photocathode is widely studied for X-ray Free Electron Laser (XFEL) and Energy Recovery Linacs (ERL) applications. A deposition system for alkali antimonide photocathode (K_2CsSb, Cs_3Sb etc.) is being commissioned at Peking University. In this paper, we present our experimental results on alkali antimonide photocathode with this deposition system. We successfully fabricated Cs_3Sb photocathode on oxygen free copper, p-type Si (100) and Mo substrates with QE of 1.4%, 2.6% and 2.6% respectively.

INTRONDUCTION

XFEL, ERL and electron cooling demand low emittance, high QE and long lifetime photocathode. The alkali antimoide photocathode has high QE (4~10%) at green light, low intrinsic emittance (~0.5 μ m/mm) and long lifetime [1]. DC-SRF injector was stable operation to generating CW electron beams in 2014 at PKU [2]. Now, a low emittance DC-SRF photocathode injector (DC-SRF-II) is under construction for XFEL at PKU. In order to meet the requirement of the upgraded version of DC-SRF-II injector (bunch charge 100 pC, lower emittance < 1μm and repetition rate ~1MHz) [3-4], we choose the alkali antimonide photocathode.

In this paper we present our alkali antimonide photocathode deposition system and experimental results on fabricating Cs_3Sb photocathode at PKU. We also measured its spectral response and dark lifetime on the UHV system.

ALKALI ANTIMONIDE PHOTOCATHODE DEPOSITION SYSTEM

We have developed an alkali antimonide deposition system which consists of a deposition chamber, a transport chamber, a suitcase chamber, a spectral response measurement system, an intrinsic emittance measurement system (under construction based on LBNL design [5]), and four manipulators to transfer the sample. The substrate was initially kept in the suitcase chamber, and then transferred to the transport chamber by two manipulators. Utilizing another manipulator, the substrate can be moved to the deposition chamber. When the photocathode was prepared, it can be transported to injector by suitcase or though the transport chamber. Three sources, Cs, K and Sb were mounted on the deposition chamber and alkali sources were separated from each other and from the chamber by ultrahigh-vacuum (UHV) gate valves. A sputtering ion pump (400L/s) and SAES NEG pumps (3500L/s and 2000L/s) can provide pressure 10^{-9} Pa in deposition chamber and transport chamber. We employed a quartz crystal monitor to record the thickness of the film during evaporation and a residual gas analyser (RGA) was utilized to analyse the partial pressure of gases in the deposition chamber (see Fig. 1). The photocathode was irradiated by a 520 nm, power adjustable laser and we employed a Keithley 6485 picoammeter to monitor the photocurrent leaving the photocathode.

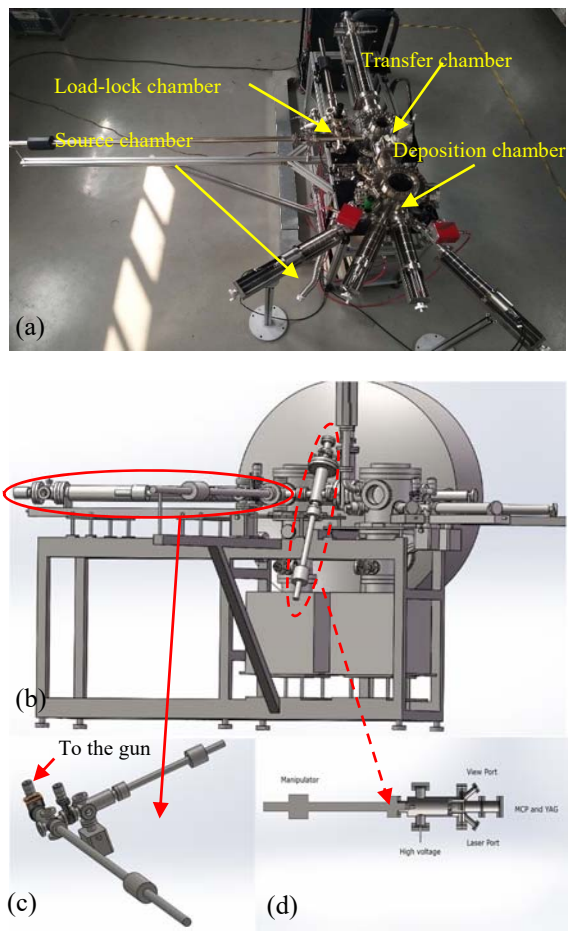

Figure 1: (a) Photograph and (b) schematic diagram of alkali antimonide photocathode deposition system. (c)Suitcase. (d)The intrinsic emittance measurement system.

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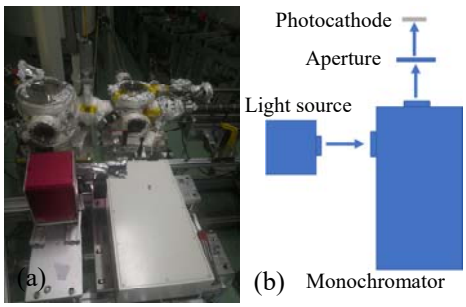

Figure 2: (a) Photograph and (b) schematic diagram of spectral response measurement system.

The spectral response measurement system consists of light source (Xenon and Mercury-Xenon Short-Arc Sources: 240 - 2400 nm), a monochromator (200-2500 nm) and an aperture (see Fig. 2). We can use the spectral response measurement system to research the work function and band structure of photocathode, especially when the photocathode is in low-temperature environment. The spectral response system can be used to measure the work function of the photocathode. And the temperature dependence of the spectral response can also be derived when the cathode is cooled by liquid nitrogen.

Cs_3Sb PHOTOCATHODE FABRICATION AND DISCCUSION

We have fabricated Cs_3Sb on Cu, Mo and p-type Si (100) substrates to research the recipe .The following will introduce our experiments and results.

Cs_3Sb Photocathode on Cu Substrate

The Cu substrates were electropolished in solution of phosphoric acid and N-butanol and then was passivated in sulfamic acid (see Fig.3). Then the substrate was ultrasonic reinsed in alcohol and dried with flowing N_2 gas.

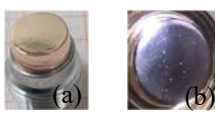

Figure 3: (a) Cu substrate after EP. (b) Cs_3Sb photocathode on Cu substrate.

The recipe of Cs_3Sb photocathode on Cu substrate is as following:

- The Cu substrate was degassed in UHV chamber @ 400 °C for about two hours.
- Deposit Sb film about 13nm~16nm at 140°C.
- Start Cs activation after Sb film is deposited. The Cs activation stopped when the photocurrent reaches a plateau. The substrate is cooled naturally.

We can see the whole process of Cs_3Sb cathode growth from Fig. 4(The peaks of the chamber pressure curve corresponds to the movement of sample holder, source arms and crystal monitor in the deposition and transferring chamber). The fresh QE of Cs_3Sb on Cu could reach 1.4% (#20190616) at 520 nm laser. The 1/e dark lifetime is about 2 weeks. The QE map of the photocathode was also measured.

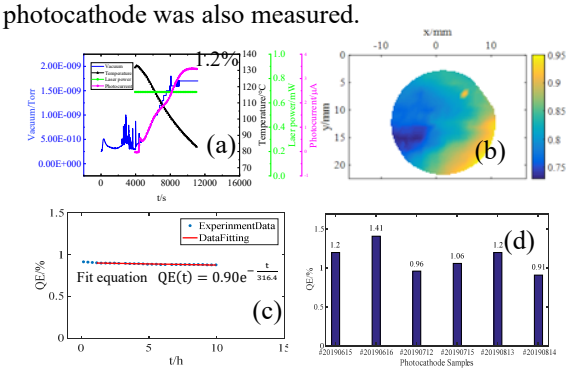

Figure 4: (a) The fabrication process of Cs_3Sb photocathode #20190813. (b)QE map of Cs_3Sb photocathode #20190813. (c)Dark lifetime of Cs_3Sb photocathode #20190813. (d)QE of Cs_3Sb on Cu substrates.

Cs_3Sb Photocathode on Mo Substrate

Mo is widely used as the substrate for photocathode deposition accounting for its chemical stability worldwide [6]. The Mo substrate was polished with sandpaper from 1500# to 7000# and diamond paste (see Fig. 5). The cleaning procedures were similar as Cu.

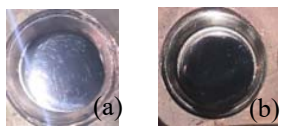

Figure 5: (a)Mo substrate after polished by sandpaper and diamond paste. (b)Cs_3Sb photocathode on Mo substrate.

As we can see in Fig. 6, the fresh QE of Cs_3Sb on Mo substrate was ~ 2.6% incident by 520nm laser.

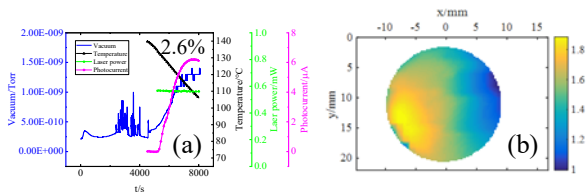

Figure 6: (a)The activation process of Cs_3Sb photocathode #20190909. (b)QE map of Cs_3Sb photocathode #20190909.

From Fig. 3 and Fig. 5, the Cu and Mo substrates were not optical polished. The surface was rough and it may also influence the film growth and the emittance of the photocathode [7].

Cs_3Sb Photocathode on Si Substrate

The Si substrate surface was smooth and no processing was needed. We also fabricated Cs_3Sb on p-type Si substrate with recipe in Table 1. The Si wafer has a resistivity of 0.001~0.009 and was cleaned by 2% HF solution for 5 min. Then the wafer was reinsed in alcohol and dried with flowing N_2 gas (see Fig. 7).

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Table 1: Recipe of Cs_3Sb on Si Substrate

Photocathode	Recipe
#20190714	Sb film: 13-16nm 140°C Cs: 140°C
#20190811	Sb film: 13-16nm 140°C Cs: 140°C
#20190906	Sb film: 13-16nm 120°C Cs: 120°C

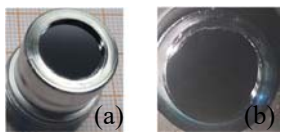

Figure 7: (a)Si substrate after cleaning. (b)Cs_3Sb photocathode on Si substrate.

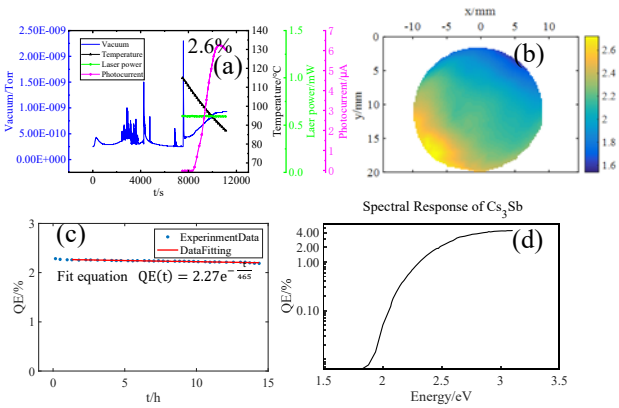

Figure 8: (a) The Cs_3Sb photocathode fabrication process of #20190906. (b)QE map of #20190906. (c)Dark lifetime of #20190906. (d)Spectral response measurement of #20190906.

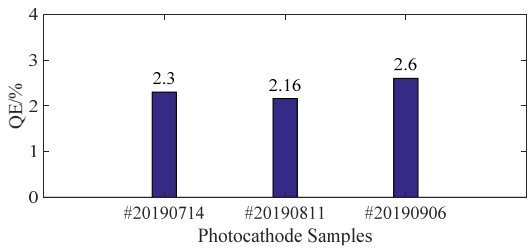

Figure 9: QE of Cs_3Sb on Si substrates.

The fresh QE of Cs_3Sb on Si substrate could reach 2.6% and the dark lifetime was about 3 weeks (see Fig. 8 & Fig. 9). From the QE map of #20190906, the QE of most area could achieve more than 2%.

In order to optimize the recipe, the morphology of the Sb film on Si substrate was investigated with SEM. The thickness of the Sb film is about 13nm. As shown in Fig.10, the Sb islands were separate which means that the Sb film might be too thin. So the Cs_3Sb could not crystallize fully and the QE was lower. Also, the reason that the quality of #20190906 was better than #20190714 and #20190811 might be the Sb film of #20190906 was thicker, because the lower temperature may be beneficial to Sb films deposition.

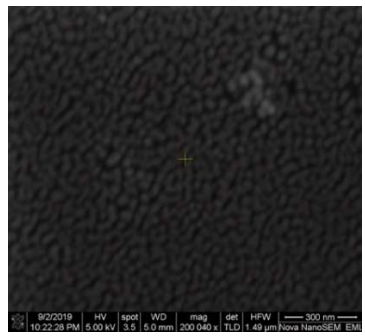

Figure 10: The morphology of Sb film on Si substrate.

CONCLUSION

We successfully fabricated Cs_3Sb photocathode on oxygen free copper, Mo and p-type Si (100) substrates with QE of 1.4%, 2.6% and 2.6% respectively.

In the future, the recipe will be further optimized and bialkali photocathode will also be fabricated and tested in the DC-SRF injector at PKU. The cryogenic effect on QE and intrinsic emittance of alkali antimonide photocathode will also be investigated.

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