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PREPARATION, TRANSPORT, AND OPERATION OF HIGH QUANTUM EFFICIENCY SEMICONDUCTOR Cs_2Te PHOTOCATHODE FOR SHINE

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Abstract

In the light of the high repetition rate, high brightness and other operating characteristics of SHINE, the photocathode with high quantum efficiency (QE), low emittance, and long operating lifetime is required to produce high-quality electron beam. After solving these problems of ultra-high vacuum acquisition, photocathode plug transmission/pick-and-place in vacuum, and photocathode preparation process, the Cs_2Te photocathode prepared on SHINE photocathode preparation device based on Te intermittent and Cs continuous deposition method has a QE greater than 5% under 265 nm light irradiation, and the QE remains almost unchanged in the photocathode preparation device, photocathode suitcase, photocathode loading device, and electron gun.

INTRODUCTION

Although Cs_2Te photocathode has a longer lifetime compared to GaAs and K_2CsSb photocathode, there is still a tremendous gap in lifetime compared to metal photocathode, and it is sensitive to H_2O, O_2, and CO_2. The Cs_2Te photocathode used in the field of electron sources needs to be prepared, transported, tested, stored, and operated under ultra-high vacuum conditions, requiring specialized ultra-high vacuum devices, the preparation and transport device are complex and expensive. Many universities and laboratories, such as INFN-LASA, DESY (PITZ, FLASH), CERN, ANL, BNL, LBNL, Peking University, etc., have conducted extensive research on Cs_2Te photocathode. SHINE photocathode facility mainly consists of a photocathode preparation device and a photocathode loading device.

PHOTOCATHODE FACILITY

Photocathode Preparation Device

SHINE photocathode preparation device draws on the experience of the design, machining, assembly, debugging and operation of SINAP photocathode preparation device. The biggest performance improvement of SHINE photocathode preparation device is to improve the vacuum degree of the photocathode preparation chamber, to prepare a Cs_2Te photocathode with better performance. The SHINE photocathode preparation device mainly consists of a plug installation and heat cleaning chamber, a preparation chamber, two evaporation source chambers, and a suitcase. There is an air lock chamber between preparation chamber and suitcase. The SHINE photocathode preparation device is shown in Fig. 1. The static vacuum of the preparation chamber is 2.78×10^{-9} Pa.

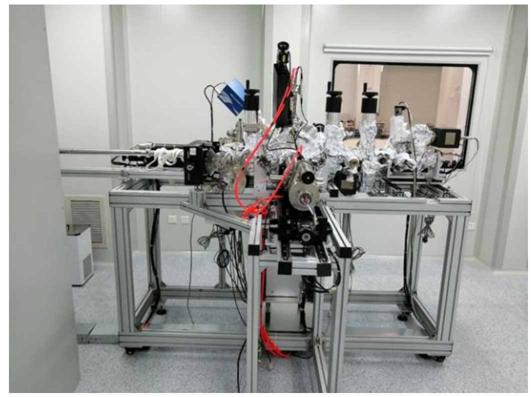

Figure 1: Photocathode preparation device.

Photocathode Loading Device

The photocathode loading device consists of a photocathode load lock, an air lock chamber, a photocathode suitcase, and a transition chamber (connected to the VHF electron gun). Under ultra-high vacuum conditions, the prepared Cs_2Te photocathode is transferred from the photocathode suitcase to the photocathode working position in the electron gun, and the degraded photocathode is transferred from the electron gun to the photocathode suitcase with photocathode loading device. The photocathode loading device is shown in Fig. 2.

Figure 2: Photocathode loading device.

The static vacuum of the photocathode load lock is 8.87×10^{-9}Pa; During the transfer process of Cs_2Te photocathode, the operation needs to be as slow as possible to ensure the dynamic vacuum is better than 5×10^{-8}Pa.The Cs_2Te photocathode transmission must be carried out

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under ultra-high vacuum conditions to prevent performance degradation. The Cs_2Te photocathode prepared by the photocathode preparation device is transferred to the photocathode suitcase, where the photocathode suitcase (the ion pump is powered by UPS to maintain ultra-high vacuum) is transported approximately 1km, as shown in Fig. 3.

Figure 3: The transport process of Cs_2Te photocathode.

PHOTOCATHODE PREPARATION

Preparation of Cs_2Te Photocathode Based on SHINE Photocathode Preparation Device

In order to eliminate the interference of dark current during the photocathode preparation process, Te intermittent and Cs continuous deposition of the high QE Cs_2Te photocathode, is developed by drawing on the GaAs photocathode Yo-Yo activation method of Cs and O activation[1]. Te and Cs are mounted on the same evaporation holder, the Ta boat is replaced by the SS boat for Te evaporation. The typical Cs_2Te photocathode preparation process with Te intermittent and Cs continuous deposition is shown in Fig. 4.

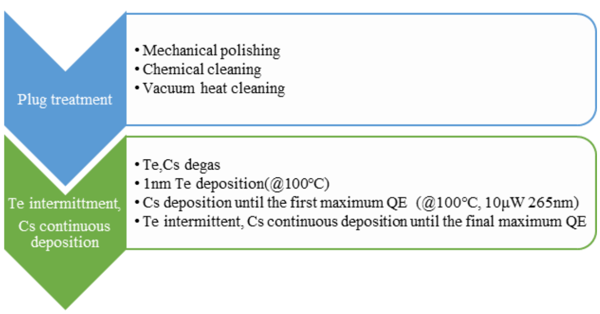


Figure 4: The typical Cs_2Te photocathode preparation process with Te intermittent and Cs continuous deposition.

The Cs_2Te photocathode preparation on SHINE photocathode preparation device with Te intermittent and Cs continuous deposition method[2]: the photocurrent is collected by Keithley 6485, the distance between the anode and cathode is 2 mm, the cathode is grounded, and a battery provides a voltage of 200 V with an electric field of 10^5 V/m; The distance between the evaporation source and the plug is 5 cm; The dynamic vacuum of the preparation chamber is better than 5×10^{-8} Pa in the photocathode preparation process; The surface roughness of SS316L plug is 5 nm, and the plug temperature is 100 ℃; the 265 nm ultraviolet light of LED is used as the driving light. The driving optical path and current collection circuit are shown in Fig. 5. The QE changing with time and the prepared Cs_2Te photocathode, as shown in Fig. 6. The Cs_2Te photocathode prepared with Te intermittent and Cs continuous deposition method has a QE greater than 5% at 265 nm.

Keithley 6485 is replaced with Keysight 2985A (equipped with '± 1000V' voltage source) to measure current between the anode and cathode with a voltage of 200V. The Cs_2Te photocathode prepared by SARI at room temperature and 100 °C on Mo plug, with a QE greater than 5% under 265nm light irradiation and 100% success rate. During the photocathode preparation process, the QE changing with time, as shown in Fig. 7.

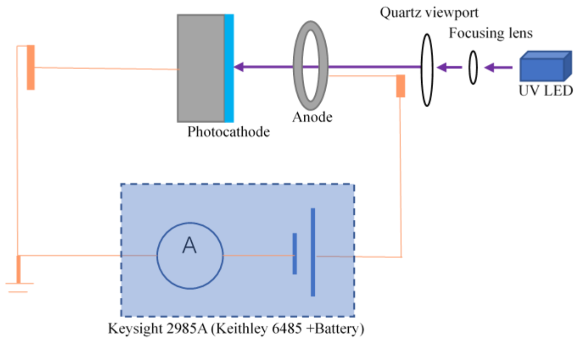


Figure 5: The driving optical path and current collection circuit.

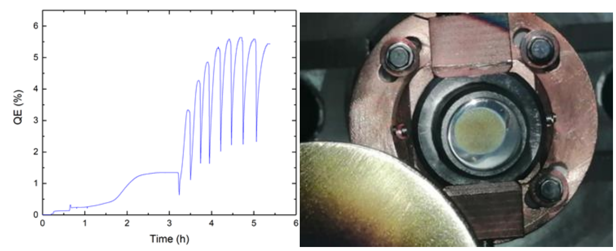
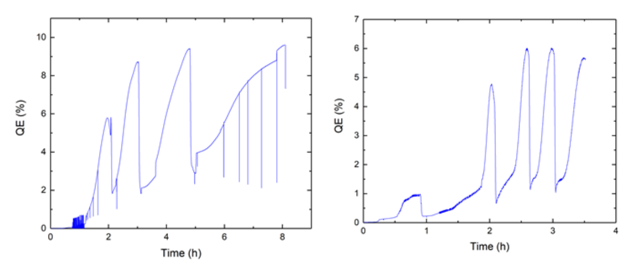


Figure 6: The QE of Cs_2Te photocathode during the photocathode preparation process and Cs_2Te photocathode.



Plug: room temperature Plug: 100℃

Figure 7: The QE of Cs_2Te photocathode during the photocathode preparation process at plug room temperature and 100 °C.

PHOTOCATHODE OPERATION

SHINE VHF Electron Gun

SHINE photocathode VHF electron gun provided by Tsinghua University is a very-high-frequency electron gun that operates in continuous-wave mode at 216.667 MHz. A continuous RF power of 75kW is successfully fed into the electron gun [3], with a cathode gradient of up to 27MV/m and a gun voltage of 780keV. The maximum dark current collected by the Faraday cup at the gun exit is less than 3 μA. Currently, the replaceable high QE Cs_2Te photocathode is driven by ultraviolet light in the SHINE VHF electron gun. SHINE photocathode loading device and VHF electron gun are shown in Fig. 8.

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Figure 8: Photocathode loading device and VHF electron gun.

Cs_2Te Photocathode Test

The electron beam spot generated by the Cs_2Te photocathode in the SHINE VHF electron gun is shown in Fig. 9. The driving laser wavelength is 257.5nm, and the laser pulse energy can be continuously adjusted within the range of 0nJ to 82nJ. It is found that the photocathode QE gradually decreases along with the laser pulse energy increases, as shown in Fig. 10. The QE of Cs_2Te photocathode prepared in SHINE VHF electron gun is greater than 8%.

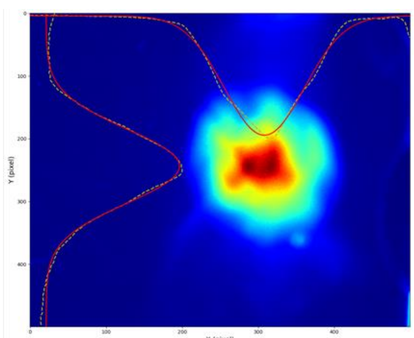

Figure 9: The electron beam spot generated by Cs_2Te photocathode.

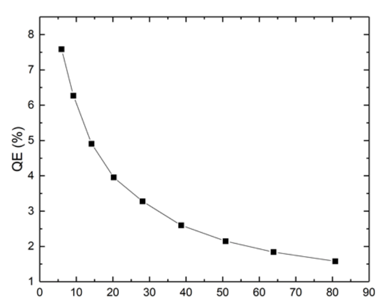

Figure 10: The relationship between QE and laser pulse energy.

The QE map of the Cs_2Te photocathode is gotten by scanning the photocathode surface with a laser. At present, because the large laser spot (with a diameter of approximately 2 mm) only can be used to irradiate the Cs_2Te photocathode, the preliminary photocathode QE map is conducted, as shown in Fig. 11. The accurate photocathode QE map will require a smaller driver laser spot.

The Cs_2Te photocathode prepared by Te intermittent and Cs continuous deposition method can operate for a long lifetime in the SHINE VHF electron gun at 50pC and 100pC, as shown in Fig. 12.

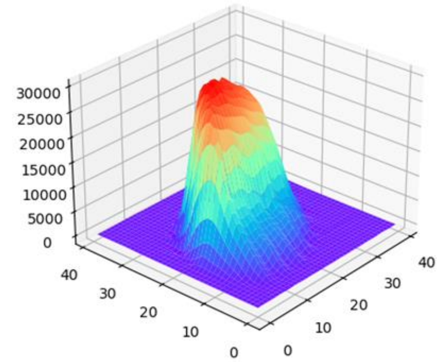

Figure 11: The QE map of Cs_2Te photocathode.

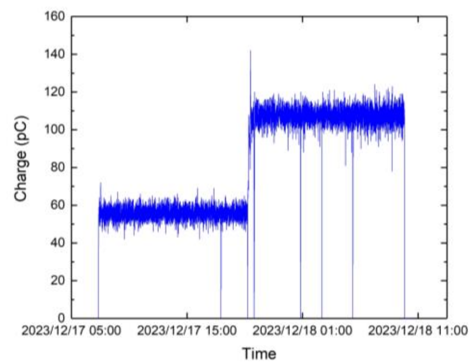

Figure 12: The Cs_2Te photocathode operation under 50pC and 100pC.

CONCLUSION

The typical process of a stable and repeatable high-quality Cs_2Te photocathode preparation is to apply Te intermittent and Cs continuous deposition has been developed with SHINE photocathode preparation device. The QE of Cs_2Te photocathode is greater than 5% under 265 nm light irradiation. The prepared Cs_2Te photocathode is transported from the photocathode preparation device to the photocathode load lock. The key technologies of long-distance transportation, ultra-high vacuum transmission and pick-and-place of high QE semiconductor photocathode are also being mastered. The Cs_2Te photocathode prepared by Te intermittent and Cs continuous deposition method for the first time is used in SHINE VHF electron gun operation.

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