Cs_2Te photocathode fabrication system at Peking University*

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Abstract: A cesium telluride (Cs_2Te) photocathode with a quantum efficiency of 13% at 253.7 nm (radiant incidence 200 $\mu W/cm^2$) is fabricated by tellurium and cesium vapor deposition onto a stainless-steel substrate. The cesium telluride cathode will be used to provide a high-brightness electron beam source for the 3+1/2 photo-injector at Peking University. The design of the system, the fabrication procedures and the preliminary experimental results are presented in this paper.

Key words: photo-injector, photocathode, Cs_2Te, quantum efficiency

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1 Introduction

Peking University (PKU) is currently developing a free electron laser facility [1, 2], adopting a home-made 1.3 GHz 3+1/2 cell photo-injector [3, 4] as the electron source. This photo-injector will be driven by a laser system with an 8 ps pulse width, a 26 MHz pulse recurrence frequency and a 3 mm spot radius. The desired result is a beam with 5 MeV energy, 100 pC bunch charge and 1.2 μm emittance.

Cs_2Te has been determined to be a suitable candidate for this laser driven superconducting photo-injector based on the following characteristics: (1) low reflectivity; (2) a negligible dark current based on the mirror-like smooth surface; (3) a high laser-induced damage threshold; (4) a laser response time at the ps range; (5) the ability to endure a 120 MV/m high field; and (6) a 3.3 eV band gap and 0.2 eV electron affinity (high quantum efficiency). Up until now, the Cs_2Te thin film photocathode fabrication system has been developed at Peking University. The preliminary experiments showed that this fabrication system has the ability to produce photocathodes with stable performance and reliable quality (a peak photocathode QE of 13%).

2 The online high vacuum photocathode fabrication system

2.1 The general layout of the photo-injector

The Cs_2Te photocathode system at PKU includes a fabrication and transmission system connected by a valve. Four cathodes can be produced at one time in this fabrication chamber. After fabrication, the cathodes are sent to the transmission chamber and stay in it until needed. When required, the cathode is transferred to the injector by a conveyor rod built in the transmission chamber. There are two viewing windows on the fabrication chamber, one that allows observation of the inner condition of the chamber and one that allows ultraviolet light to activate the Cs_2Te film on the substrate surface.

2.2 The inner structure of the fabrication chamber

All the components in the fabrication chamber are connected to a flange to facilitate support, assembly and disassembly (Fig. 1(a)). The wires associated with the sources and cathode anode high voltage, and photocurrent measurement, also come from this

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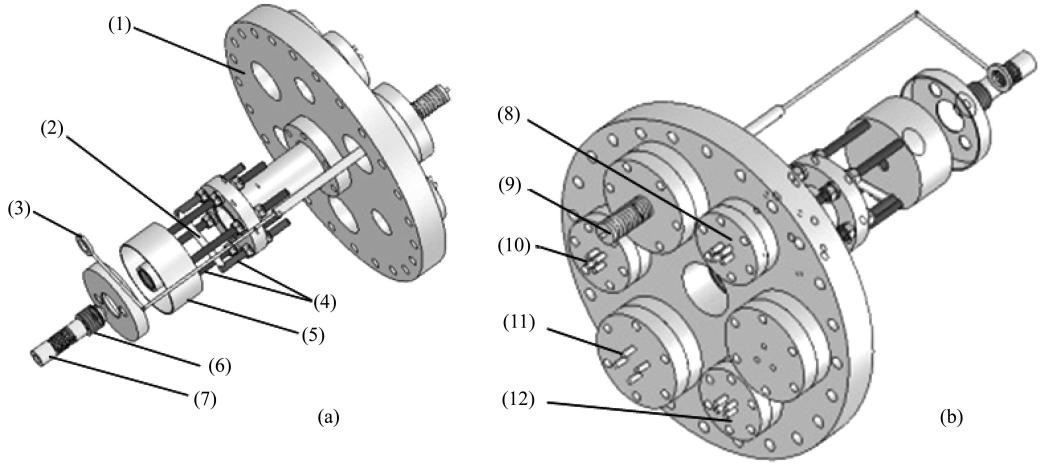

Fig. 1. The inner structure of the fabrication chamber: (1) preparation chamber flange; (2) tellurium and cesium source holder; (3) anode high voltage; (4) the screws used to adjust the evaporation parameters; (5) lampshade; (6) cathode substrate; (7) connected to the conveyor rod; (8) tellurium source heating and temperature monitoring; (9) anode high voltage; (10) cesium source heating and temperature monitoring; (11) cathode heating and temperature monitoring; (12) photocurrent measurement.

flange, as shown in Fig. 1(b). The cesium and tellurium source are supported by a 6 mm diameter screw (Fig. 1(a)). Adjusting this screw helps to achieve the optimum evaporation conditions (the different evaporation distance and angle between the cesium-tellurium source and the cathode surface). Two halogen lamps are adopted to heat the cathode. Using the lamp heating structure instead of resistance heating improves the re-crystallization effect of the photocathode through fast heat dissipation.

2.3 The vacuum

To achieve the high vacuum 10^{-6}–10^{-8} Pa for the Cs_2Te photocathode, all the tubes and chambers of this system were electro-polished, and the interior seams were welded to remove possible gas sources. The pumping system includes one dry vacuum pump (Pfeiffer vacuum as the pre-pump) and two scattering ion pumps (Shanghai Sanjing Vacuum Equipment Co. Ltd, limitation vacuum 1.33×10^{-14} Pa). This system has resulted in a vacuum level 7×10^{-7} Pa.

2.4 The cesium and tellurium source

In order to avoid the undesired off-gasses (CO, NO, CO_2, etc) generated by using a normal evaporation boat with heating wires, such as tungsten wires, a standard cesium source (5G0050 type) was ordered from SASE Getters S.P.A. This source does not use a wire-style heating structure, but utilizes a thin-wall straight Nichrome tube as both the heater and source container. The nominal composition (wt %) is 17% Cs_2CrO_4 and 83% St101 (Zr 84%-Al 16%). This kind of thin-wall resistance heating method reduces much of the off-gasses. For the telluride source, the thin-wall straight tube style evaporation boat is adopted like the cesium source from SASE Getters to avoid vacuum degeneration. The result of this improvement is an evaporation vacuum of 2×10^{-6} Pa.

2.5 The cathode substrate

It is known that surface uniformity influences the transverse uniformity of the electron beam. Since the thickness of the Cs_2Te film ranges from tens to hundreds of nanometers, the surface profile and impurity content of the substrate have a significant impact on the performance of the film. To obtain the desired substrate surface, a polishing setup was developed in-house. This system utilizes a green polishing paste and a fine wool wheel. The polishing paste is applied to the wool wheel and attached to the polishing machine. The substrate is polished for approximately 10 s of 3500 rounds per minute. The result is a mirror-like substrate surface with virtually no foreign material or surface scratches when examined by microscope (100×).

2.6 The evaporation control system

During the evaporation process, a quartz crystal thickness monitor is used to measure the film thickness on-line and in real-time. The thickness monitor (FCM-2A) was acquired from Shanghai Taiyao Vacuum Technology Co. Ltd. The features include 1 Å thickness resolution, 0.1 Å/s velocity resolution, and a controller and adjustor inside the monitor. During evaporation, the quartz oscillation frequency will change when cesium or tellurium vapor is deposited

on the substrate. The film thickness and evaporation rate can be calculated based on frequency change. After the evaporation rate is set, the controller can adjust the output power of the monitor by changing the output voltage of the oscillation control circuit according to the frequency change rate. This process maintains the temperature of the cesium and tellurium evaporation boat in a constant range and results in a stable evaporation, accurate control of film thickness and evaporation rate, and an accurate stoichiometric ratio for cesium and tellurium.

A stable cathode temperature of 120 ℃ should be maintained during evaporation. A stainless-steel lampshade with two 120 W halogen lamps for heating was designed to house the cathode. The PID (proportional-integral-derivative) controller maintains the cathode temperature at the desired temperature. The lampshade is supported by two screw bolts for thermal isolation from the fabrication chamber (see Fig. 1). This enhances the cathode temperature control and the re-crystallization of the Cs_2Te film.

3 The fabrication procedures of the Cs_2Te film

A Cs_2Te photocathode film with a desired film thickness of ≈30 nm is produced at PKU using the PVD (physical vapor deposition) process and is based on the following reaction equation:

Te+2 Cs→Cs_2Te (130–150 ℃). The following are the photocathode fabrication procedures.

(1) Preparation work Before putting the cathode into the fabrication chamber, mechanical polishing is performed to the substrate surface. Green polishing paste is applied to the wool wheel, and the wheel is mounted onto the polishing machine. The polishing velocity is set to 3500 RPM and operated for 10 s. Some residual metal powders and polishing paste will be left on the substrate surface. The surface is rinsed using high pressure water to remove obvious residual foreign substances, and ultrasonic cleaning is performed on the substrate to further remove foreign material while soaking it in acetone.

(2) Degassing When a vacuum of 10^{-7}Pa magnitude is achieved, degassing the cesium and tellurium sources is initiated. To degas the source completely, the degassing power should be greater than the fabrication power. This results in more pure cesium and tellurium vapor during final fabrication. The cathode is moved to another chamber to avoid contamination by the following degassing because cesium and tellurium vapors will be generated during degassing. After source degassing, the cathode is placed back into the lampshade to perform cathode degassing using the halogen lamp and PID controller.

(**3**) **The evaporation process** After degassing, deposition of 4 nm tellurium film on the stainless-steel substrate is initiated while being monitored by the quartz thickness monitor. The tellurium evaporation boat is connected to the power output of the quartz thickness monitor. During evaporation, the evaporation rate is normally set at 5 Å/min. The evaporation is ended when the monitor indicates that the film thickness is 4 nm. Following the tellurium evaporation, the evaporation rate is set to 1.2 Å/min for the cesium evaporation. During this process, ultraviolet light is allowed to illuminate the cathode surface. The beam flux gauge is connected to the cathode to allow monitoring of the photocurrent through it. As the cesium deposition increases, the cesium and tellurium react, resulting in an increase in the photocurrent. When the peak photocurrent is achieved, cesium evaporation continues until the photocurrent decreases by about 10%. Subsequently, the cathode temperature is maintained at 120 ℃ to allow the cesium and tellurium reaction to remove the superfluous cesium on the surface.

4 Preliminary results

The PKU laser system is still in production, so a high-pressure mercury lamp was used to activate the film in the preliminary experiments. Factors affecting the quantum efficiency are as follows: (1) a mercury lamp wavelength of 253.7 nm; (2) ultraviolet irradiance of the cathode surface at 200 μW/cm^2; (3) a cathode surface area of $S \approx \pi \times (0.4\ \text{cm})^2 \approx 0.5\ \text{cm}^2$; and (4) beam flux gauge resolution of 10^{-5} μA. The quantum efficiency is then calculated using the following formula:

$$QE = \frac{n_e}{n_\gamma} = \frac{I/e}{P_\gamma \lambda / hc} = \frac{I}{20.54},$$

where n_γ is the number of incident photons, n_e is the number of electrons generated by the incident photons, I is photocurrent, e is electric charge, P_γ is the ultraviolet irradiance of the cathode surface, λ is the wavelength of the incident ultraviolet light, h is the Planck constant, and c is the velocity of light.

Figure 2 shows how the photocurrent changes with cesium thickness. Note that the QE is very low when the cesium thickness is less than 10 nm. As cesium deposition continues over time, QE increases steadily

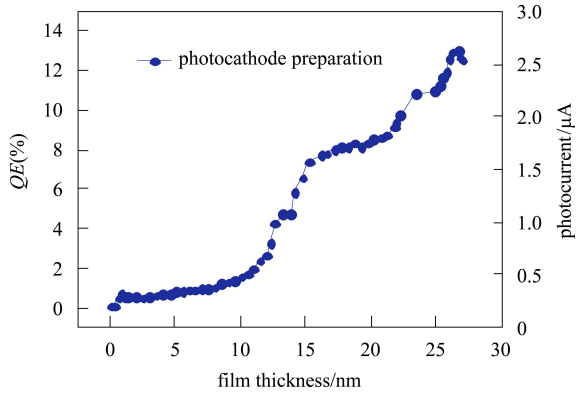

Fig. 2. Preliminary experimental results.

and continuously. When the cesium thickness increases to 27 nm, quantum efficiency reaches the highest value, ≈13%.

This result is close to the international level. For example, the Cs_2Te photocathode QE of INFN is 13% using a 254 nm laser to drive [5]; the Cs_2Te cathode in LANL achieved QE 15%–18% using a 251 nm laser to drive [6].

After QE measurement, the cathode was exposed to 10^{-5} Pa vacuum to test its tolerance to poor vacuum conditions. After 14 hours, the QE degraded from 12% to 4.5%. Subsequently, the cathode was heated up to 120 ℃ and kept at this temperature for 12 h to test the rejuvenation effect of heating. A noticeable increase in QE was observed. After the cathode was cooled to room temperature, the QE recovered to 9.3%. This result suggests that the Cs_2Te photocathode is relatively rugged and promising to remain at a 10^{-5} Pa vacuum, which is easily achieved without backing the vacuum chamber.

5 Conclusions

Stable Cs_2Te photocathode fabrication is achieved using this system. The peak quantum efficiency reaches 13%, which is close to the international level, and meets the requirements of the photo-injector at Peking University.

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