

## Manufacturing of Cs<sub>3</sub>Sb Photocathode in Atmospheric Conditions

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**Abstract:** Cs<sub>3</sub>Sb photocathode was formed by newly developed process and successive in-situ lighting devices were fabricated in a process chamber. R, G, and B phosphors were applied on the anode plate, respectively. Major parameters such as brightness, power consumption, and efficacy were measured. The wavelength of LED excitation source was 450 nm. Both high power and low power modes were applied in the measurement. Measurement values were clearly differentiated by the voltage application modes. The measured values of each parameter was good enough to be applied for general lighting source. The results showed that Cs<sub>3</sub>Sb photocathode formed in atmospheric conditions was functioning as good as the photocathode formed in UHV conditions, and thus it could be applied to advanced lighting devices.

**Keywords:** Photocathode, Quantum efficiency, Current density, Excitation source, Spectral range

### 1. INTRODUCTION

Photocathode emits electrons when it is exposed to light. When it absorbs light, electrons in the valence band are transported into the conduction band. Out of these transported electrons, some diffuse to the cathode surface directly without suffering collisions with the lattice. Some of these electrons have sufficient kinetic energy to overcome the barrier and contribute to direct photoemission. The three successive step model has provided a useful description of the photoemission process for both fundamental and practical applications [1].

Traditional method of photocathode formation is complicated and complex. It requires ultra-high

vacuum (UHV) conditions, at least  $10^{-7}$  torr, in manufacturing processes [2–6]. It also requires specialized equipment.

In this study, Cs<sub>3</sub>Sb photocathode was fabricated on a substrate in a controlled manner. The environment of the process chamber was in atmospheric conditions. Formation of Cs<sub>3</sub>Sb photocathode was carried out by thermo-chemical reactions between Sb surface and Cs vapors.

Lighting devices were made right after photocathode formation in the chamber. In order to preserve the fresh surface of newly formed photocathode in the devices, in-situ device fabrication was carried out. For the light emission from the devices, red, green, and blue phosphors were used on the anode plate, respectively.

Performance of the fabricated devices was tested by the measurement of major lighting parameters such as brightness, power consumption, and efficacy. Both a high power mode and a low power

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mode were applied in the measurements in order to find clear difference between the two. The low power mode is a current limiting mode, having a current limit that can be reached with applied anode voltages. Measured values of the lighting parameters showed definitely different values depending on the testing voltage modes.

## 2. EXPERIMENTAL

$\text{Cs}_3\text{Sb}$  photocathode was formed by newly developed process. Fig. 1 shows an experimental set-up for the formation of  $\text{Cs}_3\text{Sb}$  photocathode and device fabrication. The process chamber is a glove box type. It is connected with a load-lock chamber and a vacuum oven on the sides and a thermal evaporator at the bottom. The vacuum oven is for thermal treatment of device components. The thermal evaporator is for Sb film deposition.

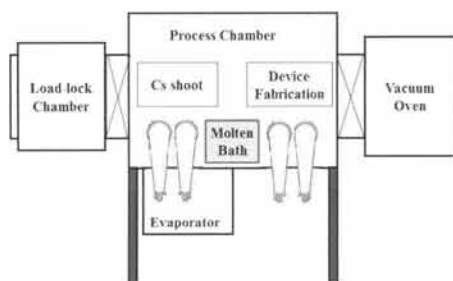


Fig. 1. Schematic diagram of equipment for  $\text{Cs}_3\text{Sb}$  photocathode formation and successive device fabrication.

The chamber is filled with  $\text{N}_2$  gas in order to prevent reaction between reactive  $\text{Cs}_3\text{Sb}$  and  $\text{O}_2$  or  $\text{H}_2\text{O}$  molecules. There is a molten bath inside the chamber. It is filled with Na metal. Very reactive Na metal is acting as getters, absorbing  $\text{O}_2$  and  $\text{H}_2\text{O}$  molecules. Thus,  $\text{O}_2$  and  $\text{H}_2\text{O}$  levels in the chamber can be maintained below 0.01 ppm, respectively, in a controlled manner. For the formation of  $\text{Cs}_3\text{Sb}$  photocathode in this process, a metal sheet is needed with patterned micro-holes on it. Fig. 2 represents the microstructure of metal

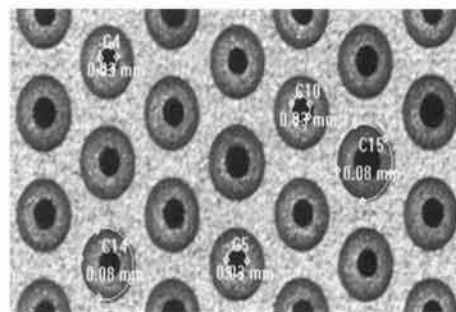


Fig. 2. Photographic image of a microstructure of a metal sheet with patterned micro-holes.

sheet with patterned micro-holes. A thickness of the sheet is  $100\ \mu\text{m}$ .

A diameter of a hole on the top side is  $30\ \mu\text{m}$  while that on the bottom side is  $80\ \mu\text{m}$ . The difference in diameter of the holes was caused by anisotropic characteristics of wet etching.

Thin Sb film ( $300\ \text{\AA}$  thick) was deposited on the bottom side of the microstructure by thermal evaporation. A mask with a 2 inch diameter hole was attached on the Sb surface for Cs shooting. Upon Cs vapor shooting, Cs reacts with Sb thermo-chemically to yield  $\text{Cs}_3\text{Sb}$ . This reaction occurs immediately to form crystalline  $\text{Cs}_3\text{Sb}$  photocathode. The thickness was controlled by the shooting time. The Cs shooting time was less than 20 seconds. Fig. 3 shows a circular  $\text{Cs}_3\text{Sb}$  photocathode formed on the microstructure. This microstructure with photocathode formed on the bottom side was attached on the cathode plate for device fabrication. And in-situ device fabrication was followed in the process chamber.

An anode plate with phosphor, a frame, and a cathode plate with microstructure are major components for the device fabrication. Thermal treatment for all components was carried out in the vacuum oven before the fabrication. Preparation processes of the anode plate are the same as those for a field emission device. However, in this case, an Al backing layer was not applied to the phosphor for the process simplicity. The frame maintains the gap distance constant between the plates. Each corner

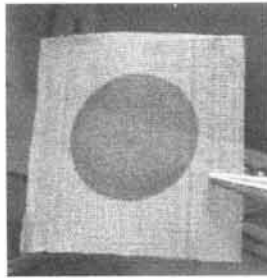


Fig. 3. Photographic image of Cs<sub>3</sub>Sb photocathode in a circular shape formed on the microstructure.

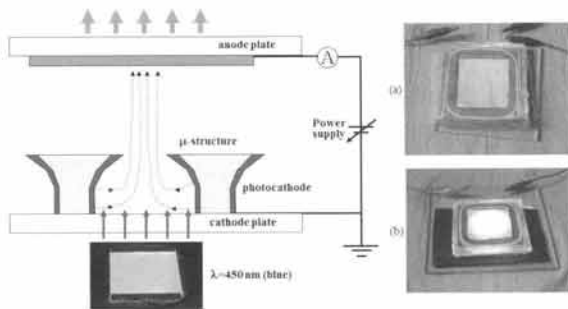


Fig. 4. Schematic diagram of a measurement set-up of the lighting device. The gap between the plates is 5 mm.

was fabricated round-shaped for the stable operation of the device. The height of the frame is 5 mm. The cathode plate has the microstructure. The bottom side of the microstructure was attached on the cathode plate to receive the excitation light. An LED planar lamp was used for the excitation light source. The wave length was 450 nm. For the device fabrication, both the anode and the cathode plates were aligned and sealed with the frame between them. The device was evacuated to make a vacuum device. When the device reached the vacuum level of  $10^{-6}$  torr, it was capped and sealed. Vacuum level of the device is actually higher than  $10^{-6}$  torr. Overall process steps are similar to those for a field emission device. For the performance measurement, the device was put on the LED planar lamp in a way that the cathode plate faced the lamp.

Figure 4 shows a schematic diagram of a test set-up. When the lamp is turned on, uniform blue

light comes out with wavelength of 450 nm. The photocathode absorbs the light and emits photoelectrons. A DC power supply provides the anode with voltages from 0 to 30 kV. A corresponding current can be read from the current meter. With the voltage off, the emitted electrons cannot be accelerated to the anode and thus there is no light emission from the phosphor. This is caused by no electric fields for acceleration between the electrodes. With voltage on, the emitted photoelectrons are accelerated to the anode plate through electric fields caused by the applied voltage. When the accelerated electrons hit the phosphor, the anode plate emits light from the phosphor. The brightness was measured by a luminance colorimeter.

### 3. RESULTS AND DISCUSSION

Previous work showed that electron emission had a long term stability with a current of around 100  $\mu$ A and current density of around 12 mA/cm<sup>2</sup> at anode voltage of 10 kV [7]. Exhibiting very low current levels at very high voltage is the characteristics of cathodoluminescent devices. The emission behavior of Cs<sub>3</sub>Sb lighting device follows the characteristics of the vacuum device.

Figure 5 shows light emission from Cs<sub>3</sub>Sb photocathode devices. An area of photocathode formation has a diameter of 2 inches for all three devices. From the left, an anode plate with red, green, and blue phosphor was utilized respectively. Efficiency of green phosphor is known to be more than those of red and blue phosphors. This is why the green light emission is the brightest at the same applied voltage of 10 kV. At the anode voltage of 5 kV, the brightness of green light emission is more than 20,000 nits. At 10 kV, it is more than 90,000 nits. The ratio of field strength of 10 kV versus 5 kV is two. However, the ratio of measured brightness is more than four at the same voltages. This means that field strength can be an important factor for the lighting parameters.

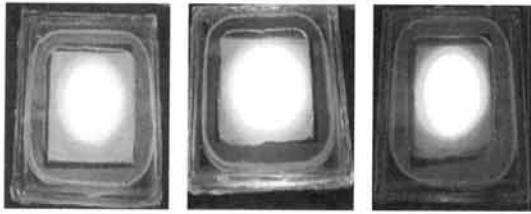


Fig. 5. Photographic images of light emission from a  $\text{Cs}_3\text{Sb}$  photocathode device at anode voltage of 10 kV.

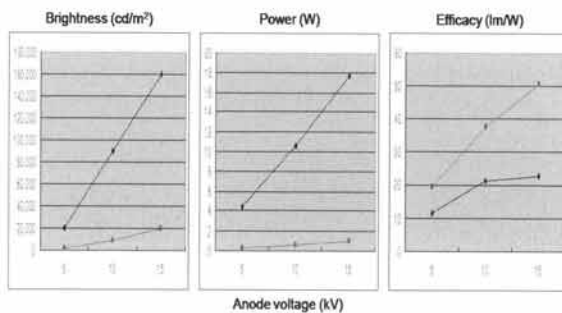


Fig. 6. A dual mode of electron emission performance depending on anode voltages.

Considering the brightness of BLU with 10,000 nits for LCD TV, these values are well over for BLU applications. As far as emission mode is concerned, a dual mode is possible. Regardless of the method used to measure device performance, the operating parameters must be set for the anticipated operating environment. Major parameters include brightness, power consumption, and efficacy.

Figure 6 represents graphical data of major parameters for the dual mode of electron emission according to applied voltages. The lines with a symbol (◆) in the figure represent a high power mode while those with a symbol (■) represent a current limiting low power mode. The high power mode is an as-is mode where any restriction does not exist in I and V. The current limiting mode is an energy saving mode. It is a low power mode where the current is set to 0.6 mA in this case. The number 0.6 mA is an arbitrarily selected for comparison.

The values of each parameter at the same anode voltage have a big difference between the two modes. If the device is used in more than one

environmental condition, a set of measurements is appropriate for each application. The high power mode can be applied to get the maximum brightness and light intensity with relatively low efficiency and more power consumption. On the other hand, the low power mode can be applied to get the higher luminance efficiency with less power consumption. Therefore choice of a mode depends solely on applications.

#### 4. CONCLUSIONS

Lighting devices based on  $\text{Cs}_3\text{Sb}$  photocathode was successfully manufactured under atmospheric conditions. Performance of the devices was clearly differentiated by the voltage application modes. Measurement parameters such as brightness, efficacy, and power consumption have values more than enough for general applications. Thus, it is believed that this process technology can be applied to wide range of advanced lighting devices.

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#### REFERENCES

- [1] W. E. Spicer, *Phys. Rev. Lett.*, 11, 243 (1963).
- [2] A. W. Bett, F. Dimroth, G. Stollwerck, and O. V. Sulima, *Appl. Phys.*, 69, 119 (1999).
- [3] A. Natarajan, A. T. Kalghatgi, B. M. Bhat, and M. Satyam, *J. Appl. Phys.*, 90, 6434 (2001).
- [4] S. Donati, *Photodetectors* (Prentice Hall PTR Upper Saddle River, NJ, USA, 2000)
- [5] P. Michelato, *Nucl. Instrum. Methods A*, 393, 455 (1997).
- [6] J.W.J. Verschuur, B. M. van Oerle, G. J. Ernst, D. Bisero, and W. J. Witteman, *Nucl. Instrum. Methods B*, 139, 541 (1998).
- [7] H. S. Jeong, *J. KIEEME*, 27, 312 (2014).