UPS STUDY FOR CSK2SB PHOTOCATHODE

Masao. Kuriki†, Lei Guo, Masahiro Urano, A.Yokota, HU/AdSM, Higashi-Hiroshikma, Japan
Taro Konomi, Yuji Seimiya (KEK, Ibaraki), Kentaro Negishi, Iwate University, Morioka, Japan

Abstract

CsK2Sb photo-cathode is one of the ideal cathode for accelerators requiring the high brightness electron beam. It can be driven with a green laser which can be generated as SHG from solid state laser. The QE (Quantum Efficiency) of photo-electron emission is as high as more than 10% with 532 nm light. The material is robust and the typical operational lifetime is more than several months. It is also vital against the high intensity beam extraction. The photo-cathode is generated as a thin film in-situ and the material property and optimized condition for the cathode formation is not understood well. In this article, we present UPS analysis of CsK2Sb cathode for deeper understanding.

INTRODUCTION

CsK2Sb is a photocathode, which is generated by evaporation in a high vacuum environment as a thin film on a substrate. The initial beam performance is very important in an accelerator based on a linear accelerator, because the performance strongly depends on the initial beam. The material is paid attention as a high performance photo-cathode material, because it can be driven with a visible light, quantum efficiency of the photo-emission (QE) is as high as more than 10% with 532 m laser [1], and it is robust comparing to other material.

To achieve the best performance of a photo-cathode material, we should understand what determines the cathode performance. Betes investigated that the property of Cs3Sb photocathode [2]. He found that the cathode performance depends on the chemical state, which can be extracted from XPS (X-ray Photo-electron Spectroscopy) spectrum. The ratio of cross sections of Cs5s Cs5p states has a correlation to the cathode performance, QE. The ratio shows the crystalline condition of CS3Sb and the result shows that the ion crystalline Cs3Sb gives a better performance. Ettema and Groot calculated CsK2Sb's band structure [3]. It is shown that Sb 5p band located at top of the valence band and the cross section of this band has a large influence to the cathode QE. In this article, we perform Ultraviolet Photoelectron Spectroscopy (UPS) experiment for CsK2Sb with UPS to evaluate correlation between the surface state and the cathode performance, what Betes did for Cs3Sb. UPS is one of the experimental way of studying material's surface electron state [4]. The experimental setup is schematically shown in Fig. 1. Monochromatic UV light obtained by a Synchrotron facility with a monochrometer, illuminates the sample and the kinetic energy of the photo-electron is measured by an electro- static analyser.

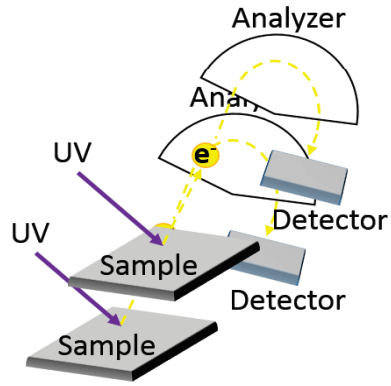

Figure 1: An image of an UPS system. Generated electrons are divided its kinetic energy through analysed by static electrical field in the analyser and counted by CCD.

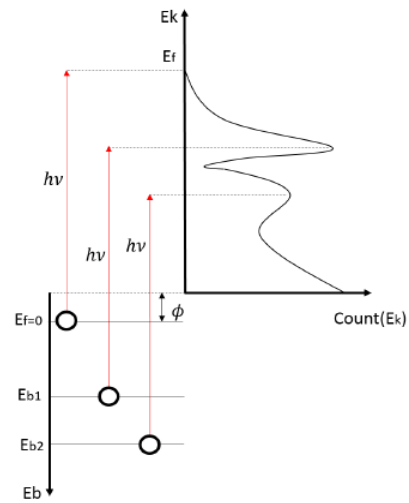

Figure 2: This figure shows UPS principle. In the figure, Ef means Fermi level, Eb means electron's binding energy. hv is photon's energy in the UV. Φ is a sample's work function.

By sweeping the energy of the analyser, an UPS spectrum is obtained. The UPS spectrum reflects the band structure of the material as shown in Fig. 2.

EXPERIMENT

The experiment was carried out at UVSOR BL2B beamline [6]. UVSOR is a synchrotron radiation facility with 750 MeV electron beam energy in Okazaki, Japan. 59eV UV light was used to take the UPS spectra. The cathode is generated by evaporation in an evaporation chamber, which is specially designed for this experiment [5]. This chamber is connected to UPS chamber where UPS spectrum was taken, and the cathode sample is transferred to

†mkuriki@hiroshima-u.ac.jp

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UPS. The UPS spectrum of the cathode can be taken in-situ.

Cathode Evaporation

CsK2Sb cathode sample was generated by evaporation in a vacuum chamber (evaporation chamber) pumped by an ion pump and a NEG pump and the pressure was typically 1×10^{-7} Pa. The cathode was fabricated on 8mm square Si(100, p-type) substrate. The substrate was cleaned by ultrasonic rinse with ethanol and pure water. The substrate was mounted on a sample holder made by Mo. IR heater in a vacuum chamber for further cleaning the surface heated up the sample holder. The evaporation was done in order of Sb, K, and Cs [7]. Sb beads are mounted on a tungsten heater and heating induced Sb vapour. Dispenser assembly by SAES getters Co [8] provides K and Cs vapour. The sample holder and a quartz thickness monitor are placed in symmetrical position as shown in Fig. 3 for the evaporation source, so that the amount of the evaporated material can be measured simultaneously. During evaporation, we measured the QE of the sample with 405 nm laser (see Fig. 4). A significant QE was observed in K evaporation and was rapidly increased in Cs evaporation. Sb thickness is determined as an experimental parameter (100 Å), but K and Cs thicknesses were determined giving a saturated QE in the evaporation.

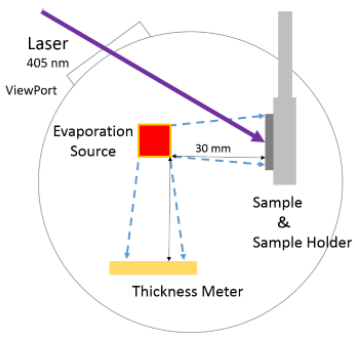

Figure 3: Schematic view of the evaporation chamber. The source generates the metal vapour symmetrical to the sample and thickness monitor. The laser was introduced to measure QE of the cathode.

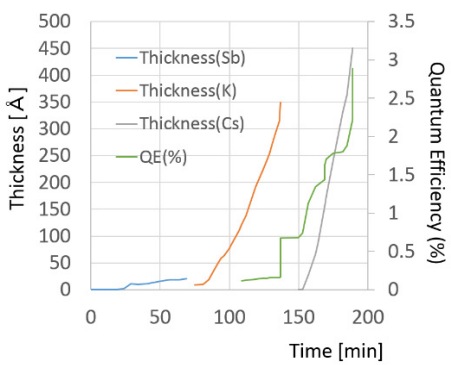

Figure 4: QE and thickness for each materials on the sample was shown as a function of time. QE measured with 420 nm was increased rapidly when Cs evaporation was started.

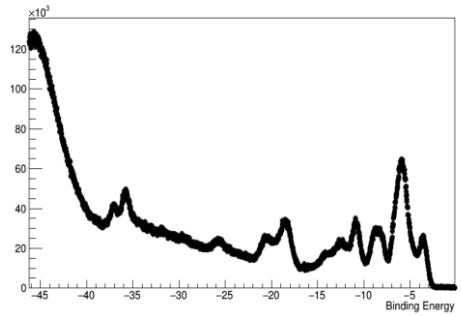

Figure 5: An example of CsK2Sb UPS spectra.

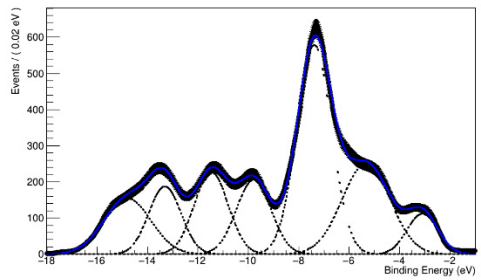

Figure 6: An example of CsK2Sb UPS spectra around valence band.

RESULT AND DISCUSSION

Figure 5 shows an example of UPS spectrum. By analysing the spectrum, the band structure and the surface chemical state can be extracted, because the mean free path of electron in several tenth eV energy range is up to several nm. The spectrum contains not only the primary photoelectron, but also the secondary electron. The primary electron signal reflects the electron band structure information, but the secondary electron signal is a background. The background is subtracted from the measured spectrum with the Shirley method [9]. Figure 6 shows the valence peaks of the spectrum. The peak at 3 eV corresponds to Sb5p[10], which has the lowest binding energy among the bands and it is expected to be that the peak has an influence to the cathode QE, because the band should be sensitive to QE with a visible laser due to the low bounding energy.

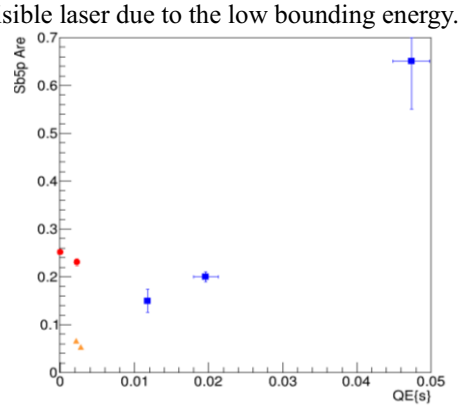

Figure 7: Cross section of Sb5p state as a function of QE.

Figures 7 and 8 show the cross section (area) and the binding energy (position) of Sb5p peak as a function of QE, where QE is the quantum efficiency defined as the area of

the spectrum in 0 - 3.06 eV, respectively. We took QE defined by the area of the spectrum, because the electrons in this energy states is able to be emitted with 405 nm laser light and it was confirmed that the area is proportional to QE measured with laser [7]. In these figures, different legends shows the data for different samples. According to these results, cross section became smaller and the binding energy became larger for smaller QE. According to Ref. [5], the bounding between Cs and Sb are loosen and CsK2Sb's ion crystal condition gets worse, when CsK2Sb photocathode is degraded. The results shown in Fig. 7 and 8 support Ref. [5]'s result. As a simple observation, Sb5p states contributes to QE of photo-electron effect with a visible light laser, because this state is the shallowest state. The cross section is simply increased as QE increased.

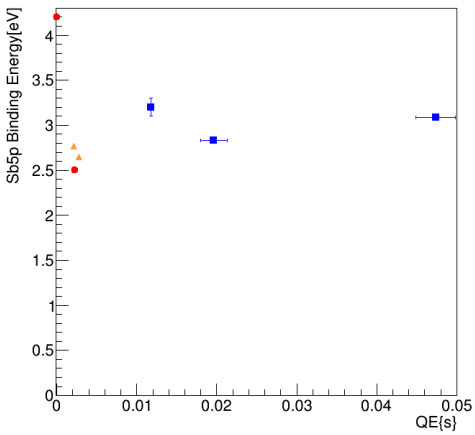

Figure 8: Binding energy of Sb5p as a function of QE.

Similar relation can be observed when the same variables are shown as a function of elapsed time after the cathode generation. The experimental condition of UPS beamline is not ideal because this is a shared beamline. The vacuum pressure is worse than that in a similar experiment [11]. The QE was quickly degraded over time in this experiment and that is why we could see the time evolution.

SUMMARY

We studied the surface state and the performance of CsK2Sb photo-cathode with UPS. The experiment was carried out at UVSOR BL2B. We found that Sb 5p contribute to the photo-electron emission with a visible laser and the cross section and binding energy has a strong correlation to the cathode performance, QE. The cross section and the binding energy becomes smaller and larger over time and this evolution can explain the QE degradation in time after the cathode generation.

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