A STUDY OF CsK2Sb MULTI-ALKALI PHOTOCATHODE BY ULTRAVIOLET PHOTOELECTRON SPECTROSCOPY AT UVSOR

M. Urano, M. Kuriki, K.Negishi, Hiroshima University AdSM, Higashihirosima, Japan
T. Konomi, Y.Seimiya, N.Yamamoto, High Energy Accelerator Research Organization, Tsukuba, Japan

Abstract

Photocathode is one of the most important components in the next-generation accelerators, especially based on linear accelerators. Photocathode performance depends not only on electronic state in its bulk material but also on the surface condition. CsK_2Sb multi-alkali photocathode is a candidate for the high brightness electron source because of its high quantum efficiency by green laser and its high robustness. We have carried out an UPS (UV Photoelectron Spectroscopy) experiment at UVSOR facility, synchrotron radiation light source in Aichi Japan. We have compared the UPS spectra among several samples, each one has a different quantum efficiency, and try to find physics which decide photocathode's performance. In this case, we focused some characters correlated to the quantum efficiency. I'm going to present a result of this analysis.

INTRODUCTION

Linear accelerator based facilities such as Linear Colldiers, X-FEL, and ERL break the limitations of the circular accelerators such as 3rd generation light source, ring colliders, etc. In the linear accelerator, high quality and high average current beam has to be provided because of no circulation. Laser photo-cathode can provide such beam, but conventional cathode material such as metal, GaAs, Cs_2Te are not ideal. CsK_2Sb multi-alkali photocathode is the candidate of the ideal cathode due to the high quantum efficiency (QE) [1], and high robustness, and green laser driver for photo-electron effect. Many experimental efforts have been made to obtain the CsK_2Sb photocathode optimized for the particle source of accelerators, but it is on the way. In this study, we perform UPS (Ultraviolet Photoemission Spectroscopy) analysis of the CsK_2Sb cathode to reveal the cathode performance and the surface states.

UPS is an experiment approach for analysing materials' surface electronic state [2]. As shown in Fig.1, monochromatic UV light is injected on a sample's surface. This light excites electrons in a sample and the electrons jump out to vacuum. The kinetic energy of the electrons is measured with an electro-static analyser. The kinetic energy E_k is expressed as,

$$E_k = h\nu - \phi - E_b, \quad (1)$$

where $h\nu$ is the photon energy, ϕ is work function of the material, and E_b is binding energy of electrons in the material. UPS spectrum which is number of observed photo-electron as a function of Ek, is schematically shown in upper right part of Fig. 2. Any peaks in UPS spectrum correspond to bands in the material as shown in lower left part of Fig.2. By comparing the measured peak position and that in a reference table (for example, XPS Data Booklet [3]), the element content can be estimated by identifying the peaks. In addition, the peak position and cross section (peak height) are modified by chemical state of the element. Mean free path oft the photo-electrons in a material is typically up to several nm with UV light and the band structure obtained from the UPS spectrum is therefore that on the material surface.

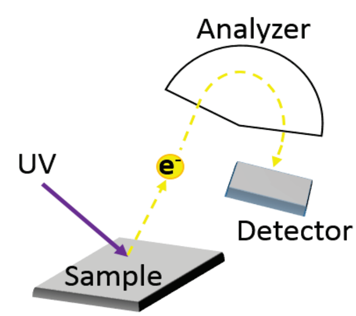

Figure 1: A schematic picture of UPS measurement. The kinetic energy of photo-electrons from a material with UV light is analysed with an electro-static analyser.

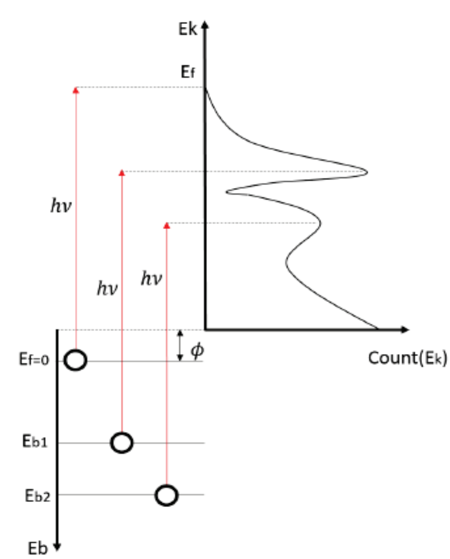

Figure 2: By measuring UPS spectrum (upper right figure), we can extract the band structure of material (lower left figure).

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EXPERIMENT

UPS experiment was carried out at UVSOR (Okazaki, Japan) BL2B beam line [4]. The CsK_2Sb sample was fabricated in situ as a thin film by evaporation. The sample was transferred to UPS chamber where we could obtain UPS spectra.

Cathode Evaporation

CsK_2Sb multi-alkali photocathode sample was fabricated on Si substrate as a thin film by evaporation as shown in Fig. 3. The Si substrate is mounted on the sample holder and metal evaporation was performed with the source. The source generates the vapour in two directions as shown in Fig. 3, one is for the cathode sample and one is for the quartz thickness monitor to measure the amount of metal. 405nm laser is illuminated on the sample to monitor quantum efficiency (QE) which is ratio of numbers of incident photons and photo-electrons.

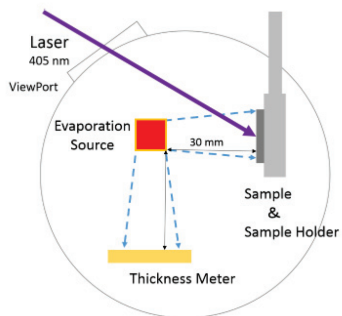

Figure 3; Schematical drawing of the evaporating chamber. The metal vapour was generated in two directions.

The high vacuum environment of the chamber is kept with an ion pump and a NEG pump to be around 1×10^{-7} Pa. The cathode fabrication with the evaporation was made as follow.

- 8mm square Si(100, p-type) substrate was cut from a wafer and ultra-sonic cleaned with ethanol and pure water. After installing the substrate to the UPS chamber, it was heated up to several hundred deg. C for further cleaning.
- The cathode fabrication was made by evaporation in order of Sb, K, and Cs. A typical example of the cathode fabrication is shown in Fig. 4. The left vertical axis shows thickness of material on the substrate measured with the thickness monitor, and the right vertical axis shows QE measured with 405nm laser. 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 by QE saturation.

Table 1: Summary of CsK2Sb Cathode Fabrication

Sample ID	Sb[Å]	K[Å]	Cs[Å]	QE(%)
CsK_2Sb #1	110	370	700	0.22
CsK_2Sb #2	90	400	470	12
CsK_2Sb #3	100	530	150	1.5

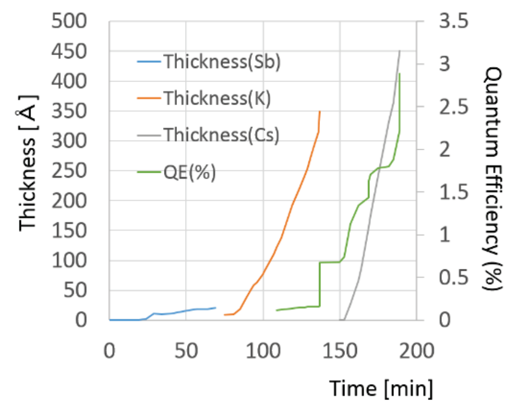

Figure 4: An example of cathode fabrication. The left and right vertical axes show thickness of each materials and QE measured with 405nm laser, respectively. The green, red, and yellow curves show thickness of Sb, K, and Cs, respectively. K and Cs evaporation was terminated when QE is saturated.

RESULT AND DISCUSSION

This UPS measurement was carried out at UVSOR BL2B. UVSOR is a synchrotron radiation facility with 750MeV electron beam energy. 59eV UV light was used to take the UPS spectra. An example of the UPS spectrum is shown in Fig. 5. Several peaks were found and identified as summarized in Table 2.

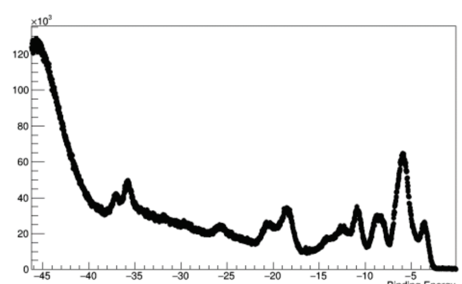

Figure 5: An example of CsK_2Sb UPS spectra.

Table 2: Peaks Found in the UPS Spectrum

Identified peak	Cs 5s	Cs 5p 1/2	Cs 5p 3/2	Sb 5p
Binding Energy[eV]	25.8	15.2	14.7	5.14

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In a similar study by Clayton with XPS (X-ray Photoemission Spectroscopy), QE of Cs_3Sb cathode and ratio of Cs 5s and Cs 5p peak heights are inversely proportional, i.e. a high ratio gives a low QE [5]. It is known that the ratio depends on the chemical state of Cs and the ratio becomes low when Cs is ionized in the material. Clayton suggested that Cs_3Sb cathode has better performance when Cs is ionized in the material. We expect a similar relation on CsK_2Sb, too. The result is shown in Fig. 6. The ratio is plotted as a function of QE. Blue, red, and green solid circles show the results for each samples summarized in Table 1. All data sets show the similar property, a smaller ratio gives a large QE. This result is similar to that for Cs_3Sb by Clayton. From this fact, the material shows a better performance as a photo-cathode when Cs is ionized. CsK_2Sb forms an ionic crystal and the crystal quality might be critical for the cathode performance.

Sb 5p binding energy is 2eV from fermi level [6]. Because this is the shallowest state in CsK_2Sb photo-cathode [7] and the only state excitable to the vacuum state by the visible light laser, the position of this state should have a significant impact on the cathode performance, i.e. QE with the visible laser. Fig. 7, 8, and 9 show the peak position, area (cross section), and width of the Sb 5p peak with the same manner as Fig. 6. Sb 5p peak become large, wide, and large binding energy when QE is decreased. The increment of Sb 5p binding energy is explained by a chemical shift caused by the loosened Cs-Sb connection. Because the electrons in the valence bands make a combined orbit when the elements compose a compound, the cross sections of the valence band become lower. When QE of the cathode is decreased, the combined orbit is partly broken up and the cross section of the valence band become higher. The observation of that the Sb 5p cross section is larger for lower QE, is consistent to this speculation. Finally, Clayton also claimed that ionized Sb makes sharper 5p peak than Sb 5p peak in metal state [8]. Result in Fig. 9 matches Clayton's indication; more Sb ions are ionized when photocathode show a high QE.

SUMMARY

We perform UPS for analysing CsK2Sb photocathode surface. We found that Cs 5s/5p ratio and QE of the cathode are inversely proportional. This is caused by Cs-Sb ion connection lost. We found also that Sb 5p state has a significant impact on the cathode QE and the spectral changes could be explained by the loss of the combined orbit of Cs-Sb valence electrons. According to these studies, Cs's state in CsK2Sb is crucial for the CsK_2Sb photocathode performance.

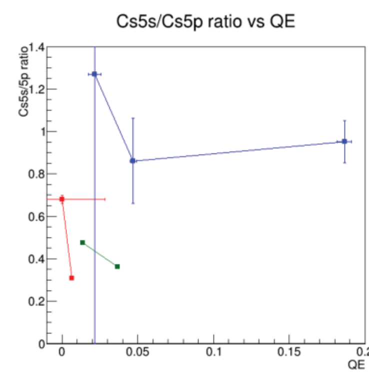

Figure 6: Cs 5s/ Cs 5p ration in CsK_2Sb UPS spectra.

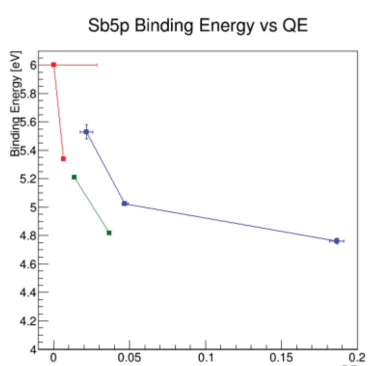

Figure 7: Sb 5p peak's binding energy

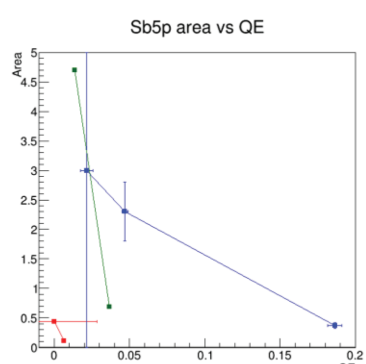

Figure 8: Sb 5p peak's Cross section

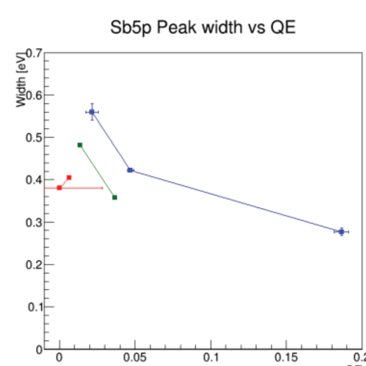

Figure 9: Sb 5p peak's width.

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