A study of an electron affinity of cesium telluride thin film

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Abstract. The photoemission spectroscopy using synchrotron radiation has been carried out to study the electron affinity of cesium telluride thin films. We observed a formation of NEA surface on p-type gallium arsenide deposited with cesium telluride. An ultra thin film of cesium telluride is discussed as a possible candidate forming an NEA surface. The electron affinity of cesium telluride thin film was found to increase with time after fabrication. An increase of the affinity resulted in deterioration of a quantum efficiency under laser light exposure with constant wavelength. The surface of photocathode in RF gun can suffer enormous damage easily at the conditioning process of RF gun before electron extraction. A method to refresh the photocathode surface after RF conditioning has been required. A photodetachment process is a candidate to refresh aged/damaged photocathode with X-ray exposure. A recovery of quantum efficiency for the aged photocathode film by this refreshing process is shown.

1. Introduction
A cesium telluride thin film, which has a high quantum efficiency and a long working lifetime, has already been established and used as a photocathode material for RF gun in practical use [1]. A cesium telluride photocathode can provide a longer lifetime under severe conditions, poor vacuum condition and higher electric field, comparing to conditions of a DC gun used as a polarized electron source with an NEA (Negative Electron Affinity) photocathode [2]. Therefore we have studied the electron affinity of cesium telluride in order to obtain hints to improve a lifetime of NEA photocathodes by the photoemission spectroscopy using synchrotron radiation [3]. The conventional NEA method uses oxygen and cesium [4]. Oxygen belongs to the same VIth group in the periodic table as cesium and is therefore a non-toxic and economic material. However, we have to consider possible side effects of the oxygen presence, for example, necessary handling with high vacuum to avoid water condensation, possible damage to the target and X-ray damages to the target. Therefore we have to consider more suitable materials for the NEA method.

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table same as tellurium. The study about the electron affinity of cesium telluride is expected a helpful way for the research to a durability of NEA surface modification. An electron affinity, which is defined by a difference between a vacuum level and a conduction band minimum, has been found to increase with time after fabrication in cesium telluride thin film. An increase of this affinity results in a deterioration of quantum efficiency under laser light exposure with constant wavelength as shown in Fig. 1. Thus the working lifetime of photocathodes has been associated with an increase electron affinity.

![Energy diagram](image)

**Figure 1.** Illustration of a deterioration of quantum efficiency with conceptual energy diagram.

The results of photoemission spectroscopic study using synchrotron radiation were shown in this report. An ultra thin film of cesium telluride is discussed as a possible candidate forming an NEA surface. We observe a construction of NEA surface on p-type gallium arsenide deposited with cesium telluride. And also, photodesorption is discussed as a refresh treatment for a wasted cesium telluride thin film photocathode. The surface of photocathode in RF gun can suffer enormous damage easily at the conditioning process of RF gun before electron extraction. A method to refresh the photocathode surface after RF conditioning is therefore highly desirable. A photodetachment process is proposed to be a candidate to refresh aged/damaged photocathode with X-ray exposure.

2. Experiment

This study has been carried out using the Saga University beamline BL13 at SAGA Light Source (SAGA-LS) [5]. The beamline BL13 consists of two end stations/branches. The one is the VLS station for the high-resolution photoelectron spectroscopy with undulator radiation. Another is the station for the vacuum ultraviolet photoelectron spectroscopy in the energy range from UV to EUV, where the UVSOR-type plane grating monochromator (PGM) has been adapted. At the end station of BL13-PGM, an analyzer of photoelectron spectroscopy which has a resolution of 100 meV at 40 eV photon energy, a system for measurement of total yield, an analyzer of Auger electron spectroscopy, and a LEED system are all set-up in the analyzer chamber which has a base pressure of 2×10⁻⁸ Pa. Cesium and tellurium sources, an oxygen gas source, a thickness monitor, a sputtering ion gun, a system of sample annealing, and so on are installed in the preparation chamber, which has a base pressure of 2×10⁻⁸ Pa. The end station has also an air-lock chamber that makes it possible to install samples without a breaking UHV of analyzer and preparation chamber.

3. NEA surface using Cs/Te deposition

The result of cesium (Cs) and tellurium (Te) deposition on p-type gallium arsenide (GaAs) is shown in this section. The p-type GaAs sample fabricated with As cap at Venture Business Laboratory of Nagoya University had a contamination free surface originally. The sample was used for another experiment for NEA surface modification, and after finishing the experiment, the sample was exposure in the air. Hence the sample contaminated with the air was used in this experiment. The Auger electron spectrum of the sample, p-type GaAs deposited with Cs/Te, is shown in figure 2. The
peaks from Ga, As, Cs, Te, oxygen (O) and carbon (C) are observed in the spectrum. O and C peaks come from the surface p-type GaAs, which are also observed before deposition Cs and Te. The thickness of Cs/Te deposition is very thin as materials of underlying substrate are observable.

![Auger electron spectrum of p-type GaAs deposited with Cs/Te.](image)

Figure 2. Auger electron spectrum of p-type GaAs deposited with Cs/Te.

The photoemission spectrum around a low energy cut-off is formed from energy distributions of secondary electrons and photoelectrons. The cut-off energy of the spectrum corresponds to the vacuum level of the sample. The photoemission spectrum around a low energy cut-off and around valence band spectrum of the sample before/after Cs and Te deposition is shown in figures 3-4 and 5-6 respectively. The measurement of the low energy cut-off was carried out under negative bias at -25 Volts in order to collect emitted electrons into the analyzer effectively. In Fig 3, the point at 25 eV corresponds to the work function of the analyzer. The sample work function, which is defined a difference between a vacuum level and the Fermi level, indicates the declination for - 0.2 eV to the work function of the analyzer. In Fig. 4, the work function of the sample decreases for 3.1 eV from that before Cs and Te deposition.

![The photoemission spectrum around a low energy cut-off before Cs and Te deposition.](image)

Figure 3. The photoemission spectrum around a low energy cut-off before Cs and Te deposition.

![The photoemission spectrum around a low energy cut-off after Cs and Te deposition.](image)

Figure 4. The photoemission spectrum around a low energy cut-off after Cs and Te deposition.

In Figs. 5-6, $E_F$ indicates the Fermi level measured from evaporated gold sample. This p-type sample was highly doped and electrons are filled in the states close to the Fermi level as shown in Figs. 5-6. In Fig. 5, the peak from Ga-3d is observed clear, and the broad peak around 7 eV of binding energy
indicates oxidation. In Fig. 6, the peak from Ga-3d still is observed after Cs and Te deposition, other peaks appear as well as a cesium telluride thick film. Since no change the valence band maximum was observed by the Cs/Te deposition, no change to the conduction band minimum might be considered. Therefore the observed shift of the cut-off energy due to the Cs/Te deposition can be recognized as the change of the electron affinity.

![Figure 5](image1.png)  ![Figure 6](image2.png)

**Figure 5.** The valence band spectrum before Cs and Te deposition.  **Figure 6.** The valence band spectrum after Cs and Te deposition.

An energy diagram summarizing results from the photoemission spectroscopy is shown in Fig. 7. All values shown in the Fig. 7 is measured value in this experiment except an energy gap of 1.4 eV to a GaAs, which is referred from the article [6]. The work function of the sample, can be derived from the work function of the analyzer at 4.6 eV, shifted down for 3.1 eV due to the Cs/Te deposition, and became to 1.3 eV from 4.4 eV. An energy gap of a GaAs semiconductor is about 1.4 eV. Consequently the sample shows a negative electron affinity of -0.1 eV from this measurement.

![Figure 7](image3.png)

**Figure 7.** Energy diagram to the summarizing results from photoemission spectroscopy.

### 4. Photodesorption effect

Figs. 8-9 shows the photoemission spectra of the sample of cesium telluride film using molybdenum as a substrate around a low energy cut-off were measured in biased to – 25 V. As shows in Fig. 10, the electron affinity becomes higher as a function of time from the fabrication. In Figs. 8-9, the red line shows the spectrum for 39 minutes from fabrication, the blue line for 2 hours 15 minutes, the black line for 40 hours 30 minutes, the green line for 138 hours, the sky blue line for 187 hours 30 minutes, the violet line for 188 hours and the grey line for 190 hours respectively. The sample used in this measurement was stored in the air-lock chamber from 150 hours to 187 hours. The vacuum of the air-lock chamber is kept by only turbo-molecular pump. Water molecule attachment under limited
vacuum condition might result in a significantly high electron affinity at 187 hour 30 minutes. The spectrum was re-measured after 15 minutes irradiation of unselected light from synchrotron (0th light) at the surface of sample. Then a recovery of the affinity by 0.2 eV (the affinity becomes 22.5 eV after irradiation from 22.7 eV before) is observed. This recovery might be explained by a photodesorption effect that detached water from the film by obtaining energy from radiated photons. The further irradiation of 90 minutes gives a increase of the affinity, which might be due to the high intensive photoemission introduced pollution on the surface.

Figure 8. Photoemission spectra of the cesium telluride sample around a low energy cut-off before exposure of 0th light.

Figure 9. The spectra before/after exposure of 0th light.

Figure 10. The change of the cut-off energy as a function of time from the sample fabrication. The dotted line is fitted log function to the data as just a guide to eye.

An RF gun needs RF conditioning after an insertion of a cathode plug where cesium telluride is deposited on. This RF conditioning inevitably gives pollution on the cathode surface before gun operation. Refreshment by photodetachment process is a promising method to recover damaged photocathode after RF conditioning. An integration of X-ray tube into RF gun is expected in future study.

5. Summary
The photoemission spectroscopy using synchrotron radiation has been carried out to study the electron affinity of cesium telluride thin films. NEA surface is observed on p-type gallium arsenide deposited with cesium telluride. Photodesorption is a useful method to refresh a wasted surface.

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