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A STUDY ON ROBUSTNESS OF NEA-GAAS PHOTOCATHODE

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Abstract

Electron source is one of the most important components in the advanced linac. There is a strong demand on the high performance cathode, such as small emittance, high brightness, and short pulse generation. NEA-GaAs photo-cathode is a unique technology which is capable for generating highly polarized and extremely low emittance beam. Quantum efficiency (QE) of the cathode is high in near IR region, so it is favor to generate a high current density beam. These advantages are originated to the Negative Electron Affinity (NEA) surface, but it is fragile so the operational lifetime is limited. A study on a robust NEA surface cathode is reported. According to the hetero-junction model, Cs-Te thin film deposited on GaAs forms a robust NEA surface. We performed the Cs-Te evaporation experiment on a clean GaAs cathode and measured QE spectra. We found that some sample showed a high quantum efficiency up to 900nm wavelength which strongly suggested a NEA surface formation.

INTRODUCTION

The NEA (Negative Electron Affinity)-GaAs photocathode is used for various accelerators because of its unique characteristic. NEA surface means that the vacuum potential on the surface is lower than the bottom of the conduction band. The NEA photocathode has advantages as an electron source for accelerators. They are highly polarized electron beam, very low emittance, high quantum efficiency (QE) and IR excitation. On the other hand, it requires extremely good vacuum environment (very low pressure) for the operation and the operational lifetime is limited. According to our studies, the NEA-GaAs surface is damaged by three processes. They are thermal de-sorption of Cs [1] and residual gases adsorption [2] and ion back bombardment [3]. The NEA is made by Cs and Oxygen (NF3) adsorption to clean GaAs surface and it is easily damaged by these processes. There are several ways to improve the lifetime, but it is not drastic. A robust NEA-GaAs photo-cathode is quite useful and increases the potential of the advanced accelerator concepts. The goal of our research is establishing a robust photo-cathode with NEA surface. As a first step, we fabricate a NEA photo-cathode, but not Cs-O receipt, standing on the hetero-junction model [4].

We show the energy level diagram of the hetero junction model in Figure 1. According to the hetero-junction model, by developing a different semi-conductor on the base material, the vacuum potential could be lower than the bottom of the conduction band in the base material. To create a NEA surface, appropriate materials have to be selected. We used GaAs as a substratum and Cs-Te as the surface thin film semi-conductor. CsTe is known for a robust semiconductor photocathode and used in both DC and RF electron gun. In 2011, Sugiyama et al. reported that the Cs-Te deposited GaAs surface may have NEA energy structure [5]. So Cs-Te/GaAs has been expected to have both robustness and NEA. We manufactured Cs-Te film on the GaAs.

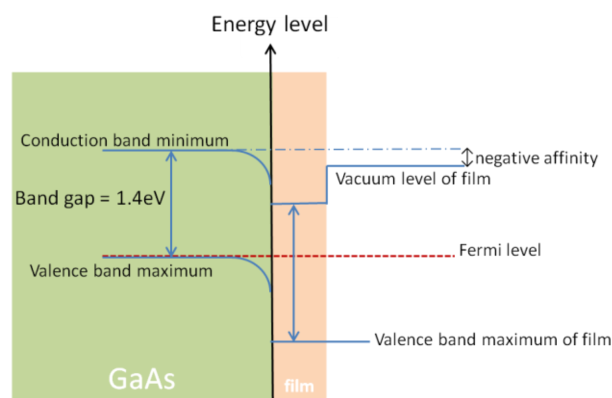

Figure 1: Energy level diagram by the hetero-junction hypothesis. If the work function of the surface state is less than the band gap of the bulk material, NEA surface is expected.

EXPERIMENT

In this section, I explain details about experimental equipments and Cs-Te thin film manufacturing process.

Equipments

The vacuum chamber cross sectional view is shown in Fig. 2. Heat cleaning of GaAs and Cs-Te evaporation on it were done in this chamber. To establish Ultra High Vacuum condition in the chamber, the chamber is closed and pumped by ion pump (160 l/s) and a NEG pump (310 l/s). The typical base pressure during the experiment 2.0e-8 Pa. Cs and Te deposition sources were equipped on the SUS plate (width: 20 mm, height: 60 mm, depth: 5 mm) and mounted on the movable stage. Their thickness was monitored by a quartz oscillator sensor. The cathode rod was electrically isolated from the main body and the photo-electron current is monitored by measuring the current to the rod. GaAs wafer was mounted on the Mo block at the end of the rod. A cartridge heater and thermo-coupled sensor were embedded in the Mo block to control and measure the temperature.

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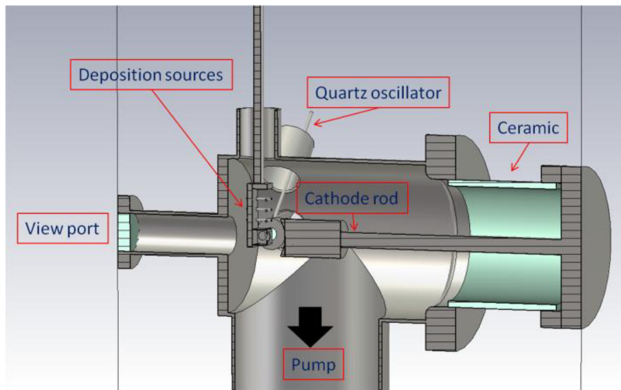

Figure 2: Cross sectional view of the vacuum chamber where the experiment was carried out. The chamber is kept in UHV as down as 2.0E-8Pa.

Cs is provided by dispensers made by saes-getters Co. Te is provided by heating Te bullet with tungsten bucket as shown in Figure 3.

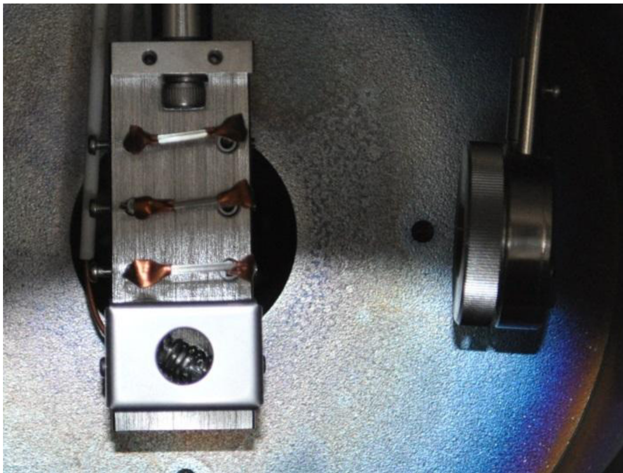

Figure 3: Cs and Te evaporation head is shown in the left. The round object in the right is the quartz oscillator for thickness monitoring. The three silver wires are Cs dispenser and the spiral wire is the tungsten basket contain Te beads.

Cs and Te sources are designed to evaporate them on GaAs surface and quartz oscillator equivalently. QE was measured by Xe lump light introduced through a front view port. The optical system is shown in Figure 4. Light from Xe lump is analyzed by a diffraction grating monochrometer. The filter (SCF 52Y, by Siguma-koki Co.) was put when we used the longer wavelength than 600 nm to remove any secondary modes. Power of light was measured by Si photodiode power meter. The spot size on the GaAs surface was several square meter at 600 nm which is smaller than the active area of cathode. The exact spot size was not measured.

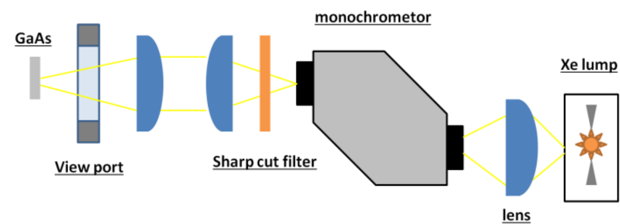

Figure 4: Schematic diagram of optical system. White light from the Xe lump is analysed by grating monochrometer. The monochromatic light is then focused on the GaAs surface placed in the vacuum chamber through a view port.

The Processes for Cs-Te Deposition

In this subsection, we explain treatment for GaAs and the process to make Cs-Te thin film on it. Zn doped bulk GaAs surface was chemically etched in the same way as in Ref. [1] before installing in the chamber. The GaAs sample was further cleaned thermally at 470 °C for several hours under the vacuum condition. Further treatments were made after it cooled down to the room temperature. First, we deposited Te on the clean GaAs surface. The thickness was about 5 Angstrom. Next, Cs was evaporated repeatedly and it was several 10s Angstrom for each evaporation. After each Cs evaporation, QE spectrum was measured. Total Cs thickness was about 200 Angstrom. Deposition rate was about 1.5 angstrom/min. QE spectra for each step were shown in Figure 5-7.

We made Cs-Te film with three different Cs deposition conditions. The Cs deposition were done in 1) room temperature, 2) 120 ºC and 3) 120 ºC followed by room temperature.

QE SPECTRA

The QE spectra of Cs-Te GaAs evaporated in room temperature is shown in Fig. 5. After the heat cleaning, bulk GaAs had a finite QE only at UV region. It did not change by Te deposition. After Cs evaporation, QE was extended up to 850nm. Total Cs thickness was 226 Angstrom. QE was 0.05% at 850nm. Figure 6 shows that on 120 °C.

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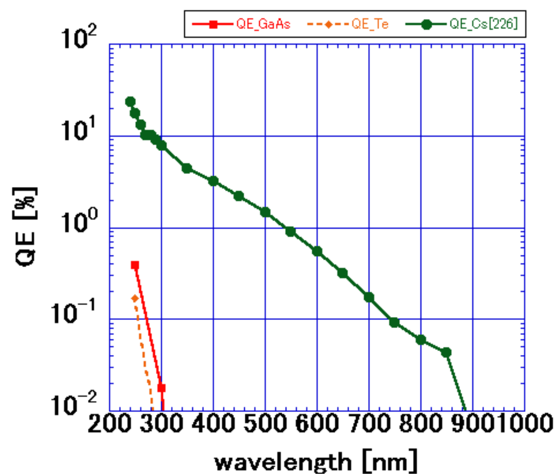

Figure 5: QE spectra of Cs-Te GaAs evaporated in room temperature is shown as solid circle. Square and diamond show those of bulk GaAs and Te-GaAs.

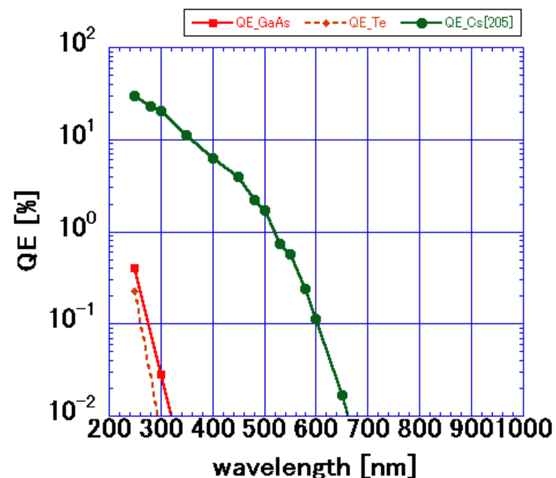

Figure 6: QE spectra of Cs-Te GaAs evaporated in 120 °C. The legends are same as in Fig. 5.

The spectra after bulk-GaAs and Te GaAs are similar them in room temperature. By Cs evaporation on GaAs in 120 °C, it extended up to 650nm. Total Cs thickness was 205 Angstrom. QE was 30% at UV, but it was only 0.1% at 600nm. GaAs was cooled down after the Cs deposition and Cs was additionally evaporated on the surface in room temperature. After the "re-cesiation" QE spectra were measured. The results are shown in Figure 7. In this procedure, QE was increased rapidly and it extended up to more than 900nm. The amount of the additional Cs evaporation was only several Angstroms in thickness. QE was the highest in all spectra. QE is rapidly decreased at near of the GaAs band gap, 900nm. Because the work function of Cs-Te photocathode is about 3.5 eV, photo-emission from the Cs-Te formed on GaAs is impossible. The QE spectrum extending up to 900 nm strongly suggests that the electrons are excited from the GaAs valence band to the conduction band and the excited electron are extracted to the vacuum through the Cs-Te GaAs NEA surface.

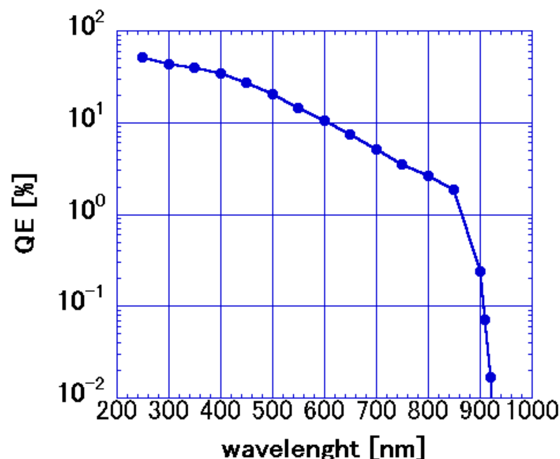

Figure 7: QE spectra after "re-cesiation". It extends up to 900nm which strongly suggests NEA state.

SUMMARY

NEA GaAs photo-cathode with Cs-Te thin film was performed. The hetero-junction hypothesis suggests that NEA surface is expected CsTe-GaAs. QE spectra were measured in three different Cs evaporation conditions. CsTe-GaAs evaporated in room temperate shows 0.05% QE at 850. CsTe-GaAs Cs deposited in 120 °C showed as high as 30% QE in UV region, but it extended only up to 600 nm. "Re-cesiated" CsTe-GaAs showed high QE up to 900 nm. This result strongly suggests that the surface is in NEA state. According to the results, the Cs evaporation process is important and further studies will reveal the critical condition.

ACKNOWLEDGMENT

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