GaAs PHOTOCATHODE ACTIVATION WITH CsTe THIN FILM

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Abstract

GaAs is an unique and advanced photocathode which can generate highly polarized and extremely low emittance electron beam. The photo-emission is possible up to 900nm wavelength. These advantages are due to NEA (Negative Electron Affinity) surface where the conduction band minimum is higher than the vacuum energy state. The NEA surface is artificially made with Cs-O/F evaporation on the cleaned GaAs surface, but the NEA surface is fragile, so that the emission is easily lost by poor vacuum environment and high emission density. NEA activation with any vital material is desirable. We found that the GaAs can be activated by CsTe thin film which is known as a vital photo-cathode material. The photo-electron emission spectrum extends up to 900 nm wavelength which corresponds to the band-gap energy of GaAs. The result strongly suggests that the surface becomes effectively NEA state by the CsTe thin film.

INTRODUCTION

GaAs is a III-V type semiconductor with 1.4 eV direct band gap energy at G point. Valence band electron states which have different angular momentum from -3/2 to 3/2 are degenerated. By employing circularly polarized laser light (+1 or -1 angular momentum) to excite these electron to the conduction band, one of the spin states (-1/2 or +1/2) is enhanced. By introducing special technique as strain and/or super-lattice to break the degeneration, only one spin state can be excited at the conduction band. To extract these spin-polarized electrons in the conduction band to the vacuum state, we need additional energy because the vacuum state is in higher energy state than that of the conduction band minimum in ordinal surface (PEA; Positive Electron Affinity). In contrast, NEA (Negative Electron Affinity) surface where the conduction band minimum energy is higher than that of the vacuum state, makes electron emission possible once they are excited to the conduction band. NEA surface is artificially made on p-type GaAs by adsorption Cs and O/F on the surface. Because the polarized electron excited to the conduction band is in the minimum, the emission is possible only with the NEA surface. NEA surface is however fragile, so it is easily damaged by a poor vacuum quality and particle bombardment. Therefore, the use of the NEA GaAs cathode is currently limited in a DC biased gun and it is not compatible to RF guns.

If the NEA surface could be made on GaAs surface with a robust thin layer, it could be compatible with RF gun and use of the polarized electron beam would be widen. There was an UPS experiment suggesting that CsTe film on GaAs surface would be NEA[1]. The energy states evaluated from the experiment is shown in Fig. 1. The surface energy state of CsTe on GaAs was 3.1 eV lower than that of bare GaAs according to the experiment[1]. By assuming the work function of bare GaAs is 4.4 eV, the work function of CsTe on GaAs is expected to be 4.1 - 3.1 = 1.3 eV which is lower than the band-gap energy, 1.4 eV. This results strongly suggest that the surface is NEA, because Fermi level of p-GaAs is at the top of the valence band energy.

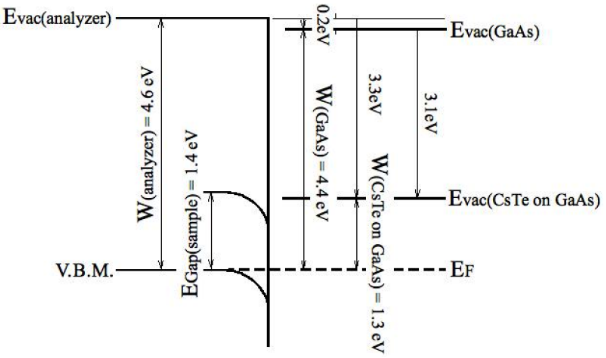

Figure 1: Energy states of CsTe film on GaAs surface. Reprinted from Ref. [1].

The surface state can be understood hetero-junction hypothesis where Fermi energy states for both materials are common. Because Fermi energy of p-GaAs is very close to the top of the valence band energy, the conduction band minimum of GaAs energy becomes higher if the work-function of the surface film f_s is lower than the band-gap energy of GaAs, E_{BG}. The condition for NEA surface is simply expressed as

$$E_{BG} - \varphi_s > 0. \qquad (1)$$

In this article, we studied the photo-elelctron emission properties of CsTe-GaAs. Because Cs_2Te is known as one of reliable and robust photo-cathode material[2], NEA activation with CsTe thin film on GaAs could improve the robustness of NEA GaAs photo-cathode.

EXPERIMENT

The experiment was performed in extremely high quality vacuum environment. Zn doped GaAs wafer is placed in a vacuum chamber pumped by ion pump and NEG pump. Typical vacuum pressure during the experiment was 4.0x10^{-9} ~ 2.0x10^{-8} Pa. An evaporator

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head can be inserted in front of GaAs wafer to make CsTe thin film on the surface. To monitor the amount of the material on the surface, a quartz thickness monitor is also placed in the chamber. GaAs and the thickness monitor are placed in a symmetrical position to the evaporator to equalize the vapour amount to both surfaces as shown in Fig. 2.

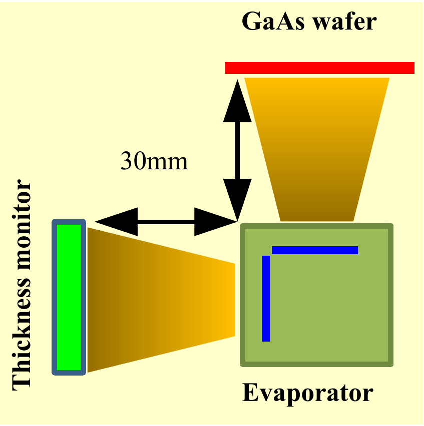

Figure 2: Schematic view of the experimental setup for the evaporation. Evaporator generates the Cs and Te vapour symmetrically to two directions for thickness monitor and GaAs wafer.

The experimental procedure was as follows. First, GaAs wafer is cleaned by heating up to 470 deg. C for one hour. The wafer is then cooled down to the room temperature. Te evaporation is first and Cs is evaporated. Te vapour is generated by heating Te beads mounted on a tungsten coil heater. Cs vapour source is dispenser made by SAES Co. During the Cs evaporation, QE is measured by Xe lamp. GaAs mount is biased (typically -100V) and QE is extracted by measuring the photo-current. QE is defined as ratio of illuminated number of photon on the surface and number of photo-electron. The light from Xe lump is monochromized with a grating. Typical width is 5nm, spot size is 4mm diameter, power is 10mW. Cs evaporation is usually terminated when QE shows saturation against the thickness,i.e. at the maximum QE.

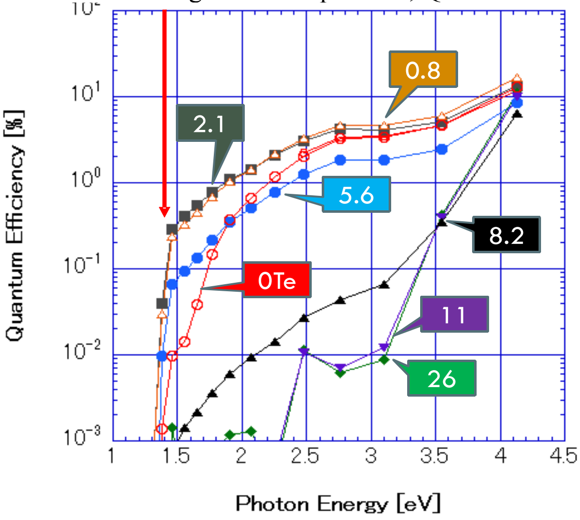

Figure 3: QE spectrum of CsTe-GaAs for various thickness conditions as shown in the legend. The first digit is Te thickness in Angstrome. The red arrow shows E_{BG} of GaAs.

Figure 3 shows QE spectra for various thickness conditions. Te thickness is in Angstrom. Spectra with thin Te layer (0.8, 2.1, and 5.6) extend down to1.4 eV which corresponds to E_{BG} of GaAs. Spectra with thick Te layer (8.2, 11, 26) decay rapidly in the low energy region. No Te activation, i.e. 0 Te thickness shows similar to that by thin Te case, but the shape in the low energy region is different. Because the finite QE was observed at E_{BG}, the results suggest that the surface becomes NEA with CsTe layer.

In the high energy photon region more than 3.5 eV which corresponds to Cs_2Te work-function, high QE was observed for all thickness configuration. That suggest that Cs_2Te thin film is formed on the surface and acting as the photo-cathode for the high energy photon. One exception is no Te case.

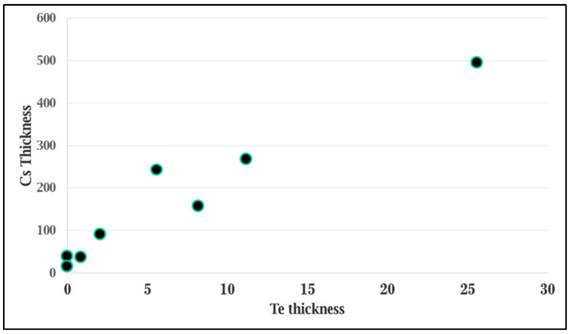

Figure 4: The relation of Cs thickness and Te thickness in the experiment. These data are in linear relation.

Figure 4 shows the relation of Te and Cs thickness in the experiment. Te thickness was determined for each experiments as a parameter, but Cs thickness was determined giving the maximum QE for each conditions. The linear relation between these two variables shows that the ratio of Te and Cs thickness giving the maximum QE is independent from Te thickness. That suggest that some compound of Cs and Te was formed on GaAs surface.

Figure 5 shows QE as a function of Te thickness in Angstrom. QE for various wavelength photon is plotted. 300nm data shows that QE is almost independent from Te thickness. It suggests that Cs_2Te (or some compound of Cs and Te) is formed on the surface and acts as photo-cathode in this wavelength, 300nm. In contrast, QE at other wavelength data show some thickness dependence. QE is large at thin Te thickness region less than 5 Angstrom and small (or almost zero) at thick Te thickness region more than 10 Angstrom. From 5 to 10 Angstrom region, QE is rapidly decreased. It can be explained that the object act as NEA-GaAs cathode less than 5 Angstrom region, thicker Te layer decreases QE by photon absorption or reflection in the surface layer. In

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case of the surface layer with more than 10 Angstrome Te, it acts as Cs_2Te cathode which has almost zero QE less than 350nm wavelength.

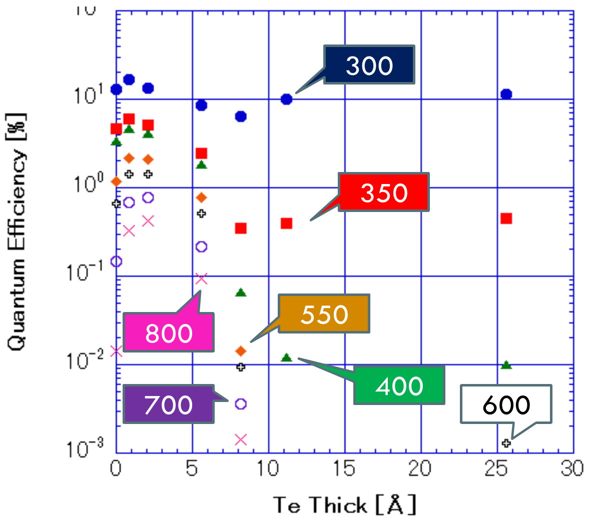

Figure 5: QE as a function of Te thickness in Angstrome. The data for different wavelength in nm are shown.

All these measurements are consistent with a speculation that Cs_2Te (or other Cs and Te compound) layer is formed on the surface of GaAs and the layer makes the GaAs surface NEA by decreasing the effective work-function. One of the difficulty is physical interpretation of the very thin Te thickness. The real thickness on the thickness monitor and on GaAs surface could be different because the adsorption rate on each surfaces could be different. Assuming the thickness monitor value is correct, the layer thickness is very thin, up to several atomic layers, because atomic radius of Te is 1.4 Angstrom. 0.8 Angstrom in the thickness measurement can be interpreted as coverage less than 1, i.e. less than mono-layer. Up to 5.6 Angstrom, a finite QE is kept. On the other hand, in the thicker case more than 10 Angstrom, QE is almost zero at low energy region as shown in Fig. 3 and 4. It shows the Te layer more than 10 Angstrom is enough to absorb or reflect the 1.4 eV photon.

Figure 6 shows the spectra decay in time. The spectra condition is 5.6 Angstrom Te thickness. The solid circle, square, diamond, triangle, and open cross show the spectra time evolution and each spectra were taken at 0 hour, 15 hours, 66 hours, 87 hours, and 120 hours after the activation, respectively. The life time defined as 1/e time constant depends on the wavelength of photon to measure QE and 100 hours for 2.0 eV photon and 1000 hours for 3.5 eV photon. The lifetime is not greatly long comparing to ordinal NEA GaAs cathode activated with Cs/O. It strongly depends on the vacuum pressure and residual gas species[3]. From those point of views, the experimental environment was not ideal. To make a quantitative comparison, we have to control the vacuum condition.

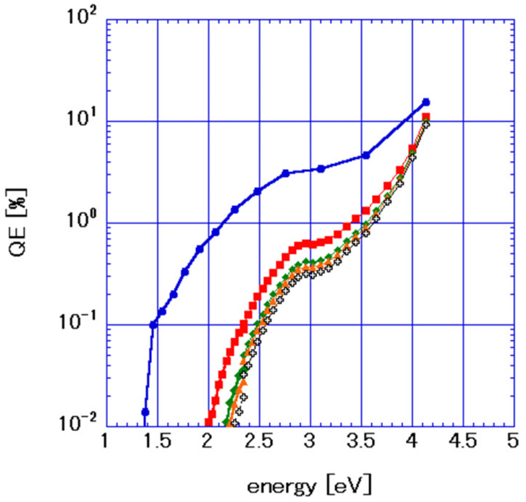

Figure 6: QE spectra temporal evolution is shown. QE (5.6 Te thickness) was measured as a function of phton energy in several times. Each spectra shown with the solid circle, square, diamond, triangle, and open cross were taken at 0 hour, 15 hours, 66 hours, 87 hours, and 120 hours after the activation, respectively.

SUMMARY

GaAs NEA activation with Cs_2Te thin film was studied experimentally. Cs and Te were adsorbed on cleaned GaAs surface. Cs and Te ratio was almost constant giving the maximum QE for various Te thickness. This result suggest that a compound of Cs and Te was formed on GaAs. We found that GaAs is activated with CsTe layer and finite QE at E_{BG} of GaAs which strongly suggest NEA surface. CsTe-GaAs acts as CsTe cathode for high energy photon more than 3.5 eV and as NEA GaAs for low energy region less than 2.5 eV. QE for the low energy photon is suppressed by increasing Te thickness suggesting that a strong absorption or reflection of photon on the surface. If we develop a transparent layer on GaAs which satisfies NEA condition as shown in Eq. 1, it can be a robust NEA GaAs cathode.

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