The Study of the Activated GaAs Surface for Application as an Electron Source in Particle Accelerators

N. Chanlek[a,b], J.D. Herbert[b] , L.B. Jones[b] , R.M. Jones[a] and K.J. Middleman[b]

[a]*University of Manchester, Manchester, M13 9PL, United Kingdom*
[b]*STFC Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom*

Abstract. The use of Type III-V semiconductor materials as photocathodes has in recent years become a focus for the High Energy Physics community. Once activated to a Negative Electron Affinity (NEA) state and illuminated by a laser, these materials can be used as a high-brightness source of both polarised and un-polarised electrons in some modern accelerators, e.g., The ALICE (Accelerators and Lasers in Combined Experiments) at Daresbury Laboratory. This paper will focus on the use of Gallium Arsenide (GaAs) as a photocathode, and detail the re-configuration and re-commissioning of two vacuum systems that support standard surface science techniques such as Ultraviolet / X-ray Photoelectron Spectroscopy (UPS/XPS), Low Energy Electron Diffraction (LEED) and Auger Electron Spectroscopy (AES). The paper will present details of cleaning GaAs in order to maximise quantum efficiency and will provide evidence from XPS and LEED to demonstrate what is happening at the atomic level.

Keywords: Negative Electron Affinity (NEA), Gallium Arsenide (GaAs), Photocathode, X-ray Photoelectron Spectroscopy (XPS) and Low Energy Electron Diffraction (LEED)
PACS: 29.20.-c, 29.25.Bx, 61.05.cj, 61.05.jh

INTRODUCTION

Gallium Arsenide (GaAs) photocathodes are being used as electron sources for various modern particle accelerators and next generation light sources. For example, the ALICE ERL prototype, a 35 MeV energy recovery test facility, is currently under commissioning at Daresbury Laboratory [1]. The current design of this machine requires an electron source that can generate a continuous wave (CW) current of 6.5 *mA* (electron beam) as a pre-cursor to the 100 mA injector with a normalised emittance of $< 2\ \pi$ mm mrad [2].

It is well known that once activated to a Negative Electron Affinity (NEA) state, the GaAs photocathode can be used as a high-brightness, low emmitance electron source [3,4]. This state is prepared by depositing caesium and an oxidant (either O_2 or NF_3) onto its atomically clean surface. The preparation process involving handling, preparation and cleaning processes is an essential step in the performance of the NEA GaAs photocathode. However, the fundamental nature and mechanism of these processes is not well understood, and clarification has been the subject of research for many years.

In this article we report on the progress of the re-configuration and re-commissioning of two vacuum systems which will allow the study and investigation of the photocathode activation process using the surface science techniques available within the same vacuum system. We also present the preliminary results of an X-ray Photoelectron Spectroscopy (XPS) and Low Energy Electron Diffraction (LEED) study on the effects of heating temperature on the GaAs surface in the heat cleaning process.

EXPERIMENT SET UP

Figure 1 shows our present experimental chamber configured at the Cockcroft Institute, STFC Daresbury Laboratory.

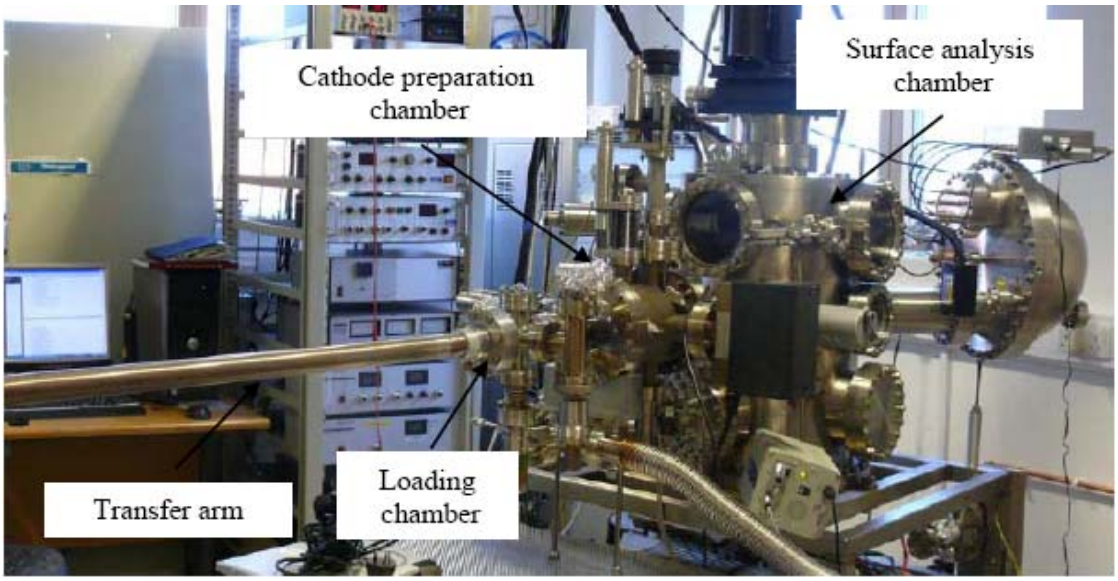

FIGURE 1. Picture of Photocathode experimental chamber which has been set up at the Cockcroft Institute, STFC Daresbury Laboratory.

The chamber consists of three sections, a loading chamber, cathode preparation chamber and surface analysis chamber which are isolated by gate valves. The photocathode sample is introduced to the system through the loading chamber which is pumped down via a dry turbomolecular pumping system. Once a suitable pressure has been reached the sample can be transferred between the sections using a transfer arm. The cathode preparation chamber includes a manipulator with sample holder and all of the components needed to clean and activate a cathode to the NEA state. The sample holder is isolated from the chamber wall by a ceramic ring and connected to a UHV electrical feedthrough so that a bias voltage can be applied to the sample. The chamber is also equipped with a caesium dispenser and a hydrogen gas cracker. The chamber is kept at a base pressure of 1×10^{-10} mbar by a dry turbomolecular pumping system, a DI ion pump and additional NEG pumping modules. The surface analysis chamber is equipped with a twin anode X-ray source, a hemispherical analyser for Ultraviolet / X-ray Photoelectron Spectroscopy (UPS/XPS) technique, a LEED optics

for Low Energy Electron Diffraction (LEED) and Auger Electron Spectroscopy (AES) technique, ion gun for sample sputter cleaning and RGA for residual gas analysis. This chamber is maintained at a base pressure of 1×10^{-10} mbar via a turbopump connected directly and supported by a turbomolecular drag dry pump system and two NEG pumps.

RESULTS AND DISCUSSION

For preliminary results, the heat cleaning procedures for a GaAs photocathode were studied. Bulk VGF (Vertical Gradient Freeze) GaAs samples of p-type doping (Zn) without any chemical cleaning were loaded in order to leave native contaminants on the surface. The samples were heated to five different temperatures; 450, 500, 550, 600 and 625 °C for 60 minutes in the surface analysis chamber. During heating, the temperature of the sample surface was monitored via an infrared pyrometer which has the resolution of ±15 °C. Note that this error comes from the rough calibration because, presently, no accurate emissivity of the GaAs photocathode could be estimated. The XPS spectra of the GaAs surface excited by Al $K\alpha$ (1486.6 eV) radiation were taken before and after heat cleaning process. The typical contaminants for GaAs such as oxygen, carbon and chlorine were observed on the dirty sample surface [5]. The removal by heat cleaning of oxides which are the main coverage contaminants on the GaAs surface was studied, with representative results as shown in Fig. 2.

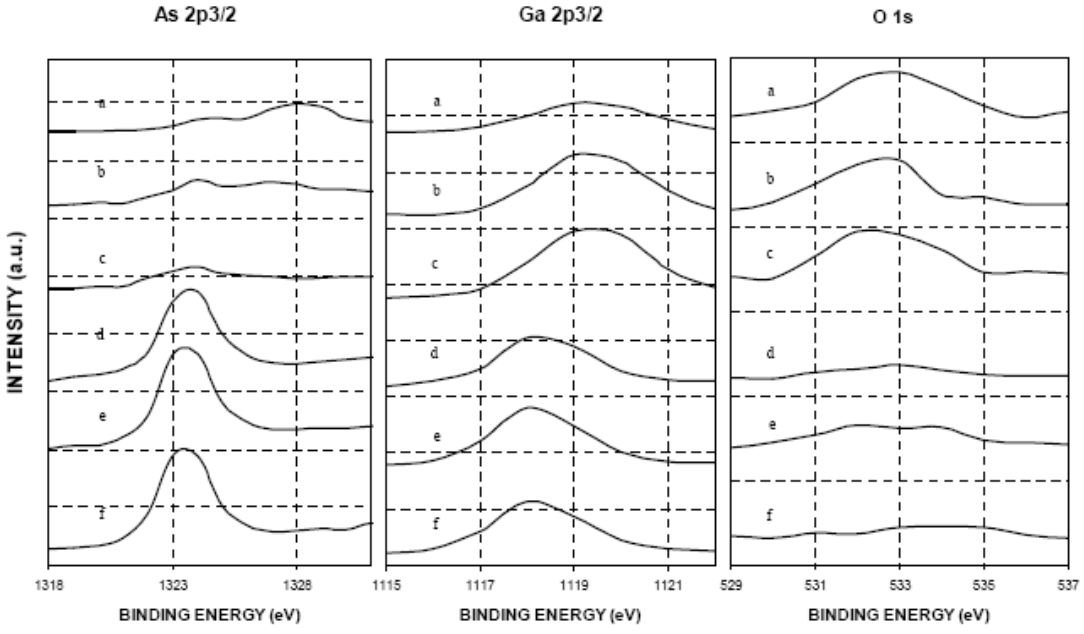

FIGURE 2. XPS spectra of the As $2p_{3/2}$, Ga $2p_{3/2}$ and O 1s for (a) the initial dirty sample, (b) after heating to 450°C for 60 min, (c) 500°C for 60 min, (d) 550°C for 60 min, (e) 600°C for 60 min and (f) 625°C for 60 min.

The core-level energy of the As $2p_{3/2}$ (1324 eV), Ga $2p_{3/2}$ (1117 eV) were observed and the presence of As_2O_3 and Ga_2O_3 were determined by the core-level energy shifts of 3 and 1 eV toward higher energies, respectively [6, 7]. The XPS spectra show that the energy shifts of the As $2p_{3/2}$, Ga $2p_{3/2}$ peaks decreased when the heating temperature was increased, and at the same time the intensity of As core-level energies increased. These results indicate that the surface oxides are desorbed from the GaAs surface under heat cleaning, and are completely removed after heating to a temperature higher than 550 °C for 60 min. This is also consistent with the reduction in the O 1s intensity.

The activation to NEA surface and measurement of the Quantum Efficiency (QE) was made after heating the sample to each of the different temperatures. Caesium and oxygen were deposited onto the sample by using the standard "Yo-Yo" method [3]. The samples were illuminated with a HeNe laser at 632.8 nm during the activation process to drive the photocurrent and calculate the highest QE of the sample. The QE of the GaAs samples are shown in Fig. 3. As is clearly seen, the QE of the GaAs samples increases when the cleaning temperature is increased, agreeing with the XPS results that the oxide overlayer is removed under heat cleaning. A QE of 4.12% was obtained as a result of heating the sample at 600°C, however, the QE dropped to 3.81% after heating to 625°C. This result shows that heating to excessive temperatures might damage the properties of the GaAs, resulting in a detrimental effect on the QE.

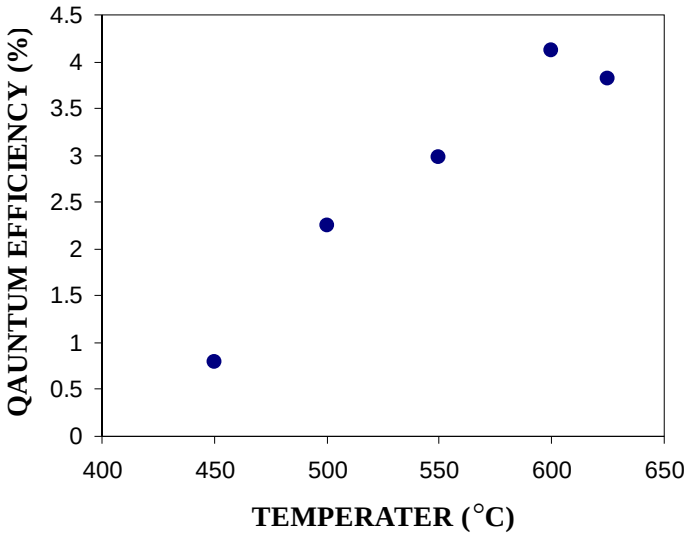

FIGURE 3. Quantum Efficiency as a function of heat temperature in heat cleaning procedure.

To further our studies, the LEED pattern of the GaAs sample was also taken after heating to the different temperatures. It was found that a clear LEED pattern can be observed after heating the sample to a temperature of 550°C for 60 min, as shown in Fig. 4, indicating that the sample has a clean and well-ordered surface.

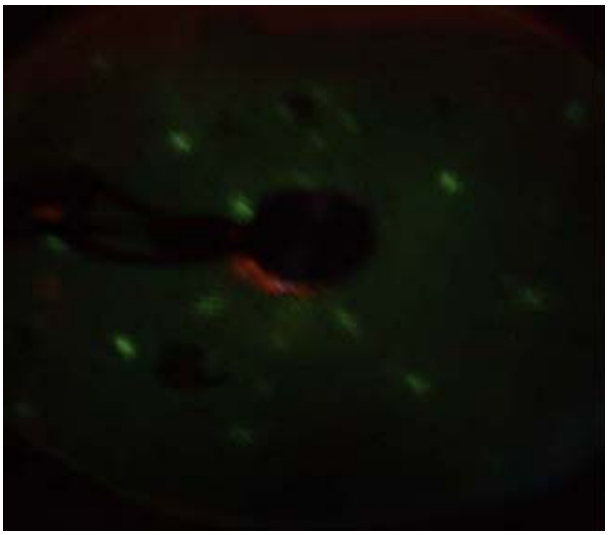

Figure 4. LEED pattern of the GaAs surface after heat the sample to 550°C for 60 min.

CONCLUSIONS

The amalgamation of two vacuum systems has been completed at the Cockcroft Institute, Daresbury Laboratory in order to study and investigate the photocathode material in detail. This experimental set up allows us to prepare and study the properties of the photocathode material using the application of surface science techniques such as Ultraviolet / X-ray Photoelectron Spectroscopy (UPS/XPS), Low Energy Electron Diffraction (LEED) and Auger Electron Spectroscopy (AES) within the same vacuum system.

The heat cleaning procedure for the NEA GaAs photocathode was studied. It was found that oxides from the GaAs surface can be removed after heating to a temperature higher than 550°C for 60 min. However, the heating temperature need to be optimized, as excessive temperatures can result in decreasing in the QE.

ACKNOWLEDGMENTS

The authors are grateful for support from ASTeC and STFC Daresbury Laboratory.

REFERENCES

1. Daresbury Laboratory, 4thGeneration Light Source, ERLP Construction, accesses September 2008, http://www.4gls.ac.uk/ERLP.htm
2. B.L. Militsyn (private communication).
3. D.T. Pierce and F. Meier, *Phys. Rev. B* **13**, 5484(1980).
4. T. Maruyama, D.-A. Luh, A. Brachmann, J.E. Clendenin, E.L. Garwin, S. Harvey, R.E. Kirby and C.Y. Prescott, *Appl. Phys. Lett.* **82**, 4184 (2003).
5. J. Uebbing, *J. Appl. Phys*. **41** 802(1969).
6. E. J. Petit and F. Houzay, *J. Vac. Sci. Technol. B.* **12**, 547(1994).
7. Z. Lu, M.T. Schmidt, D. Chen, R.M. Osgood, W.M. Holber, D.V. Podlesnik and J. Forster, *Appl. Phys. Lett.* **58**, 1143(1991).