

FIRST RESULTS FROM THE III-V PHOTOCATHODE PREPARATION FACILITY FOR THE ALICE ERL PHOTOINJECTOR

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Abstract

Accelerators and Lasers In Combined Experiments (ALICE) is an Energy Recovery Linac (ERL) built at STFC Daresbury Laboratory to investigate the process of energy recovery [1]. The project is an accelerator research facility intended to develop the technology and expertise required to build new light sources in the UK based on of Free-Electron Lasers. The original design of the ALICE photoinjector derives from the Jefferson Laboratory IR-FEL photocathode gun. In its current configuration, the ALICE gun accommodates only a single photocathode, and the system must be vented to atmospheric pressure to facilitate photocathode replacement. To meet the stringent vacuum demands for good photocathode lifetime, the system then requires baking for up to three weeks.

A new load-lock *photocathode preparation facility* (PPF) has been designed as part of an upgrade to the ALICE photoinjector. The PPF can accommodate up to six photocathodes, and permits rapid transfer of photocathodes between the PPF activation chamber and the ALICE gun, thus maintaining the integrity of the photoinjector vacuum system. The PPF was successfully commissioned with a GaAs photocathode in spring 2009, and has since permitted a quantum yield of 15 % to be achieved at a wavelength of 635 nm. Presently, a new photoinjector gun vessel and photocathode transport system is under design/manufacture, with a view to this being fully-installed on ALICE in spring 2011.

ALICE PHOTOINJECTOR UPGRADE

The whole ALICE photoinjector upgrade program includes: the development of photocathodes capable of delivering of 10-100 mA CW current; an integrated gun and PPF with a transfer system allowing for replacement of the photocathode in the gun within few hours; and a new gun vessel with improved pumping capabilities [2].

The current ALICE photocathode is a 25 mm Ø GaAs wafer activated *in-situ* and illuminated over a 4 mm Ø area by a 532 nm laser to drive electron emission [3]. The new photocathode assembly has been designed to

accommodate a semiconductor heterostructure (1) with a 9.5 mm Ø active area, as shown in Fig. 1. As the laser only illuminates an area ~ 4 mm Ø, use of a smaller active area could help reduce the beam halo. The photocathode wafer is bound to 1.4 mm recess on the bottom of upturned 2 mm thick molybdenum “Petri dish” (2) with a diameter of 19 mm and a height of 6.5 mm. The polished surface of the cup (3) improves heat flow away from the photocathode surface when a high power laser is used to drive emission of high beam currents. The

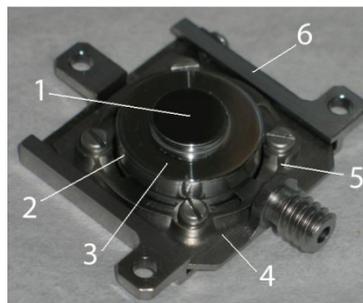


Figure 1. GaAs photocathode in the mounting socket.

photocathode is retained in a transport holder (4) by a flat Inconel spring (5). During preparation and operation, the photocathode is installed into a socket (6).

The design of the three-chamber extreme-high vacuum PPF has been described in detail [4]. It comprises a *loading chamber* (LC), an atomic *hydrogen cleaning chamber* (HCC) and a *preparation chamber* (PC) (Fig. 2). Photocathodes are transferred between the chambers and also from the PPF into the photoinjector gun using magnetically-coupled linear manipulators.

The proposed upgrade scheme permits usage of a variety of III-V photocathodes which may be activated with the PPF. The upgrade design will allow for the easy replacement of the III-V PPF with a facility for preparation or transport of a *different* type of photocathodes without venting the gun. One of the possible options under consideration is usage of ultra fast alkali antimonide-based photocathodes, which may operate at a wavelength of 532 nm with reasonably high levels of quantum efficiency.

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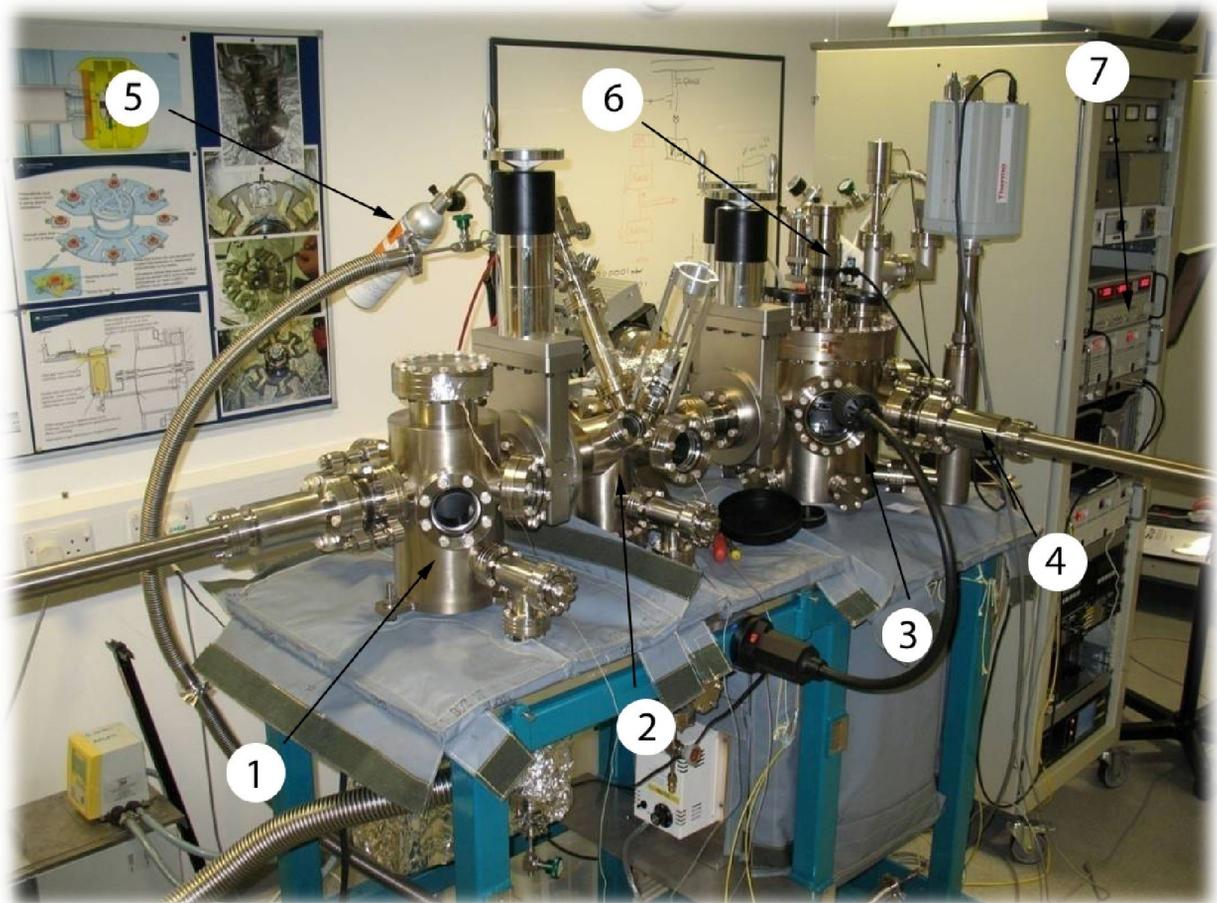


Figure 2. III-V Photocathode Preparation Facility in the ASTeC vacuum laboratory. 1 – Loading Chamber (LC), 2 - Atomic Hydrogen Cleaning Chamber (HCC), 3- Preparation Chamber (PC), 4 - magnetic manipulator, 5 - hydrogen cylinder, 6 - oxygen piezo-electric leak valve, 7 - control rack

Embodiment of the ALICE photoinjector upgrade is currently underway. The PPF has been constructed and commissioned in ‘stand-alone’ mode using GaAs heterostructures. A sophisticated side-load photocathode transport mechanism has been designed, and will be tested first in atmosphere, then in an extra-high vacuum facility which duplicates the vacuum conditions of the real gun. The test facility is now being commissioned.

OPERATION OF THE III-V PPF IN STAND-ALONE COMMISSIONING MODE

In order to commission and to optimize our photocathode preparation procedure, the PPF has been operating in stand-alone mode. The vacuum port which will connect the PPF to the gun via an all-metal gate valve has been connected to a turbo vacuum pump which is used during the bake-out procedure. This solution will permit connection of the PPF to the operational gun without its ventilation.

Originally, the III-V photocathode family (such as GaAs, GaAsP, InGaAsP, as grown) have a Positive Electron Affinity (PEA), which for GaAs is 4 eV. In order to make GaAs photocathodes able to emit electrons when illuminated by 532 nm light typical for ERL DC guns, the electron affinity should be lowered to less than 1 eV - or even brought to a negative value. This process requires

deposition on the atomically-clean photocathode surface of alternating thin layers of Cs and an oxidant, typically O_2 or NF_3 , and is called *activation*. In the vacuum laboratory where the PPF is installed, O_2 oxidant is used.

An ideal photocathode preparation procedure includes chemical etching of the photocathode surface in hydrochloric acid to remove As and Ga oxides in a dedicated glove box under a pure nitrogen atmosphere. The photocathode is then transferred to the LC via a nitrogen-filled transport vessel to prevent the formation of new oxide species (see Fig. 2). The transport vessel can accommodate up to four samples simultaneously, though the full glove box procedure has not yet been implemented, so photocathodes are placed into the transport vessel as delivered rather than etched.

The LC pumping system includes an oil-free preliminary pumping station, backed by an ion pump. During loading, the LC is vented to dry nitrogen gas. It is then pumped down to a typical pressure of 10^{-9} mbar, and then subjected to a short bake at a temperature of 120-150 °C in order to remove water from the samples.

Once acceptable vacuum in the LC is established, the photocathode is transferred to the HCC for exposure to atomic hydrogen. Although it was originally implemented for *rejuvenation* of spent photocathodes, atomic hydrogen cleaning is now used for *initial* photocathode cleaning.

Typically, photocathodes are heated to 450 °C (measured with a pyrometer) and exposed to hydrogen at 2×10^{-5} mbar for 15 minutes.

Hydrogen-cleaned photocathodes are then transferred into the PC where they undergo a further heat-cleaning process at a temperature of 600 °C for 1-2 hours. This high cleaning temperature is set because the photocathode has **not** been chemically etched to remove oxides. The heat-cleaning temperature for an *etched* photocathode may be reduced significantly to 450 °C. A heat-cleaned photocathode is then activated by means of a Cs-O₂ “Yo-Yo” procedure. Caesium is evaporated from dispensers while the high-purity oxidant gas is delivered from a cylinder via a piezoelectric leak valve. During activation, the photocathode is illuminated by a 635 nm laser and the photocurrent is monitored with a picoammeter. The Cs sources emit ions because of their high operating temperature, and this generates a background current which masks photocurrent produced by the activated cathode. To counteract this, the laser is modulated at 3 kHz and a synchronous detector used for current measurement in a lock-in configuration.

XHV conditions are maintained in the PC. As activated photocathodes are very sensitive to the presence of oxidants in the residual atmosphere, for example the 1/e lifetime of GaAs does not exceed 2×10^{-8} mbar-s of oxygen exposition [5]. The typical pressure in the PC is of the order 10^{-11} mbar, with the partial pressures of oxygen, water vapour and CO₂ less than 10^{-15} mbar. In order to routinely maintain such extreme vacuum conditions, the PC is equipped with a high performance ion pump and eight non-evaporable getter strips, and it is *never* vented to atmosphere. Vacuum in the PC is monitored constantly with an extractor gauge and a RGA.

The lifetime of photocathodes is expressed by *total extracted charge*, and operation in a DC gun restricts this to only a few hundred Coulombs [6], corresponding to an operational life-time of a few hours under ERL operating conditions with average extracted current of 100 mA. The PPF should be ready to deliver an activated photocathode every few hours, and consequently, the PPF will normally contain several photocathodes, one of which is activated.

RESULTS FOR GaAs PHOTOCATHODE ACTIVATION

Initial commissioning of the PPF was performed with GaAs heterostructures bound via an In layer to a Mo substrate. The active layers have thicknesses of 400 nm and 1.5 μm. The samples were activated with the procedure described above. During activation, the Cs source was powered constantly, but oxygen injection was alternated with the piezoelectric leak valve. The base pressure in the PC was 1.2×10^{-11} mbar, though during oxygen injection the pressure rose to 5×10^{-10} mbar. The “Yo-Yo” procedure was halted when the photocurrent reached its saturation level, and a typical activation curve is shown in Fig. 3. Overall, the results from many

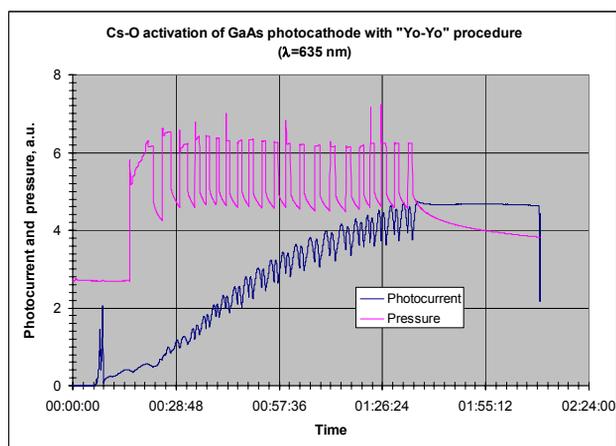


Figure 3. Activation curve of GaAs photocathode.

activations have demonstrated a significant level of spread in the final QE, and this is very likely to be due to the absence of chemical etching, and problems in the accurate measurement of the sample temperature during cleaning.

CONCLUSION

The III-V Photocathode Preparation Facility developed at Daresbury Laboratory in the framework of the ALICE gun upgrade has been commissioned successfully during 2009 – 2010. Photocathodes based on GaAs heterostructures have been successfully activated by simplified technology (without chemical etching). A maximum QE of 15 % at a wavelength of 635 nm has been achieved. Further development of the PPF and its processes are directed at the implementation of chemical etching in a dedicated glove box, and development of an alternative *contactless* method of temperature measurement.

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