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NEGATIVE ELECTRON-AFFINITY ACTIVATION PROCEDURES FOR GaAs PHOTOCATHODES AT PHOTO-CATCH*

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Abstract

State-of-the-art spin-polarized photo-electron sources use GaAs-based photocathodes to provide electron beams with high degrees of spin-polarization and high brightness. Such photo-guns are required to operate with both quantum efficiency and cathode lifetime as high as possible in order to meet the requirements of high-current applications such as energy-recovery linacs and colliders. Both quantum efficiency and lifetime are determined by the quality of the thin surface layer, typically consisting of Cs in combination with an oxidant, required for GaAs photocathodes to achieve negative electron affinity. This layer is applied during a so-called activation process. It is therefore of great interest to optimize and standardize this procedure in order to provide the best possible conditions for reliable photo-gun operation.

This contribution presents the analysis of bulk-GaAs activations using Cs and O_2 conducted at the Photo-CATCH test stand. The effects of Cs and O_2 partial pressures on final quantum efficiency, as well as the duration of the activation process, were scrutinized in order to find an optimal partial pressure ratio at a reasonable duration of the procedure.

INTRODUCTION

The Institut für Kernphysik (IKP) at TU Darmstadt operates the superconducting Darmstadt linear accelerator S-DALINAC [1]. It features a thrice-recirculating lattice design, capable of operation in energy-recovery mode [2, 3]. Two electron sources are available: a thermionic gun for unpolarized beam and the S-DALINAC polarized injector SPIn [4] for spin-polarized beam. SPIn uses a DC photo-electron gun with negative electron-affinity (NEA) GaAs-based photocathodes as electron source.

For future experimental campaigns at the S-DALINAC utilizing spin-polarized electron beams, such as polarization transfer and correlation studies [5], it is of great interest to optimize photocathode parameters such as quantum efficiency η and lifetime τ. For this purpose a separate test stand for photo-cathode activation, test and cleaning using atomic hydrogen Photo-CATCH is available [6] at the IKP, allowing for research on photogun development [7] and photocathode activation studies [8–10] independent of beamtime at the S-DALINAC.

The analysis and optimization of a co-deposition (Co-De) activation scheme at Photo-CATCH is presented in this contribution. The first section introduces the test stand and the activation setup used for the experiments presented in the second section. Future investigations at Photo-CATCH will be presented in the final section.

PHOTO-CATCH TEST STAND

Photo-CATCH features a set of vacuum chambers, separated by all-metal gate valves, for photocathode cleaning, activation, and testing. New samples are loaded into the vacuum system through a load-lock chamber. A dedicated cleaning chamber houses a hydrogen atom beam source and heating coils for hydrogen cleaning and heat cleaning of the cathode. The NEA surface layer is applied onto the cathode in the activation chamber. A gun chamber with a -60 kV inverted-insulator geometry is available for beam production. The electron beam can be analyzed in the adjacent beam line that is equipped with several setups to measure the emittance, bunch shape and spin-polarization of the electron beam. The vacuum system provides XHV conditions with base pressures in the low 10^{-11} mbar range after bake-out, with exception of the beamline and the load-lock chamber which are not baked out and where base pressures in the low 10^{-9} mbar are reached.

Activation Setup

NEA activations at Photo-CATCH are carried out in the dedicated activation chamber. It features two tungsten coils for heat cleaning and a separate activation unit, consisting of a ring-anode and two dispensers, one for Cs and one for Li. The ring-anode is connected to a digital multimeter and bias voltage power supply for photocurrent measurements. Oxygen is introduced from an external reservoir through a piezo-electric leak valve. A cold-cathode ionization gauge, connected to a gauge controller, provides online pressure measurements. The photocathode, placed inside a molybdenum puck, is positioned within the chamber using a vertically and radially movable carousel assembly.

Incident light is introduced through a large window at the bottom of the chamber. During activation, a white-light LED array is used. A laser diode placed on an adjacent laser table provides a laser beam with $\lambda = (785 \pm 5)$ nm and variable laser power, which is is transferred to Photo-CATCH via a fiber optic patch cable for measurements of η in the activation chamber. Incident laser power is monitored indirectly by using a beam splitter cube and a photodiode. All components are connected to an EPICS IOC server, as shown in Fig. 1.

ACTIVATION EXPERIMENTS

All activations presented in this contribution were carried out using the so-called co-deposition (Co-De) scheme: after

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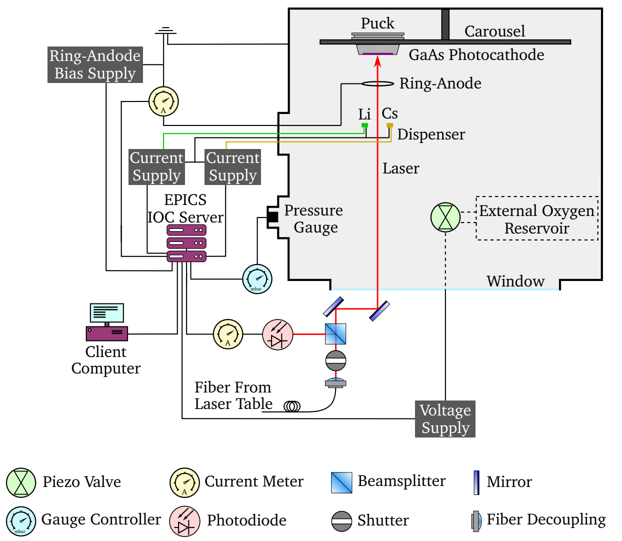

Figure 1: Schematic representation of the used activation setup.

heat cleaning of the photocathode surface, Cs is introduced into the activation chamber and the sample is illuminated with white light from the LED array. After a short duration (usually no more than a few minutes), a rising amount of photocurrent can be observed that reaches saturation peak after another few minutes. Once the photocurrent has dropped to about 75 % of the saturation peak value, O_2 is introduced, leading to a steep rise in photocurrent. The amount of oxygen is repeatedly adjusted to keep the pressure within the chamber at a constant level. Once a saturation in photocurrent is observed, both Cs and O_2 exposure is stopped. The LED array is turned off and the laser shutter is opened to introduce laser light with power in the range of 40 μW to 60 μW is introduced in order to measure η.

The partial pressure of Cs, p_{cs}, is obtained by subtracting the initial pressure p_0 at the start of the activation from the current pressure p during Cs introduction. Once O_2 is introduced, p_{cs} can no longer be obtained by this method and is approximated for the rest of the activation by its value at the start of O_2 introduction. The oxygen partial pressure p_{ox} is then calculated by subtracting both p_0 and p_{cs} from the current pressure p. The partial pressure ratio is defined as $r = p_{\text{cs}}/p_{\text{ox}}$.

Previous studies at Photo-CATCH suggested a favorable partial pressure ratio of $r = 0.043$ [6]. Hence, a series of activations was carried out in order to validate this value. In total, 18 consecutive activations were conducted using the same sample of p-type bulk-GaAs[1].

Figure 2 shows η depending on r. As can be seen, for most activations r was higher than the target value of 0.043, with a mean value of $\overline{r} = 0.049 \pm 0.004$ over all activations. The reason for this deviation is the manual calculation of the partial pressures and r during the activation, which is not

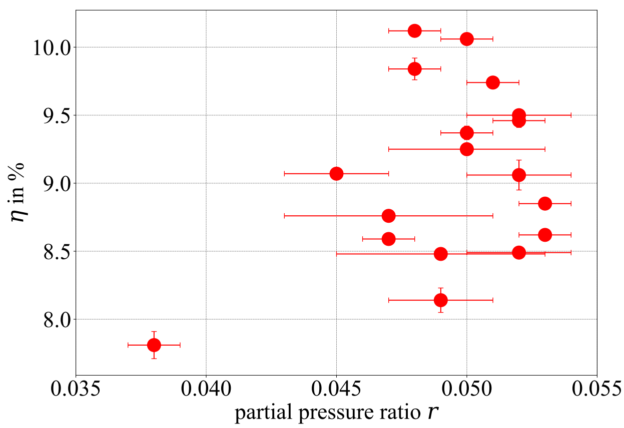

Figure 2: Final quantum efficiency η after activation depending on partial pressure $r = p_{\text{cs}}/p_{\text{ox}}$ during activation.

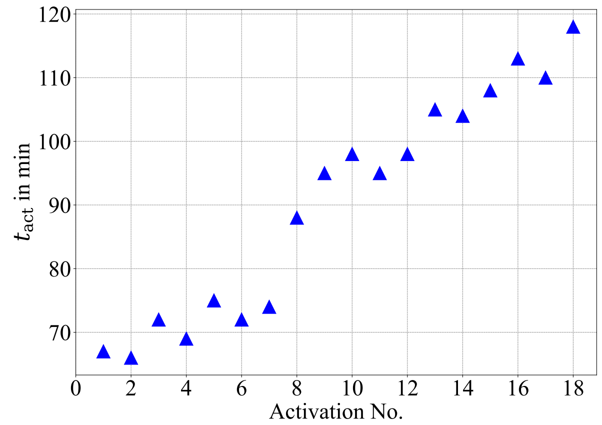

Figure 3: Duration of the activation process t_{act} for each activation in chronological order. An increase in t_{act} over time was observed.

as precise as a thorough analysis of the data post-activation, hence causing a systematic error. Nevertheless, good values for η were achieved, with a mean quantum efficiency of $\overline{\eta} = (9.1 \pm 0.6)$ %.

While one activation showed a lower quantum efficiency of $\eta = (7.81 \pm 0.10)$ % at a lower ratio of $r = 0.038 \pm 0.001$, this is not sufficient to draw a conclusion on the effect of lower r on η. High values of η in the range of 8 % to 10 % were achieved consistently for r in the range of 0.043 to 0.054. However, the uncertainties of r are still high since both p_{cs} and p_{ox} cannot be determined accurately enough. Since the precision of this method is limited, we aim to use different methods for future optimization of the activation process, such as exact timing of process steps and online photocurrent slope measurements.

During the activation study, an increase in overall time to complete the activation t_{act} was observed, as shown in Fig. 3, with the duration of the last activation almost double the time

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[1] Commercially available sample from Wafer Technology Ltd., Zn carrier concentration in the range of $5 \times 10^{18}\,\text{cm}^{-3}$ to $5 \times 10^{19}\,\text{cm}^{-3}$ as specified by the manufacturer

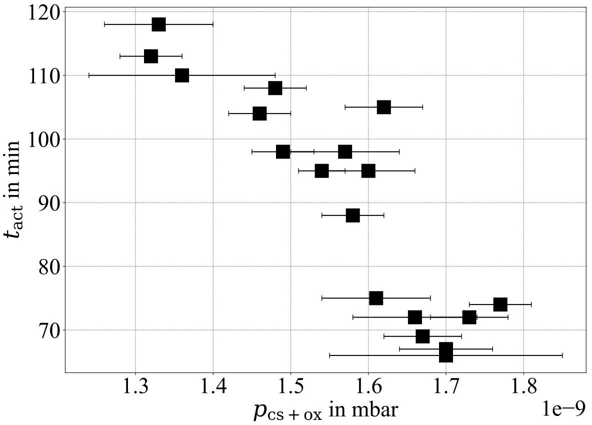

Figure 4: Duration of the activation process t_{act} as a function of the mean amount of ingredients introduced during the activation process $p_{\mathrm{cs+ox}}$. The duration is significantly increased for lower amounts of introduced ingredients.

required for the first activation of the series. The cause for this increase was found to be a decrease in the overall amount of introduced ingredients, i.e. the sum of mean Cs and O_2 partial pressures during activation $p_{\mathrm{cs+ox}} = p_{\mathrm{cs}} + p_{\mathrm{ox}}$, as can be seen in Fig. 4. A slow decrease in p_{cs} for a fixed dispenser operating current was found, most likely caused by the wear of the Cs dispenser. Since p_{ox} was chosen for each activation to meet the target value for r, p_{ox} and hence $p_{\mathrm{cs+ox}}$ decreased continuously for each consecutive activation. However, an influence of $p_{\mathrm{cs+ox}}$ on the final η after each activation process was not observed. Hence, the amount of ingredients for future activations need to be chosen and adapted such that the duration of the activation process is kept below 60 min.

CONCLUSION AND OUTLOOK

At Photo-CATCH, an optimized Co-De scheme using Cs and O_2 has been established, achieving high quantum efficiencies in the range of 8 % to 10 % at an incident wavelength of 785 nm. Wear of the used Cs dispenser caused a decrease of introduced Cs was observed, leading to a decrease of introduced O_2. The lower amount of ingredients caused an increase in the duration of the activation process. An analysis of the partial pressure ratio did not show a clear trend for the used values of r. Hence, more precise methods such as timing of the process steps and photocurrent slope measurements are planned for further optimization of the activation process, aiming to further improve the reproducibility of η. Additionally, the effect of different activation parameters on photocathode lifetime needs to be scrutinized in future activation studies. This optimization of the activation procedure will be used for the ongoing development of a fully automated activation scheme at Photo-CATCH.

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