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Cryogenic GaAs cathode development for improved lifetime

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GaAs photocathodes provide a source of highly polarized electron beams. To ensure reliable operation for high current applications, it is necessary to increase charge lifetime. To improve the local vacuum condition around the cathode the use of a cryogenic sub-volume is proposed. It is expected that the cryogenic adsorption of reactive residual-gas molecules yield an enhanced lifetime of the negative-electron-affinity surface of the cathode. Additional cooling of the cathode itself allows a higher laser power to be deposited in the material, resulting in higher possible beam currents. Implementation and first measurements are planned to be conducted at the TU-Darmstadt Photo-CATCH test set-up to investigate the operational parameters of the new source.

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1. Introduction

Photo-guns with semiconductor photo-cathodes like GaAs provide a source for high-current, low emittance electron beams necessary for ERL experiments [1], positron production [2], or future colliders in general [3]. For highly polarized beams a negative-electron affinity (NEA) coating of the cathode is essential for photo emission. The process of applying this layer is called activation. In our case cesium and oxygen are used. The destruction of this coating limits the operational usability of the cathode. One distinguishes between the dark lifetime, describing the lifetime while the cathode is activated, but not in operation, and the operational lifetime. Both can be increased by reducing the residual-gas pressure around the cathode [4]. This work describes an approach to improve the vacuum conditions and therefore the dark and operational lifetimes of GaAs cathodes by putting the cathode in a cryogenic sub-volume. This contribution updates the report given at IPAC 2018 [5].

2. Lifetime limiting factors

The quantum efficiency (QE) of a photo cathode describes the ratio between the number of photons hitting the cathode surface and the emitted electrons. The time until the QE is reduced to 1/e of its initial value is called the lifetime of the cathode. The dark lifetime describes the lifetime of an activated cathode which is not in operation and the operational lifetime describes the deterioration of the QE during beam extraction, induced by the destruction of the NEA coating. The total lifetime can be described as follows [6]:

$$\frac{1}{\tau} = \sum_i \frac{1}{\tau_i} = \frac{1}{\tau_{vac}} + \frac{1}{\tau_{fe}} + \frac{1}{\tau_{loss}} + \frac{1}{\tau_{ibb}},$$

where τ is the total lifetime of the cathode. The first two terms describes the dark lifetime with the vacuum lifetime τ_{vac} caused by chemical reactions of the NEA layer with residual gases and τ_{fe} the lifetime due to field emission. The latter two terms limit the operational hours, where τ_{loss} describes the lifetime related to beam loss, and τ_{ibb} describes the destruction of the NEA layer due to residual gas, ionized by the electrons and accelerated backwards by the electric field towards the cathode, which is called ion back-bombardment (IBB). Field emission and beam-loss effects are determined by the geometry and voltage layout of the source. The vacuum lifetime and ion back-bombardment are directly related to the vacuum conditions. Molecules containing oxygen have the strongest effect on the chemical degeneration of the CsO layer. However, at temperatures around and below 10 K, such gases (O_2, CO_2, CO) condense on a cold surface, and the significantly reduced residual-gas pressure is dominated by H_2 and He.

In an attempt to improve the vacuum, the cathode is put inside a cryogenic sub-volume to significantly improve the vacuum conditions around the cathode to reduce these lifetime limiting effects. At the expected temperatures the outgassing of H_2 can not be prevented completely. However, H_2 does not contribute to the corrosion of the cathode, but it is the main cause of IBB [7]. Preliminary estimates of the vacuum conditions inside an almost completely closed cryogenic sub-volume show that a H_2 pressure of a factor of 10^{-3} lower compared to the outer chamber can be achieved.

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3. Source Design

Figure 1 shows the current design of the cryosource setup. The puck, which houses the cathode is inserted into the top part of a chamber with 10 cm diameter. The top part consist of aluminum, features a Pierce geometry for optimum beam emittance and is on a -30 kV negative potential. The chamber walls consist of an alumina insulator and are closed on the bottom by a grounded aluminum plate with an exit tube. The top of the chamber is connected through an insulator and a copper plate to a cryocooler, which provides the cooling power to achieve the needed temperature. The copper plate is slightly lager than the diameter of the chamber to shield the cryocooler from the electric field of the applied potential. For better thermal conductivity indium foils are placed between each parts. To reach temperatures of around 10 K, a heat shield made of polished aluminum is inserted between the sub-volume and the outer vacuum chamber wall.

With this setup an almost closed sub volume is created, which reduces the flux of residual gases from the outer, lager vacuum chamber into the sub volume. Simulations show that with a combination of NEG and turbo pumps, a pressure of around 10^{-12} mbar inside the sub-volume before cooling is achievable. After cooling, the pressure should improve to 10^{-15} mbar, which should result in drastic increase in lifetime.

A detailed simulation on the beam transport has been carried out using the CST Studio Software A simulation of a 10 pC electron bunch inside this sub-volume with a bias voltage of 30 kV can be seen in figure 2.

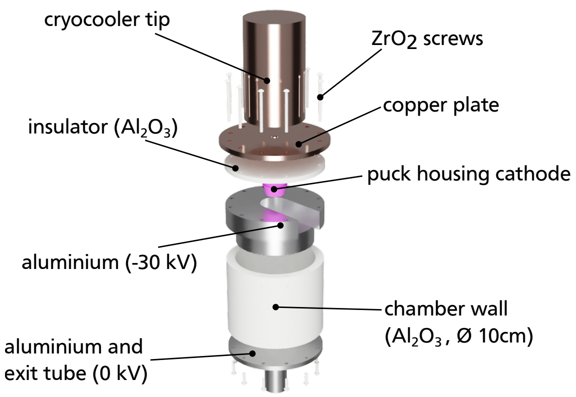

Figure 1: Rendering of the cryogenic sub-volume, including cryo cooler tip, puck with cathode, insulator and copper plate to shield the cryo cooler from the electric field.

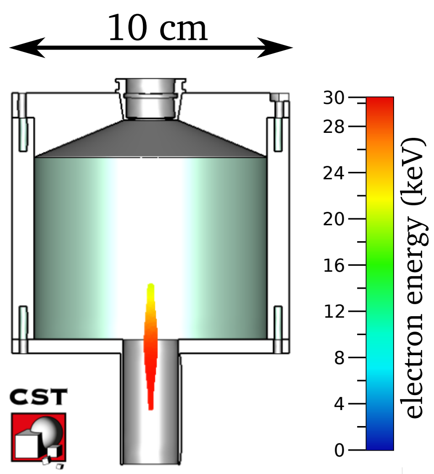

Figure 2: Simulation of 10 pC bunch inside the cryogenic sub-volume with an electric potential of 30 kV.

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4. Conclusion Outlook

High-current applications of spin-polarized electron beams could be realized using a cryogenic photo gun. First simulations and calculations show that a significant improvement in the local vacuum conditions around the cathode is expected, by inserting the cathode into a cryogenic sub-volume at around 10 K. A prototype was manufactured (see fig. 3), which will be used to measure the achievable temperature and cooling duration in near future. A test stand (Photo-CATCH) with a cleaning and activation chamber, as well as a short beamline with diagnostic instruments is available in Darmstadt [8] for further testing and setup of the final source.

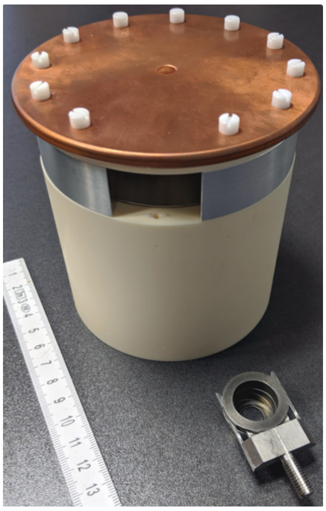

Figure 3: Photo of the prototype of the cryogenic sub-volume with puck and transport fork.

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