ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK100

SETUP FOR COOLED GaAs CATHODES WITH INCREASED CHARGE LIFETIME*

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Abstract

GaAs photocathode lifetime is limited, and to ensure reliable operation for high power-applications it is necessary to maximize its charge lifetime. By using a cryogenic subvolume it is expected to improve the local vacuum conditions due to cryogenic adsorption of reactive residual gas molecules.Yielding an enhanced lifetime of the negative-electron-affinity surface of the cathode. Furthermore the cooling of the cathode itself ishould allow higher laser power deposition in the material. Introducing an electrostatic bend is expected to reduces the ion-backbombardment on the cathode surface.

A dedicated set-up is being developed at the Photo-CATCH test facility in Darmstadt, Germany to measure the characteristics of such a cryogenic source.

This contribution updates the report given at PSTP 2017 [1].

INTRODUCTION

Applications like ERL experiments [2], positron production [3], or future colliders in general [4] require high-intensity polarized electron beams. A suited source are photo-guns. In the case of GaAs cathodes, however, the operation time is limited by the lifetime of the sensitive negative-electron-affinity (NEA) layer. This layer is necessary for electron emission from the material into the vacuum. Lifetime limiting effects comprise chemical reactions of oxygen-containing residual gases with the NEA layer and ion-backbombardment (IBB), which describes the ionization of the residual gas molecules by the accelerated electrons. These molecules are accelerated back towards the cathodes and hit the NEA layer. While the destruction of the NEA layer with the residual gas gives rise to the dark lifetime, IBB reduces the charge lifetime of the cathode while in operation [5].

Both effects can be reduced by better vaccum conditions. We proposte to reduce gas pressure using a cryogenic subvolume in which the cathodes will be installed. The cold volume surface creates a cryopumping effect and reduces the pressure around the cathode. In addition the cooling of the cathode itself allows a higher heat deposition of the laser beam.

To reduce the charge lifetime further an electrostatic bend of the electron beam is introduced to reduce IBB.

By means of a cryogenic source design described in this article, it could be therefore possible to achieve greater cathode lifetimes compared to conventional semiconductor-based photo-electron guns.

INCREASING CATHODE LIFETIME

The sensitive negative electron affinity (NEA) layer of the GaAs cathode is the limiting factor for its lifetime. It is composed of four parts and can be represented as [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, τ_{vac} is the vacuum lifetime, τ_{fe} the lifetime due to field emission, τ_{loss} describes the lifetime related to beam loss, and τ_{ibb} describes the destruction of the NEA layer due to ion back bombardment .

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.

The residual gas molecules corrode the NEA CsO layer over time due to chemical reactions. Molecules containing oxygen have the strongest effect on the lifetime [7]. With the setup described below temperatures of around and below 10 K will be achievable. At this temperature the saturation pressure of oxygen containing gases is sufficiently low to achieve a significant lifetime improvement [8]. Preliminary estimates of the vacuum conditions inside an almost completely closed cryogenic subvolume show that pressures of a factor 10^{-3} lower compared to the outer chamber can be achieved.

However H_2 is still present at the expected temperature. While H_2 does not corrode the cathode [7] it contributes to IBB. Therefore in addition to cryocooling an electrostatic bend of the electron beam is introduced. Due to the higher mass, the ionized gas molecules take a different path, and therefore miss the cathode, which results in significant IBB reduction.

SOURCE DESIGN

Figure 1 shows a preliminary layout of the cryo source. An almost completely closed cryogenic subvolume is installed in an outer vacuum chamber. Cooling is provided by a cryocooler, connected to the top of the subvolume. The cathode is placed in the subvolume in a way, that it is in proper thermal contact to the cooled chamber for sufficient cathode cooling. The beam tube of the subvolume is the only connection to the warm outside chamber which

* Work supported by DFG (GRK 2128) and BMBF (05H15RDRB1)
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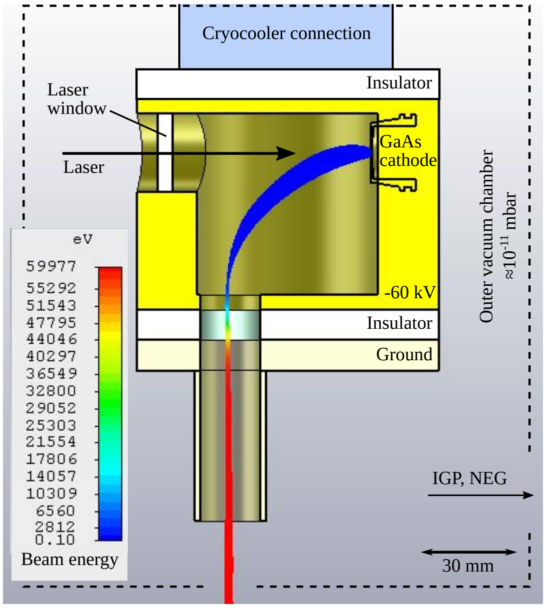

Figure 1: Simulation of the electron beam with a first layout of the cryogenic source (CST studio suite®).

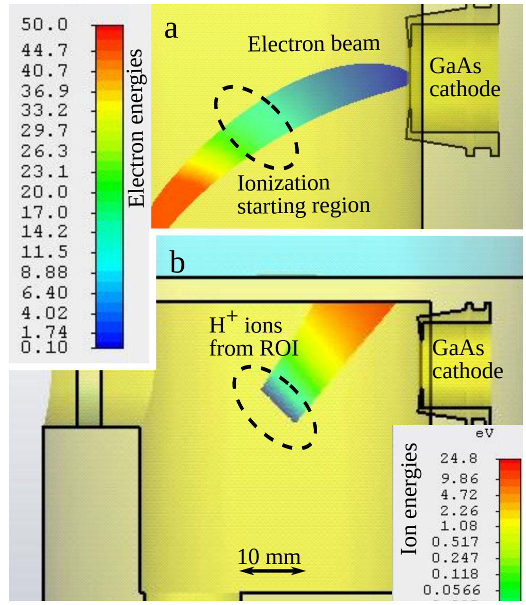

Figure 2: The region within the electrode chamber where the electron beam reaches sufficient energies to ionize molecular hydrogen (a). Ions originating from this ROI travel back a ddifferent path the the electrons and miss the GaAs cathode (b), presuming they have no initial kinetic energy.

reduces the flow of molecules into the cryo-chamber. This prevents the contamination of the cold surface, which would reduce the cryopumping effect [8]. An insulator (Al_2O_3) is placed between the top of the inner chamber and the cryocooler to seperate the cooler from the electrode potential. Al_2O_3 provides a high thermal conductivity at cryogenic temperatures as well as high dielectric strength. A combination of different pumps connected to the outer chamber provides a pressure in the range of 10^{-12} mbar at room temperature.

For minimal outgassing rates, the inner chamber will be manufactured from aluminum. To ensure a stable operation at cryogenic temperatures, the outer surface of the subvolume will be polished for minimal emissivity to reduce radiation heat load.

Figure 2 shows a simulation of the path of ionized gas molecules. In the region of interest (ROI) the electrons gain sufficient energy of around 15.6 eV to efficiently ionize H_2 [9]. As it can be seen, ions originating from this region will not be guided to the cathode due to the electrostatic bend. Hence, direct IBB is expected to be prevented nearly completely due to the electrostatic bend of the beam.
The current design uses an electrode voltage of −60 kV. However, current simulations of different chamber geometries and voltages are conducted to study the influence on the beam quality. It is worhtwhile to point out that the electrostatic design including the bend and the rather 'slow' acceleration after exiting the cathode is expected to result in an increasde emittance, in particular at high bunch charges. The focus of this setup, however, is to maximize cathode lifetime so that a reduced beam qualitiy is acceptable.

VACUUM SIMULATIONS

The cryopumping effect only works up to a maximum of two monolayers of molecules sticking on the cold surface. Therefore a proper pre-vacuum ($<10^{-10}$ mbar) at room temperature in the cryo-volume is essential before starting the cryopump. Due to the limited conduction from the inner chamber to the outer this could be problematic. However, vacuum simulations (Molflow+) with the current chamber design and planned pump setup shows that a pre-vacuum in the order of 10^{-12} mbar can be achieved.

CONCLUSION AND OUTLOOK

A cryogenic electron source could enable high-current applications of spin-polarized electron beams. The required lifetime of the cathode can be achieved by a cryogenic subvolume and an electrostatic bend to reduce IBB. Compared to conventional sources a significant improvement in lifetime is expected. For optimal beam quality, alternative chamber geometries and different potentials will be tested in simulations. Implementation and first measurements are planned to be conducted at the Darmstadt Photo-CATCH test set-up [10] to investigate the parameters of the new source.

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