DEVELOPMENT OF A CRYOGENIC GaAs PHOTO-GUN FOR HIGH-CURRENT APPLICATIONS*

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Abstract

For high-current applications of GaAs photocathodes it is necessary to maximize the charge lifetime of the cathode material to ensure reliable operation. By means of cryogenic cooling of the electrode, the local vacuum conditions around the source can be improved due to cryogenic adsorption of reactive rest-gas molecules at the surrounding walls. Furthermore, the cooling also allows a higher laser power deposited in the material, resulting in higher currents that can be extracted from the cathode. Ion-backbombardment is expected to be reduced using electrostatic bending of the electrons behind the cathode. To measure the characteristics of such an electron source, a dedicated set-up is being developed at the Photo-CATCH test facility in Darmstadt.

INTRODUCTION

For the generation of high-intensity electron beams for ERL experiments [1], positron production [2], or future colliders in general [3], photo-guns can be used as high-current, low emittance electron sources. In the case of GaAs photocathodes, it is possible to generate spin-polarized beams as an additional feature. To ensure reliable operation of a high-current mode, the lifetime of the cathode material has to be maximized as well as efficient cooling is required to counter laser-induced heating, since the rate of quantum efficiency (QE) degeneration is proportional to temperature [4]. During operation, also ion-backbombardment (IBB) of the cathode has to be reduced to increase the charge lifetime. If the cathode is installed in a cryogenic environment, in addition to the provided cooling, the local vacuum conditions are increased due to cryopumping at the cold surfaces. An electrostatic bend of the electron beam additional decreases the 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.

SOURCE DESIGN

Figure 1 shows a preliminary layout of the cold source. The cooling is provided by a cryocooler attached to the top of the electrode chamber. To separate the cryocooler from the electrode potential, an insulator has to be placed between these two parts. A larger vacuum chamber houses the source and is connected to a combination of different pumps to achieve pressures in the range of 10^{-11} mbar at room temperature. To create an almost closed volume inside the electrode chamber for an effective local cryopumping, the opening for the laser is closed by a window. Thus, the only conduction to the warm outside volume is provided by the beam tube. This minimizes the probability that molecules from the outside volume reach the inner surfaces of the source and contaminate them. To ensure sufficient cathode cooling during operation, the GaAs cathode has to be in proper thermal contact with the electrode chamber, which can be achieved with a modified puck design. In order to suppress IBB, an electrostatic bend, which deflects the electrons in a 90° angle away from the incident laser axis, is added directly behind the cathode. This bending field prevents ions produced by the extracted beam from travelling back towards the cathode and destroying the NEA layer on their impact by diverting them to the chamber walls.

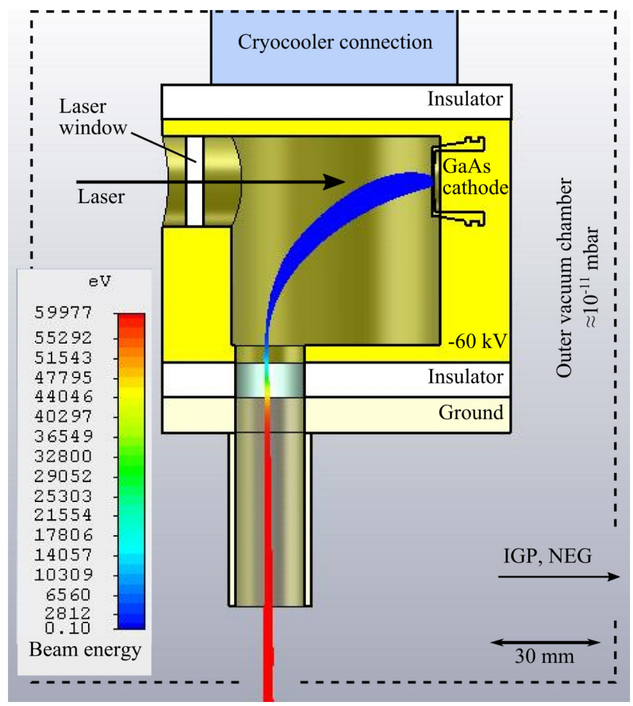

Figure 1: A first layout of the cryogenic source with simulated electron beam (CST studio suite®).

On the downside, the confined volume reduces the "pre"-pumping speed (pumping in the warm state) of the source. This challenge could be solved by an additional pumping opening of the source chamber, which is closed just before the cool-down. In the current design, a voltage of -60 kV is applied to the electrode. However, further simulations of different voltage designs and electrode geometries are planned to be carried out in order to study the influence on the quality of the extracted beam. The source chamber material needs low outgassing rates for

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optimum vacuum conditions as well as low emissivity to minimize radiation heat load in order to ensure stable operation at the cryogenic temperature. Therefore, the electrode chamber is planned to be manufactured from aluminum with a high polished surface on the outside to reduce radiation heat load. The insulator material has to provide a high thermal conductivity while keeping the cold-head free from potential. Al_2O_3 is an excellent heat conductor at cryogenic temperatures and has a high dielectric strength, why it is a suited insulator material for the cold-source application.

INCREASING CATHODE LIFETIME

The lifetime of a GaAs photocathode is determined by the lifetime of the negative electron affinity (NEA) CsO layer applied to the GaAs semiconductor surface to achieve high QEs. It can be represented as [5]

$$\frac{1}{\tau}=\sum_i \tau_i^{-1}=\frac{1}{\tau_{vac}}+\frac{1}{\tau_{FE}}+\frac{1}{\tau_{loss}}+\frac{1}{\tau_{IBB}},$$

where 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. Vacuum lifetime and ion back bombardment are directly related to the vacuum conditions, whereas field emission and beam loss effects are determined by the geometry and voltage layout of the source. The vacuum lifetime is influenced by chemical reactions of the CsO layer with residual gas molecules, which corrode the NEA layer over time. Molecules containing oxygen have the strongest impact on the vacuum lifetime [6]. However, for cryogenic temperatures of around 10 K which could be achieved with the planned setup, those gases have already a negligible saturation pressure. Thus a cryocooling of the source would contribute directly to an increased vacuum lifetime. Preliminary estimates of the vacuum conditions inside the cryovolume show that pressures of a factor 10^{-3} lower compared to the outer chamber can be achieved. However, at the expected cryogenic temperatures, the outgassing of H_2 cannot be prevented. It is known that this has no effect on the vacuum lifetime, since H_2 does not corrode the cathode [6], but the presence of H_2 is contributing to the IBB so that the electrostatic bend is introduced. Significant electron impact ionization of H_2 occurs at electron energies from 15.6 eV to around 1 keV [7]. As it can be seen from the simulations (Fig. 2), ions originating from the region where the electron beam reaches sufficient ionization energies are already missing the cathode due to the electrostatic bend. Therefore, direct IBB of the GaAs cathode is expected to be prevented almost completely with the new source design.

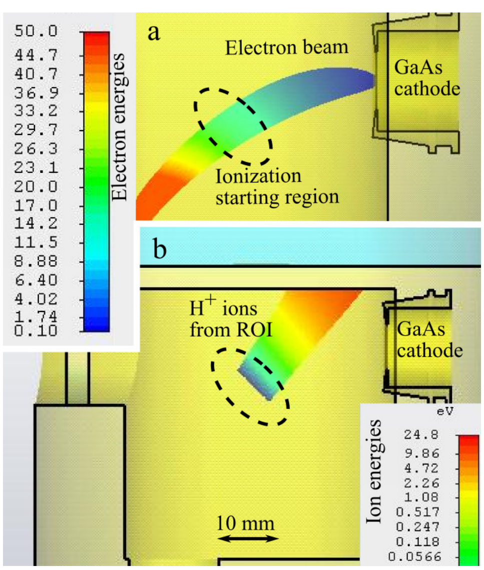

Figure 2: The region within the electrode chamber where the electron beam reaches sufficient energies to ionize molecular hydrogen (a). Ions originating from this ROI travel back on the bent field lines and miss the GaAs cathode (b), presuming they have no initial kinetic energy. Simulated with CST studio suite®.

CONCLUSION

By placing the GaAs photocathode in a cryogenic, confined subvolume and using an electrostatic bend for IBB reduction, the overall cathode lifetime is expected to be increased significantly compared to conventional sources, which would enable high-current applications of spin-polarized electron beams. After the implementation of the design, first measurements are planned to be conducted at the Darmstadt photo-CATCH test set-up [8] to investigate the lifetime as well as the quantum efficiency at cryogenic temperatures.

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