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TEST ELECTRON SOURCE FOR INCREASED BRIGHTNESS EMISSION BY NEAR BAND GAP PHOTOEMISSION*

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Abstract

A new photoemissive electron source is being built in order to make use of the reduction of ensemble temperature in near band gap photoemission. It will operate at up to 200 kV bias voltage with NEA GaAs photocathodes. High bunch charges will be investigated in pulsed mode with respect to the conservation of emittances at low energy excitations. High field gradients at the cathode surface will also allow further investigation of the field emission process of these photocathodes.

INTRODUCTION

The temperature of electron ensembles emitted from NEA photocathodes, e. g. GaAs(Cs:O), is reduced if the exciting photon energy approaches the band gap of the semiconductor [1]. This promises to increase the beam brightness $\propto 1/T$. We want to explore if it is possible to exploit this phenomenon for the production of high bunch charges, which may be relevant for applications such as ERL-based light sources. In order to achieve such bunches, a high gradient, high voltage source is needed to cope with the effects of space charge in a vacuum and also internal effects, for instance photovoltage [2]. A particular challenge is that the work function of the material is extremely low (≈ 1.4 eV) - at least if GaAs is chosen as a cathode. A variable field strength in the new source will allow to investigate field emission thresholds for these low work function cathodes.

In respect of that, a new photoemission electron source is under development at the institute for nuclear physics Mainz. The bias voltage will be up to 200 kV and the accelerating field strength will reach up to 5 MV/m. A more detailed view on the design and some simulations are discussed in the following.

SOURCE DESIGN

The design of the Small Thermalized Electron source At Mainz (STEAM) is based on the photoemission electron sources used at MAMI [3] and CEBAF at Jefferson Laboratory [4]. It is illustrated in Fig. 1.

As photoemissive material a p-doped gallium arsenide (GaAs) crystal held by a molybdenum carrier called the "puck" will be used. It is coated with a thin caesium and oxygen layer which forms the negative electron affinity (NEA). The work function is reduced to ≈ 1.4 eV allowing to achieve high quantum efficiencies at low excitation energies. On the other hand, the low work function may provoke field emission if the electric field gets too high.

Inverted Insulator

In order to get a compact source, the cathode electrode holding the photoemissive material is mounted on an R30 "inverted" insulator that points directly into the source chamber. It has three advantages compared to the old insulator tubes: Its size is smaller and allows a compact design, it offers less metallic surfaces that may lead to parasitic field emission and it is cheaper because it is used commercially in the X-ray industry.

Cathode Electrode Design

The cathode electrode is made of low-permeable stainless steel 1.4429 ESU. It is mounted vertically on the insulator and holds the photocathode with the NEA GaAs, which is kept in position due to gravitation.

After exceeding its lifetime, the photocathode needs to be refreshed and for the new preparation it needs to be extracted. Therefore, the source will operate in a load-lock operation: A second chamber for the photocathode preparation will be connected to the source chamber, not affecting its ultra-high vacuum.

Elevator Construction

To provide the mechanical movements needed for cathode exchange, an elevator construction is implemented into the cathode electrode design, see Fig. 2. A rack and pinion gear that is driven by a manipulator levitates the puck inside the cathode electrode so that it can be grabbed by a "fork" mounted on a second manipulator and transferred into the preparation chamber. Using copper in combination with titanium prevents galling and reduces attrition to a minimum [5]. This elevator construction will be tested under ultra-high vacuum conditions after a bake-out procedure at 250 °C at the end of 2015. The manipulator driving the elevator is retracted from the high voltage region during operation.

Anode Design

The shape of the anode is convex in order to keep the outer field strength at the cathode electrode side low while achieving a field strength at the photocathode surface of up to 5 MV/m at a distance of 37 mm between photocathode and anode (200 kV bias). These values were simulated and optimized using CST EM Studio [6] with respect to the goal of keeping the global absolute field strength below 8 MV/m, see Fig. 3. The anode is mounted on a potential-free tube and thereby allows to measure the lost beam and field emission currents emitted from the cathode electrode

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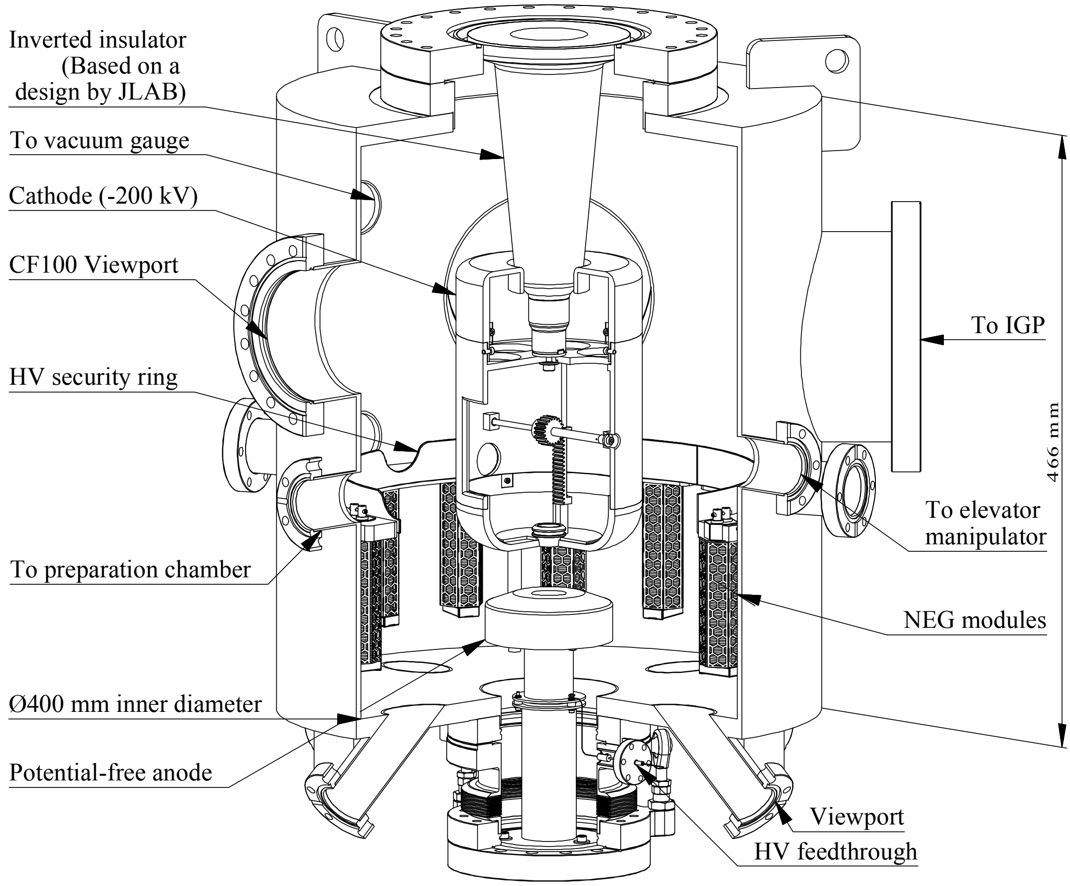

Figure 1: CAD-model of the Small Thermalized Electron source At Mainz (STEAM).

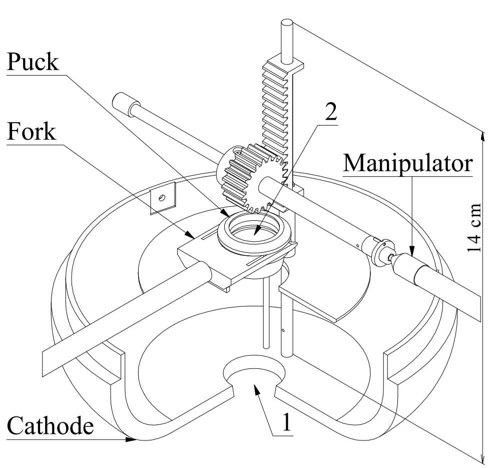

Figure 2: Sketch of the elevator construction built in the cathode electrode design. (1) final position; (2) extraction position.

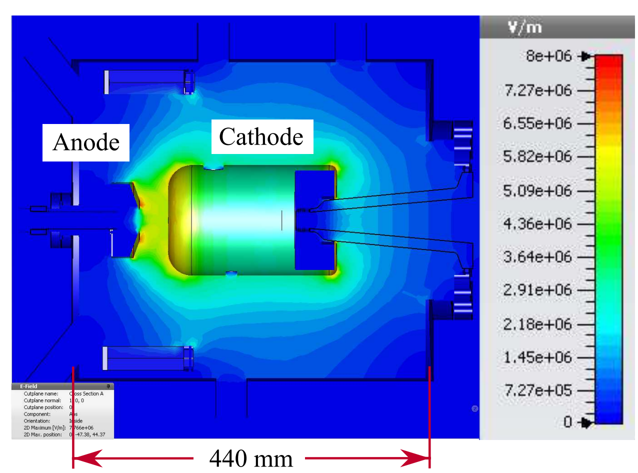

Figure 3: Simulation of the source using CST EM Studio. The absolute global field strength – shown in this figure – stays below 8 MV/m while the accelerating field strength at the photocathode surface reaches up to 5 MV/m. That allows field emission studies for NEA GaAs photocathodes while keeping parasitic field emission low.

(stainless steel) and photocathode (NEA GaAs). A second tube holding the isolated one is screwed onto a bellows so that the whole anode can be aligned properly with respect to the photocathode.

Vacuum Generation

The lifetime of NEA GaAs is strongly dependant on a very good vacuum [7]. To achieve that, fourteen NEG modules

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with a total hydrogen pumping speed of 5600 L/s are equally distributed around the cathode-anode gap. In addition, a 150 L/s ion getter pump with a noble diode is attached to pump the remaining noble gases and methane. The main part of the chamber and its components will be mounted in a clean room and baked out.

PHASE SPACE SIMULATIONS

The six-dimensional phase space of STEAM was simulated using CST Particle Studio [6]. Especially the particle-in-cell (PIC) solver allows to generate Maxwell-distributed bunches of charge q for a given temperature T and circular emission area with the radius σ_0 (corresponds to the total laser spot size) within a longitudinal time length of Δt that includes 100 % of the bunch charge. The transverse and longitudinal emittances of the MAMI source and STEAM are shown in Fig. 4 for a bunch charge of $q = 1$ pC. Such a bunch charge is already relevant for accelerator projects, e. g. stage-1 operation of the Mainz Energy-recovering Superconducting Accelerator (MESA) which is presently being build in our institute [8]. The other parameters were chosen as $k_B T = 200$ meV, $\sigma_0 = 500$ µm and $\Delta t = 200$ ps.

While the calculated transverse normalized rms-emittance of 0.14 µm stays the same for both sources, the energy spread at 100 kV bias voltage can be improved from 150 eV to 84 eV due to the higher field strength (STEAM@100 kV: 2.5 MV/m, MAMI@100 kV: 0.89 MV/m). At a higher bias voltage of 200 kV and a higher field strength of 5 MV/m, the energy spread can be improved again and will provide a basis for higher bunch charges, as they are needed for stage-2 operation of MESA.

OUTLOOK

After the production process, a first test setup including mounting and bake-out procedures will be built at the end of 2015. Afterwards, a diagnostic beamline will be connected to the source. An available Ti:Sapphire laser may be used to vary the exciting photon energy while applying pulse parameters similar to those discussed above. Furthermore, we will investigate if a slightly increased transverse emittance ($\leq$ 1 µm) may allow for further increased bunch charges.

SUMMARY

The design of STEAM is finished, orders are made, mechanical productions are ongoing, and first tests will start at the end of 2015. The simulations show an improvement of the longitudinal energy spread due to the higher bias voltage and field strength while keeping the transverse rms-emittance considerably lower than 1 µm.

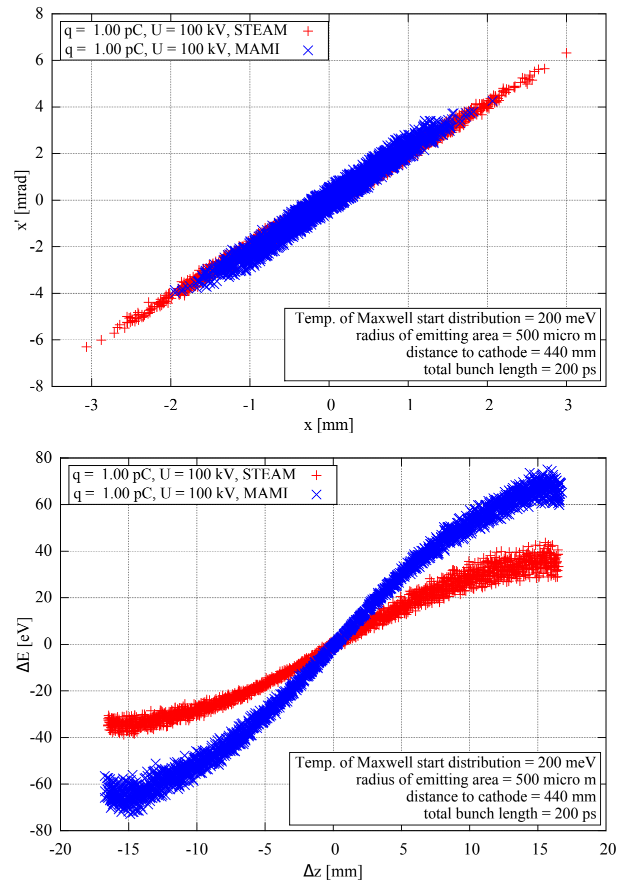

Figure 4: The transverse (above) and longitudinal (below) phase space for STEAM (red) compared to the MAMI source (blue). The transverse normalized rms-emittance is 0.14 µm for both sources while the energy difference decreases from 150 eV (MAMI) to 84 eV (STEAM) due to the higher field strength.

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