ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP005

THE SMALL THERMALIZED ELECTRON SOURCE AT MAINZ (STEAM)

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Abstract

The Small Thermalized Electron Source at Mainz (STEAM) is a photoelectron source which will be operated using NEA GaAs excited near its band gap with an infrared laser wavelength to reach smallest emittances. CST simulations indicate that emittance growth due to vacuum space charge effects can be controlled up to bunch charges of several tens of pC. The goal of the project is to demonstrate that the intrinsic high brightness can still be achieved at such charges. The current status will be presented.

INTRODUCTION

The brightness of a particle source can be calculated by the fraction of the emitted electron current I, the transverse emittances ε_x and ε_y and the relative energy spread $\frac{\Delta E}{E}$, see Eq. 1. It is a figure of merit for an ERL accelerator source.

$$B \propto \frac{I}{\varepsilon_\mathrm{x}\,\varepsilon_\mathrm{y}\,\Delta E/E} \propto \frac{QE(\lambda)\,P_\mathrm{L}}{\varepsilon_\mathrm{x}\,\varepsilon_\mathrm{y}\,\Delta E/E} \tag{1}$$

The current of a photoemission electron source is mainly given by the power of the laser and the quantum efficiency $QE = N_\mathrm{electrons}/N_\mathrm{photons}$, which depends on the laser wavelength λ. The normalized thermal residual-mean-square (rms) emittance can be derived from the exciting laser spot size σ_0 and the thermal energy $k_\mathrm{B}T$, see Eq. 2 [1].

$$\varepsilon_\mathrm{n,rms} = \frac{\sigma_0}{2}\sqrt{\frac{k_\mathrm{B}T}{m_\mathrm{e}c^2}} \tag{2}$$

The thermal energy decreases with increasing laser wavelength [2], therefore the smallest emittance can be achieved at the maximum possible exciting wavelength near the band gap energy E_g of the used semiconductor material, e.g. for NEA GaAs ($E_\mathrm{g} = 1.4\,\mathrm{eV}$) $\lambda_\mathrm{L} \approx 800\,\mathrm{nm}$ is only 130 meV above the band gap, which should result in high QE but still low thermal energy and corresponds to the typical wavelength of powerful semiconductor lasers. Seen from this solid state physics point of view, it is important for high current accelerators how the emittance develops with increasing bunch charges. To investigate this aspect further, a high extracting field gradient is needed to suppress space charge effects, which is above all a low energy issue.

THE DESIGN OF STEAM

STEAM was designed and optimized to operate at 200 kV with an extracting field gradient of $5\,\mathrm{MV\,m^{-1}}$. Its vertical design was inspired by the existing photoemission electron source Polarisierte Kanone (PKA) at the Institute of Nuclear Physics in Mainz and it uses the “inverted” R30 insulator adopted by the Jefferson Laboratory [3], see Fig. 1. The simulation program Computer Simulation Technology (CST) [4] was used to find an applicable cathode and anode geometry so that the field gradient on any point of the electrode structure stays below $10\,\mathrm{MV\,m^{-1}}$, see Fig. 2. This is to reduce the risk of field emission.

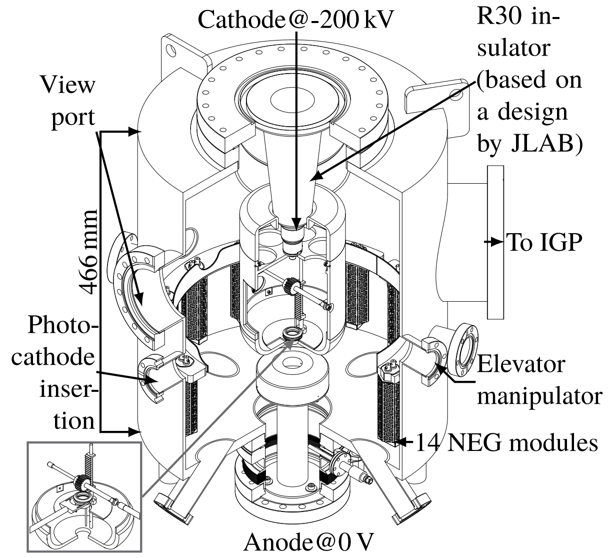

Figure 1: STEAM chamber, cathode and anode design. A working sketch of the elevator is shown in the lower left corner.

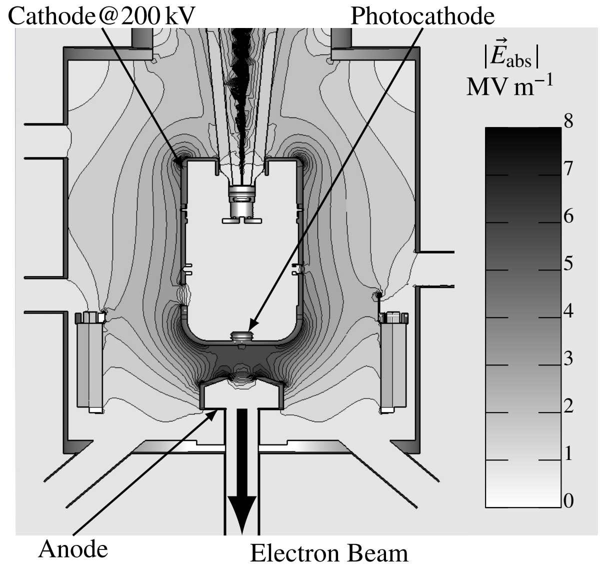

Figure 2: Electrostatic simulation using CST. The absolute field gradient in STEAM @ $U = 200\,\mathrm{kV}$ stays below $10\,\mathrm{MV\,m^{-1}}$, while an extracting field gradient of $|\vec{E}|_\mathrm{acc} \approx 5\,\mathrm{MV\,m^{-1}}$ is achieved. The HV cable is also simulated.

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PIC SIMULATION RESULTS

The source performance was simulated using the Particle-in-Cell (PIC) code of CST Particle Studio and compared to the geometry of the PKA. With respect to the same cathode potential of 100 kV, the main difference between the sources is the extracting field gradient, i. e. $|\vec{E}|_{\mathrm{acc}}^{\mathrm{STEAM}} \approx 2.5|\vec{E}|_{\mathrm{acc}}^{\mathrm{PKA}}$. The simulation parameters are listed in Tab. 1 and Fig. 3 shows a scheme of the longitudinal bunch profile used in the simulation. The normalized thermal rms emittance $\varepsilon_{\mathrm{x,n,rms}}$ and the energy spread were calculated using Eq. 3 and 4, and the results are shown in Fig. 4.

$$\varepsilon_{\mathrm{x,n,rms}} = \beta\gamma\sqrt{\langle x^2\rangle \cdot \langle x'^2\rangle - \langle x \cdot x'\rangle^2} \tag{3}$$

$$\frac{\Delta E}{E} = \frac{E_{\mathrm{max}} - E_{\mathrm{min}}}{eU + m_{\mathrm{e}}c^2} \tag{4}$$

Table 1: CST PIC simulation parameters

Source	STEAM	PKA
Number of particles	≈ 450 000	≈ 570 000
Thermal start energy kT	200 meV	
Radius of emitting area	0.5 mm	
Interaction point $\approx d_{\mathrm{cathode\text{-}anode}}$+ Drift	240 mm	400 mm
$\lvert\vec{E}_{\mathrm{acc}}\rvert$ @ 100 kV	2.5 MV m^{-1}	1 MV m^{-1}
Gaussian emission model	t_σ = 100 ps	

When increasing the bunch charge, the space charge affects the emittance growth and therefore the brilliance. The higher extracting field gradient of STEAM accelerates the electrons faster and allows to reach higher bunch charges at practical accelerator emittances below 1 µm.

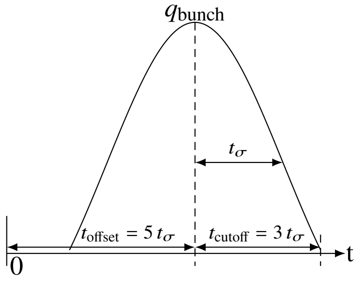

Figure 3: Longitudinal gaussian bunch profile used in CST. As indicated, t_{cutoff} limits the longitudinal dimension of the emitted bunch.

Figures 5 and 6 show examples for 1 fC and 7.7 pC of the transverse phase space and for the longitudinal bunch profile. The extracted bunches are more divergent at STEAM because the shape of the puck that holds the photocathode crystal has a flat geometry, which is due to the trade-off for the higher extracting field gradient. At the PKA the puck is concave-formed. To compensate for that a little, the anode at STEAM is formed slightly convex.

CURRENT PROGRESS

A platform was built in January 2016 and the fully assembled STEAM with its photocathode preparation chamber was put on top of it. After finishing the bake-out procedure the source has reached ultra high vacuum condition, i. e. its pressure is at 5×10^{-12} mbar. As soon as the 200 kV high voltage power supply (HVPS) is ready, the source will be processed with krypton gas based on a technique by JLAB [5].

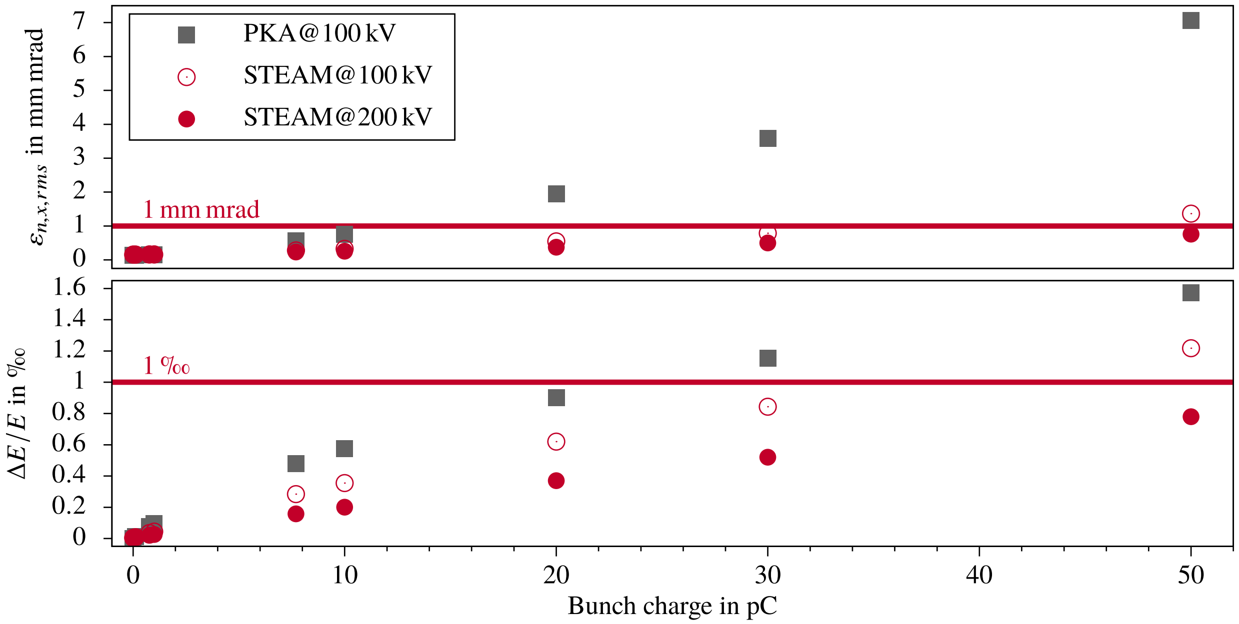

Figure 4: (Above) Normalized transverse rms emittance and (below) energy spread calculated from PIC simulations of PKA and STEAM for increasing bunch charges. Further simulation parameters are given in Tab. 1.

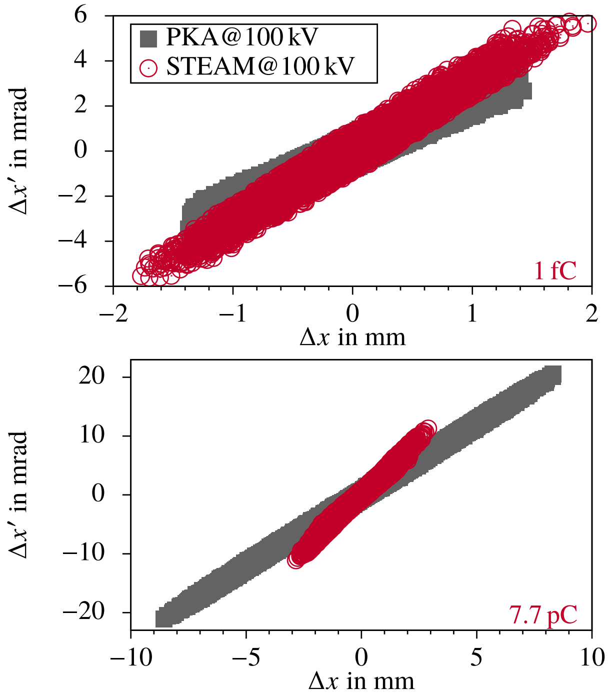

Figure 5: Examples of the transverse phase space for 1 fC (above) and 7.7 pC (below). Only every 50th particle is plotted. The higher divergency at STEAM can be explained by the flat puck geometry, which is concave-formed at PKA. The STEAM anode is formed convex.

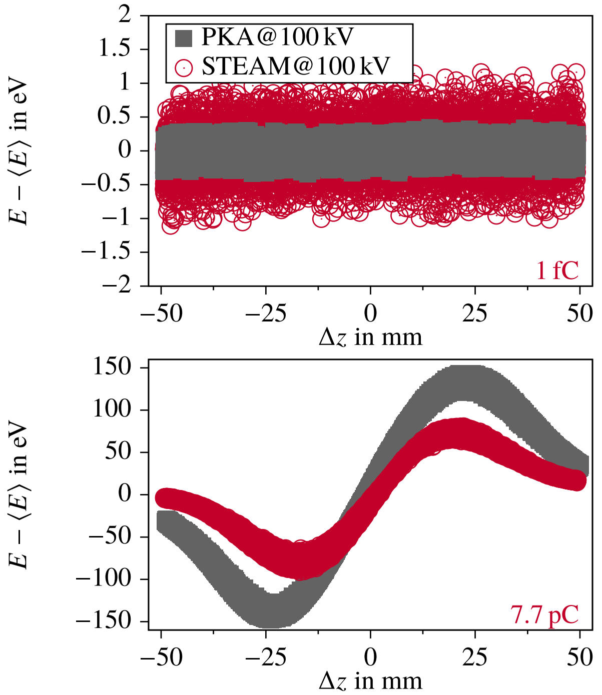

Figure 6: Examples of the longitudinal phase space for 1 fC (above) and 7.7 pC (below). Only every 50th particle is plotted. The effect of the non-linearities of space charge can be seen in the lower plot. STEAM's higher field gradient compensates for that more.

Testing the preparation chamber, the first NEA bulk GaAs photocathode was prepared and its lifetime was measured. The quantum efficiency reached 5 % at 635 nm but decreased rapidly down to 1.7 % within 16.5 h. This was due to a comparatively high gas pressure inside the preparation chamber ($\approx 1 \times 10^{-10}$ mbar).

The 200 kV HVPS was tested concerning its interlock mechanism and the remote controllability. Due to difficulties with the remote communication and problems with the sustainability of the HV near the maximum output level, the HVPS was sent back to the vendor for repair. The problems have been solved recently and operation is starting.

FUTURE PLANS

The STEAM will be investigated using the Mainz Energy-Recovering Superconducting Accelerator (MESA) Low-Energy Beam Apparatus (MELBA). This diagnostic and spin manipulating beam line offers i. a. the possibility to measure the transverse emittance using the quadrupole scan or the slit-and-grid method. The MELBA is fully assembled and is currently being baked out. Preparations for the laser system are going on. The control system will be based on the Experimental Physics and Industrial Control System (EPICS) and first experiences for MESA will be gathered in this context. After the HV krypton gas processing, the MELBA will be ready, so that the first electron beam coming from STEAM can be expected in summer 2017. Further information about the MELBA is presented in [6].

ACKNOWLEDGMENT

This work is sponsored by the Federal Ministry of Education and Research via the joint project HOPE. The work is associated with the RTG 2128 “Accelence” funded by the DFG.

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