CHARACTERIZATION OF THE ELECTRON BEAM FROM THE THz-DRIVEN GUN FOR AXSIS

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Abstract

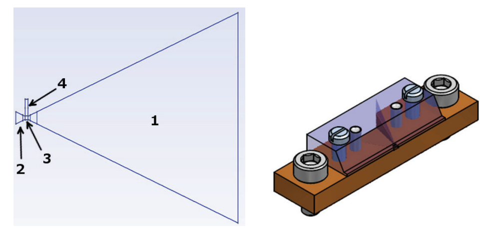
The AXSIS (Attosecond X-ray Science: Imaging and Spectroscopy) project aims for development of a compact, fully coherent, THz-driven, attosecond X-ray source. A compact THz-driven gun was developed, produced and tested as a source of the ultra-short electron bunches required for the project. To characterize the low-energy, low-charge beam produced by such a gun tailored diagnostic devices were developed and commissioned at a test-stand chamber in CFEL (DESY). Results of the first experiments on the production and characterization of the electron beam are presented.

INTRODUCTION

The AXSIS project aims to develop a compact THz-driven X-ray source [1]. In the frame of the project it is planned to use a THz-driven electron gun and a dielectric-loaded linac to achieve electron energies of about 15 MeV. For the first experiments a THz-driven gun capable of delivering 25 keV electron energies was developed and tested at DESY CFEL. In order to characterize the electron beam from this gun, diagnostics capable of detecting low energy, low charge electron beam are required. In this paper first results on the characterization of the electron beam are presented.

HORN GUN

For the first experiments on the electron beam acceleration using the THz pulse, the so called "Horn gun" was developed [2]. Gun geometry is shown in Fig.1a and comprises two horns, a waveguide and a slit. The THz power is coupled into the large horn and the small horn reflects part of it for more efficient acceleration. The electron acceleration takes place in the waveguide and the slit is required to couple UV light in and couple the electrons out. Electrons are generated by a 1 kHz UV laser using the copper waveguide plane as a cathode. The produced gun model is shown in Fig.1b. Originally this gun was designed for operation with the THz pulse parameters presented in Table 1. At the original design this gun had to deliver several tens of fC electron bunches with 25 keV kinetic energy [2]. Due to various reasons and production problems the experimental conditions did not match the design. Therefore a set of simulations which match the geometry of the produced gun and available THz parameters was carried out. The UV laser used for electron generation during experiment has a wavelength



(a) Schematics (b) 3D model

Figure 1: Schematics and 3D model of the Horn gun. Left figure numbers indicate: 1 - big horn for THz pulse coupling, 2 - small horn for THz reflection, 3 - accelerating waveguide, 4 - slit. Upper side on the right figure is made transparent for details.

of 258 nm, 200 fs rms pulse duration and Gaussian distributions in transverse and longitudinal directions. The UV laser energy during experiments was around 75 nJ, which corresponds to an electron bunch charge of about 31 fC, taking into account the assumed copper quantum efficiency of $2 \cdot 10^{-6}$. Simulations were done using LEIST code [3]. The result of this simulation is shown in Fig. 2.

Table 1: THz Pulse Parameters

Parameter	Design	Experiment
Frequency, GHz	450	300
Beam size (waist), mm	1	2
Rms beam length, ps	2.5	2.5
Energy, μJ	17	4
Transverse profile	Gaussian	Gaussian
Longitudinal profile	Gaussian	Gaussian

As expected, the electron beam energy is significantly lower than in the design case.

DIAGNOSTIC DEVICES AND EXPERIMENT

Diagnostics were developed to characterize the charge, spatial distribution and energy of the electron beam produced by the Horn gun. In order to have high charge sensitivity, a Channeltron (continuous channel electron multiplier from PHOTONIS [4]) was implemented with the capability of detecting few or single electron bunches. This Channeltron has a multiplication of $1.3 \cdot 10^7$ at the working point of 2 kV

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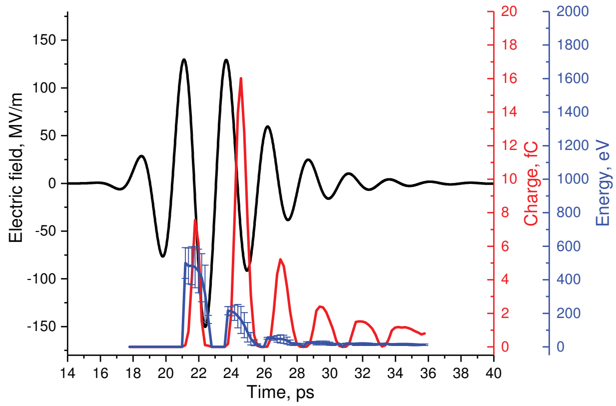

Figure 2: Beam dynamics simulations for the experimental parameters from Table 1. Each point of the red and blue curves corresponds to different times of injection of the UV pulse with respect to the THz pulse and represents beam parameters at the exit of the gun. The black curve represents the electric field amplitude at the cathode.

DC voltage applied to its anode. As the positive DC voltage is applied to the anode which serves as an electron collector, the readout scheme to separate it from the electron signal was developed and realized. The Channeltron and readout circuit are shown in Fig. 3.

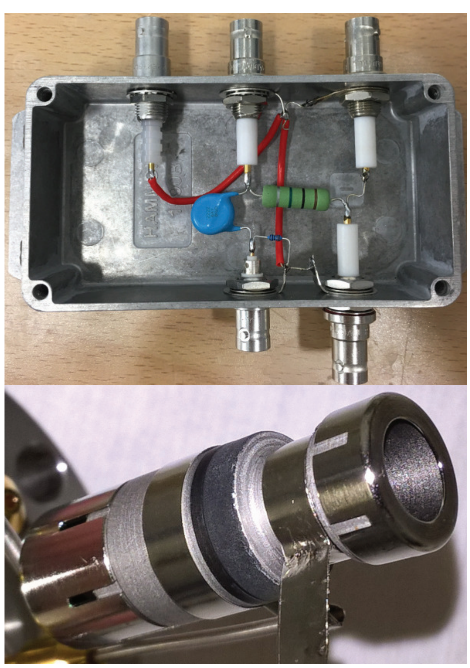

Figure 3: Channeltron (bottom) and electric circuit box (top).

In addition, the electrostatic parallel plates were designed to allow horizontal control of the beam direction using the CST code [5] and manufactured at the DESY workshop. By design these plates allow a deflection of a 25 keV electron beam by 10°.

The time delay scan between the THz and UV pulses was done using the Channeltron and results are presented in Fig 4. As one can see the general peak structure predicted by simulations (see Fig. 2) is well reproduced in the experiment.

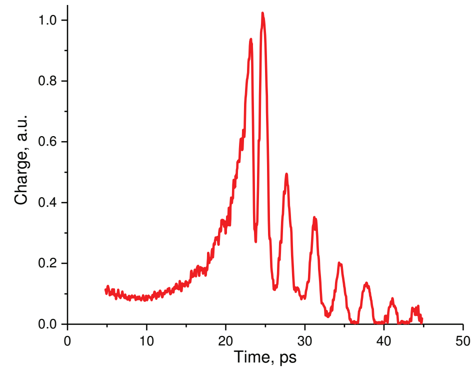

Figure 4: Charge time delay scan using the Channeltron.

For the transverse bunch profile measurement the MCP from PHOTONIS was used. This MCP has a moderate gain of $2 \cdot 10^4$ at 1 kV and a pore size of 5 μm. A P43 phosphor screen attached to the MCP allows further signal amplification and imaging is done with the help of the CMOS camera and telescope lens. First images recorded with the MCP installed at about 13 cm from the gun (as close as possible taking into account the chamber geometry) showed that the electron beam is larger than the sensor size of about 20 mm. An example of the transverse electron beam distribution obtained with the MCP is shown in Fig. 5. In order to focus

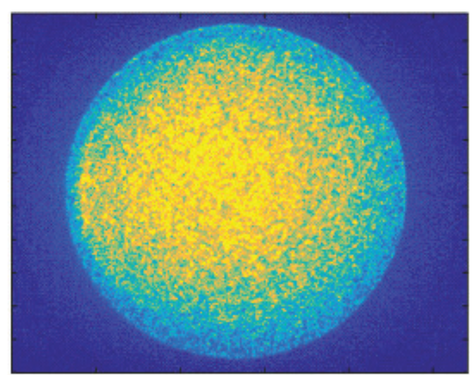

Figure 5: First example of the electron beam transverse distribution recorded using the MCP.

the electron beam onto the MCP, an air coil (solenoid) was implemented. In addition to the air coil the PCB steerer [6] was installed that allowed to measure the electron beam energy. The final setup is shown in Fig. 6 and comprises the THz-driven gun, air coil, PCB steerer and MCP, including the phosphor screen and optical readout system.

In such a setup the horizontal plane was used as the dispersion plane for the PCB steerer. Preliminary analysis of the first experiments revealed higher energy electrons than predicted by simulations from Fig. 2. The resulted images recorded with the MCP and processed with several filters are shown in Fig. 7 for dipole currents of 0 and 0.5 A. One can

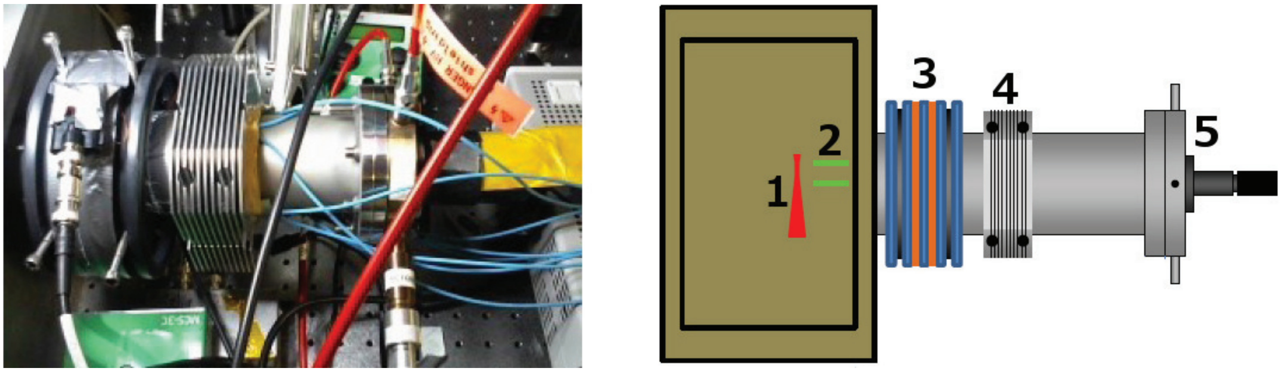

Figure 6: Experimental setup including the Horn gun (1), parallel plates (2) air coil (3), PCB steerer (4) and MCP (5).

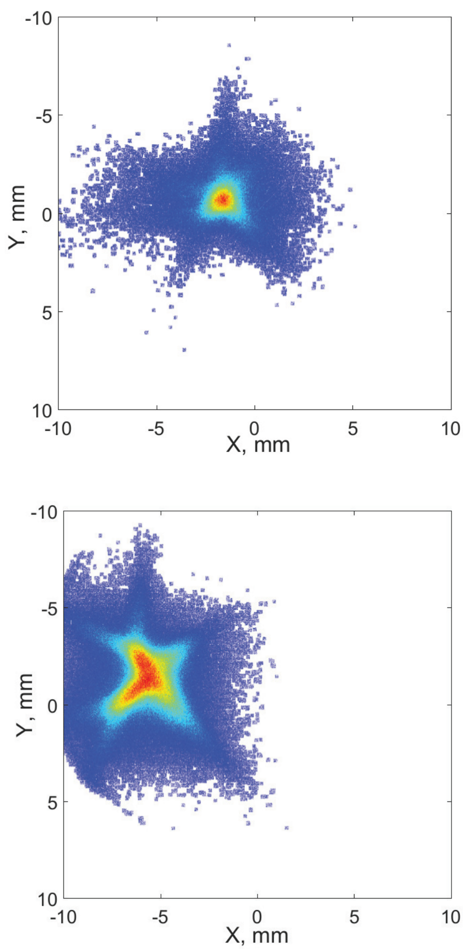

Figure 7: Transverse beam distribution recorded by the MCP for dipole currents of 0 (top) and 0.5 A (bottom). Color represents charge density in a.u.

see clear displacement of the beam on the screen by a couple of millimeters while applying a dipole. Based on the calibration for the PCB steerer, determined previously [6], the electron beam energy of few keV was preliminary estimated.

SUMMARY

A first THz gun potentially capable of delivering electron beams of tens of fC and tens of keV was successfully put into operation. First experiments allow measurement of the energy, which is lower than could be potentially achieved with this gun, as the experimental conditions were worse than the design case. In such a way an improvement of the experimental parameters is required to match the design case. Nevertheless, preliminary analysis of first results showed an electron energy of a few keV. More experiments will be done in the nearest future and detailed analysis of the electron energy will be done.

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