LOW ENERGY PHOTOEMISSION ELECTRON SOURCE FOR APPLICATIONS IN THZ RADIATION PRODUCTION AND TIME-RESOLVED ELECTRON MICROSCOPY*

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Abstract

A simple, inexpensive, and compact low-energy (~20 KeV) photoemission electron source was designed, built and recently commissioned. It uses a commercial ultraviolet photocathode drive laser producing 3 ns (FWHM) pulse. The source will eventually be used to drive a table-top THz radiation source, based on the Smith-Purcell free-electron laser scheme, and could also have potential application to time-resolved electron microcopy. We present experimental measurements of the photoemitted electron beam and numerical simulations of the anticipated parameters. We also discuss the generation of flat beams required to efficiently drive the THz radiation source.

INTRODUCTION

Generation of pulsed electron beams is essential for a variety of applications. In the electron sources based on thermionic and field emission effects it can be obtained by pulsing the extracting voltage, therefore, the temporal beam properties in this case are defined by the performance of the pulsed high voltage power supply. In the case of photoemission-based sources, the electron bunch mirrors the driving laser pulse that dictates the longitudinal and transverse properties of the bunch [1]. Low-energy pulsed electron beam can be generated using a simple, compact structure with dc accelerating field between anode and photocathode. This beam is characterized by very low transverse emittance because the initial transverse energy of the photoelectron is the same as its work function, i.e. a few eV. An additional advantage of photoemission-based sources is a possibility of producing spin-polarized electron beams that can be done, for instance, by impinging a circularly-polarized laser on a strained GaAs photocathode [2]. The time-resolved microscopy and spin-polarized electron microscopy are examples of promising applications for a low-energy photoemission electron gun. Besides, such a source can ideally serve as a driver for compact Smith-Purcell Free-Electron Laser in order to produce THz radiation [3]. In this approach a flat electron beam is propagated over metallic grating thereby producing radiation by periodical motion of the induced surface charge.

Recently we have constructed and commissioned the electron gun to study the physics and operation of a source based on the aforementioned conceptual framework [4]. The source generated >20 keV electron bunches with 1.3±0.1 ns RMS duration and 4±0.2 nC charge that corresponds to a peak current of about 1 A. The experimental results of the source commissioning along with detailed numerical model for the flat beam generation are subjects of this report.

SOURCE DESIGN AND PERFORMANCE

The source structure consists of grounded anode with the beam aperture in the center and biased cathode shaped as a truncated cone for initial focusing of photoelectrons emitted from the central planar area of the electrode. Pure copper was chosen as a cathode material due to simplicity, low cost and modest vacuum requirements. The work function of copper is relatively high (4.65 eV) and requires an ultraviolet (uv) laser as a driver. We used a commercial frequency-quadrupled Nd:YAG laser from Continuum Inc. [5]. The laser operates at 266 nm wavelength (corresponding to a photon energy of 4.66 eV) and is specified to produce 1.3~2.1 ns RMS pulses with energy up to 4 mJ per pulse at repetition rate of 1 to 15 Hz. The quantum efficiency (ratio of number of emitted electrons over the number of photons in the incoming laser pulse) is typically low for pure metals and was reported to be in the range $10^{-6} \div 10^{-4}$ for copper. For the given laser beam energy, the expected total bunch charge of a photoemitted bunch is a few nC. The laser beam is transported using an optical system composed of uv lenses and mirrors to irradiate the cathode through a sapphire window at 45 deg incidence angle. Measurements of the laser pulse energy and duration are performed using a powermeter and a fast photodiode respectively. The transverse distribution of the laser intensity on the cathode is directly monitored using a combination of CCD camera and “virtual cathode” that is one-to-one optical image of the real cathode on a uv-sensitive screen located outside of the vacuum enclosure. The dc bias voltage applied to the cathode can reach 20 kV that corresponds to 0.5 MV/m for axial surface field in the center of cathode and 1.1 MV/m maximum field achieved approximately in the middle of anode-cathode gap. A fast Faraday Cup for bunch charge and length measurements was fabricated and installed on the source axis about 1 cm downstream the anode aperture. All components of the source are mounted inside the vacuum chamber equipped with various ports to connect the vacuum pumps, sapphire window, electrical feedthrough, etc. An overview of the experiment setup appears in the Fig. 1.

Extensive beam measurements have been carried out for a wide range of accelerating voltage, laser pulse energy, and size of the laser spot on the cathode. An

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example of measured bunch intensity distribution is shown on Fig. 2.

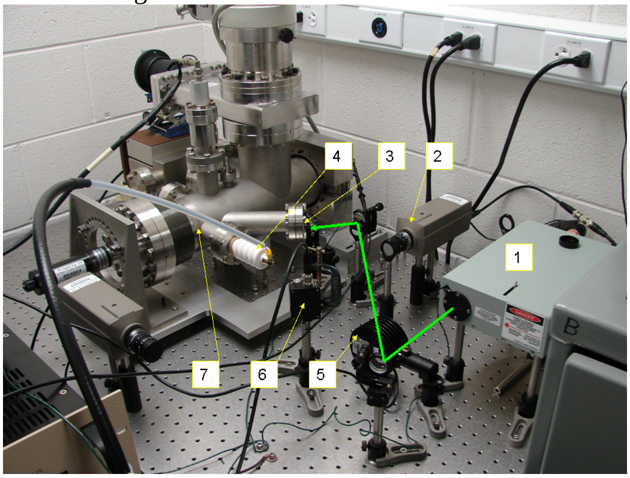

Figure 1. The experimental setup includes laser MINILITEII (1), CCD camera (2), UV viewport (3), high voltage feedthrough (4), powermeter (5), fast photodiode (6), vacuum chamber with pumps (7). The laser beam path is shown as a green line.

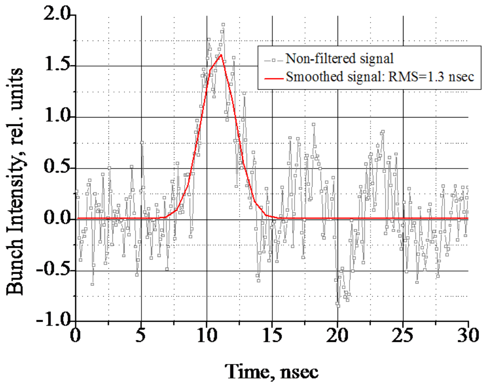

Figure2. Measured eletron bunch temporal distribution.

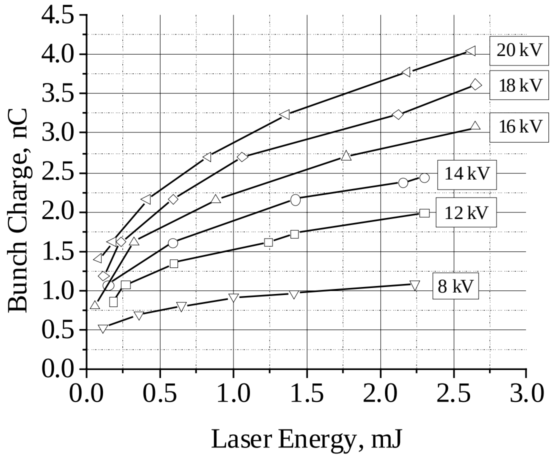

Figure 3. Extracted bunch charge as a function of laser beam energy for different values of extracting voltage.

The longitudinal space charge effects in the bunch have been found to be insignificant. Figure 3 shows an example of measured bunch charge as a function of laser pulse energy and accelerating voltage. Extrapolation of the quantum efficiency value to the zero laser energy limit inferred from these graphs gives $5\cdot10^{-5}$ for 20 kV accelerating voltage, which is consistent with previously reported results. The total extracted bunch charge of 4±0.2 nC corresponds to ~ 1 A peak current for the given bunch duration.

GENERATION OF FLAT BEAM FOR SP-FEL APPLICATION

A promising application of the described source is the generation of copious amount of THz radiation via Smith-Purcell free-electron laser (SP-FEL) scheme. In a SP-FEL an electron beam propagate above a metallic grating and under certain condition can interact with a backward evanescent wave propagating in the grating [6]. A flat beam could enhance the interaction between the electrons and metal grating surface, thus reducing the gain length associated with the SP-FEL mechanism [7]. We plan to generate a flat beam starting from a magnetized beam as initially proposed in Reference [8]. The photocathode will be immersed in an axial magnetic field provided by a solenoid and a set of three quadrupole located downstream of the electron source will remove the angular momentum thereby generating a flat beam, i.e. a beam with high transverse emittance ratio

Numerical modeling of the proposed round-to-flat beam transformation has been performed using the ASTRA particle tracking code [9]. The transformation channel will be located approximately 70 cm downstream of the cathode and consists of three printed-circuit quadrupoles provided by University of Maryland [10]. An electrostatic lens (Einzel lens) will be installed 17 cm downstream of the cathode to adjust the transverse parameters of the photoemitted beam at the entrance of the first quadrupole. Start-to-end simulation of the beamline were performed with ASTRA following the procedure outlined in [11]. An example of simulated flat beam is shown on the Fig. 4; the achieved final transverse emittances ratio $\varepsilon_y/\varepsilon_x$=141.

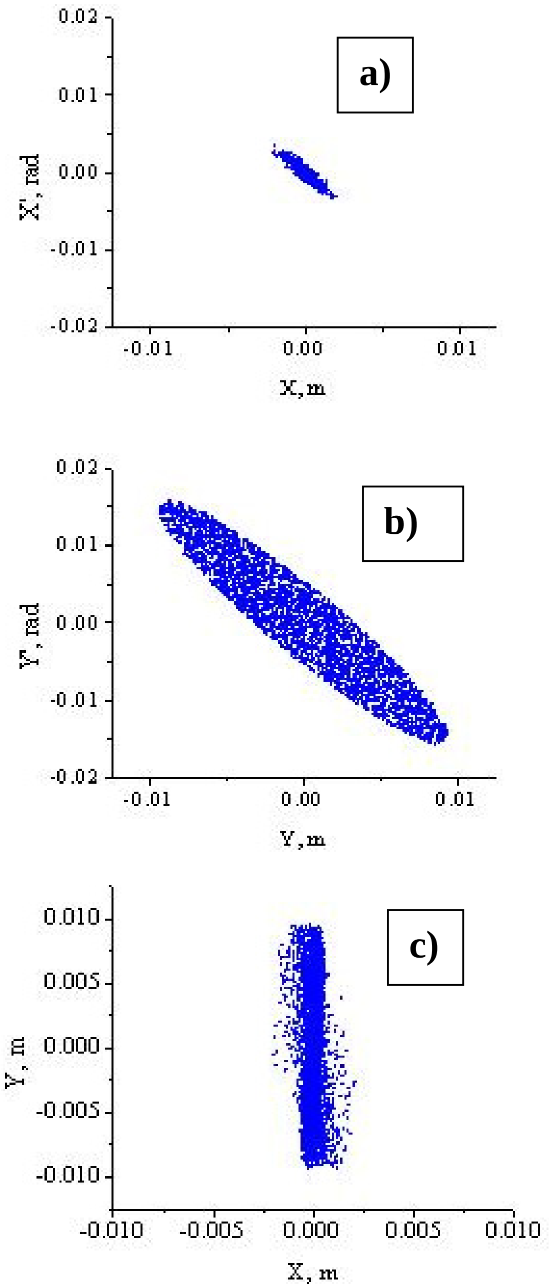

Figure 4. Simulated horizontal (a) and vertical (b) phase space distributions and the beam front view (c) at the exit of transformation channel.

Table 1. Flat Beam Parameters at the Entrance (IN) and at the Exit (OUT) of the Transformation Channel

	IN	OUT
RMS X, mm	2	0.4
RMS Y, mm	2	4.7
RMS ε_x, mm mrad	6.4	0.09
RMS ε_y, mm mrad	6.4	12.7

SUMMARY

A new photoemission-based low-energy pulsed electron source has been commissioned. The source is capable of producing up to 4 nC bunches with RMS duration of 1.3 nsec that correspond to a peak cuurent of 1 A. We have also studied the application of the proposed source for production of Terahertz light via Smith-Purcell Free Electron Laser (SP-FEL) scheme. The numerical model has been developed to establish the parameters of transformation channel incorporating three quadrupoles in order to produce a flat beam required for SP-FEL. Experimental production of flat beams is foreseen in the nearest future.

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