POLARIZED PULSED BEAM SOURCE FOR ELECTRONIC MICROSCOPY

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Abstract

A novel pulsed spin-polarized electron source is discussed. Unlike conventional devices based either on a thermionic cathodes or field-emission needle cathodes, the present source is based on photoemission. A gallium arsenide (GaAs) planar cathode impinged with a suitable circularly polarized laser can produce a polarized pulsed electron bunch with duration of the order of the laser pulse. Numerical simulations of the electron dynamics in the optimized cathode-anode geometry have shown that the beam with initial transverse size of a few mm can be focused down to 1 μm root-mean-square (RMS). The suggested source can, in principle, be installed on existing electron microscope thereby opening the path to time-resolved microscopy. Spin-polarization offers an effective probe for some magnetic phenomena. The design of the source and subsequent fabrication has been completed. In the present paper we discuss numerical studies of the source performance, its conceptual design, and report on the experimental status.

INTRODUCTION

Existing electron beam sources are generally based on one of the three processes: thermionic, field-emission or photoemission. Although the latter process requires a laser of appropriate wavelength for the photocathode drive, photoemission has a number of advantages: controlling the laser intensity, size and pulse duration directly affects the photoemitted bunch charge, size and duration. In addition photoemission offers higher current density compared to the other emission processes. The remarkable feature of photoemission is the possibility to produce spin-polarized electrons. Conventionally, the spin-polarized beams are generated by photoemission from semiconductor-based Gallium Arsenide (GaAs) negative electron affinity (NEA) photocathodes [1]. The main disadvantage of GaAs NEA photocathode is the demanding vacuum level (10^{-12} Torr). Although the electron source presented here can in principle accommodate a GaAs photocathode, we opted to commission and perform the first experimental test of the source using a copper cathode. Metallic photocathodes [3] typically have a long lifetime and can operate in relatively poor vacuum of about 10^{-7} Torr. The disadvantages of metallic cathode are the impossibility to produce spin-polarized beams and low quantum efficiency (QE) of typically about 10^{-5} e-/photon. A significant effort has been applied for decades towards investigation of photoemission phenomena in metals [3]. It was shown that the QE of properly cleaned copper cathode irradiated by 266 μm laser can reach ~ 10^{-4} e-/photon. Also, it was demonstrated that the QE increases with the surface field via Shottky effect [3]. This later feature has been used in rf guns, where the surface fields are considerably high. For example, in [4] QE of 1×10^{-4} was achieved at 500 kV/cm electric field on the cathode.

In electron microscopy the beam kinetic energy is usually in the range of 10−30 keV, corresponding to surface field of 5−15 kV/cm. Nevertheless, considering the capabilities of modern commercial UV lasers, the electron beam with a few pC bunch charge can be produced from the copper cathode with modest QE of ~ 10^{-7}. This value of bunch charge is typical for electron microscopy needs and probably can be significantly increased by a proper treatment of the copper cathode surface. Also, the actual value of the QE in the considered case is expected to be much higher. Presently, a photoemission-type dc accelerating voltage source of spin-polarized electrons [5] is being developed at Northern Illinois University (NIU) in collaboration with Argonne National Laboratory (ANL) for applications in electron microscopy. This report presents the beam dynamics studies along with conceptual and engineering design of the source.

BEAM DYNAMICS SIMULATIONS

Initially, two different configurations were considered as possible candidates for the source design. One consisted of a planar cathode in combination with a series of focusing ring lenses; and another employed specially shaped focusing cathode followed by a simple anode. Since both configurations manifested the same performance at preliminary calculations by GPT [6], the second one has been chosen for the sake of simplicity. The electrodes arrangement for this setup appears in Fig. 1. The anode is a grounded disk of 5 mm thickness with a hole in the center. The aperture radius is 4.5 mm and the whole accelerating gap is approximately 20 mm long. The cathode shape and cathode-anode separation were optimized to achieve a tight beam waist suitable to serve as a virtual source for an electron microscope. The field value at the surface of cathode is 5 kV/cm and reaches about 11.5 kV/cm approximately in the middle of cathode-anode gap as shown at Fig. 2.

More accurate numerical simulations of the beam dynamics in the considered source have been performed using ASTRA [7]. According to these calculations the emitted electron beam of 0.3 mm RMS size at the cathode

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has a focus or waist located at 39 mm from the cathode surface as shown at the Fig. 3, where z=0 corresponds to the photocathode and z=0.0217 to the center of anode. The waist RMS transverse size is 840 nm as shown at Fig. 4. This point can be used as a "virtual cathode" in an existing electron microscope without significant modifications of the column and detection assembly. The main results of the performed simulations are presented in the Table 1.

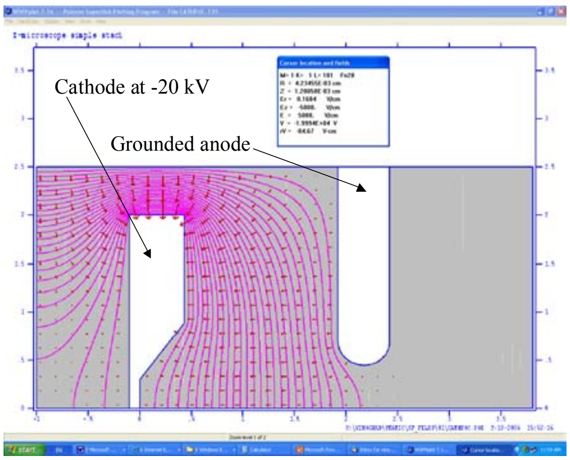

Figure 1. The source electrodes arrangement in POISSON model. The purple line represent the equipotential lines.

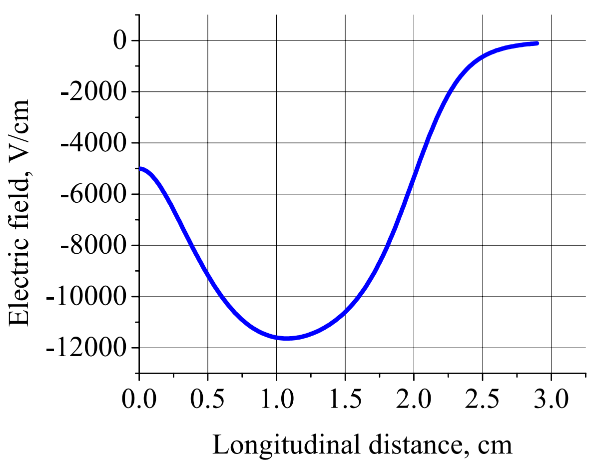

Figure 2. Electric field distribution along the axis.

Table 1. Simulations by ASTRA.

Parameter	Value
Laser wavelength, nm	266
Laser beam power, mJ	3
RMS pulse duration, ns	2
RMS beam spot at the cathode, mm	0.3
Intensity distribution in laser beam	Gaussian
Bunch charge, pC	12.5
Focus location from the cathode, mm	39
RMS transverse size of the focuse, μm	0.8

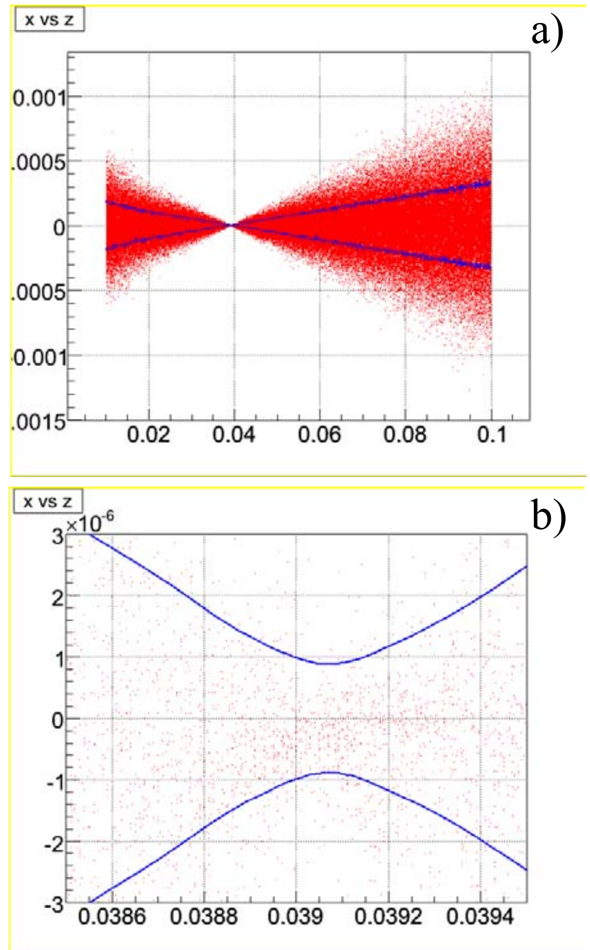

Figure 3. Beam transverse evolution in the electron source (a) and zoom of the focus point (b) simulated by ASTRA. Red dots – macroparticles, blue line – RMS envelope. All dimensions are in meters.

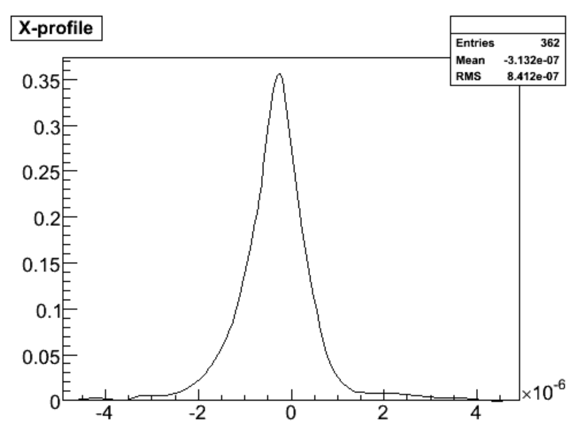

Figure 4. The transverse beam profile at the waist (the transverse distance is in meters, intensity is in arbitrary units).

SOURCE DESIGN AND FABRICATION

The actual source consists of the anode on its fixture and the cathode sitting on isolated holder connected to the linear motion actuator for longitudinal adjustment of cathode location. This assembly is mounted on 6” CF flange that is bolted to the back flange of the main vacuum chamber of the device. The chamber is also equipped with two 6” flange ports to connect turbo and ion pumps, two 2-3/4” flange ports to connect the linear motion feedthrough for transverse beam profiling, one 2-3/4” flange port for the high voltage feedthrough, and one 2-3/4” flange port orientated at 45 deg. with respect to the source axis. The laser beam is sent to the cathode via Sapphire window bolted to this flange, effects related to the 45 deg incidence of the laser on the photocathode have been found to be insignificant. A Faraday cup for the beam current and QE measurements during commissioning of the device is temporarily installed on the 6” front flange of the source. The general layout of the device appears at Fig. 5.

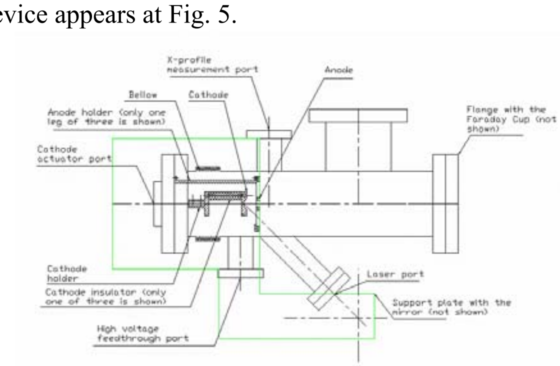

Figure 5. Top view drawings of the proposed source. One 6” flange, one 2-3/4” flange, cathode actuator, Faraday cup, and two cathode insulators are not shown for simplicity.

The ports for transverse measurements of the beam are welded at the expected location of the focus. The bellow (see Fig. 5) allows the measurement of the beam profile at different longitudinal location by moving the actual source. This feature will provide the beam envelope evolution in the vicinity of the beam waist. Therefore, the proposed design offers a noteworthy flexibility in adjusting the source geometry and implementing of a variety of different beam diagnostics.

At the moment, fabrication of all the components of the device has been completed. The source parts were manufactured at Argonne Central Machine Shop while the main vacuum chamber was welded by MDC Vacuum Corporation [8]. Presently, assembling and tuning of the source is in progress. Fig. 6, 7 show some components of the device and the vacuum chamber. Commissioning of the source is expected within a few months.

CONCLUSIONS AND FUTURE PLANS

A spin-polarized pulsed photoemission electron source is being developed at NIU in collaboration with ANL. At the first stage the source will provide unpolarized electron beam. All components of the device have been fabricated and delivered to NIU. Presently, assembling and tuning of the source, preparation of vacuum system, beam diagnostic tools, and related electronics is in progress. The source will be commissioned in the nearest future. Successful photoemission of a pulsed electron beam from a copper cathode at a low dc accelerating voltage will be a significant step in progression towards time-resolved electron microscopy. Additionally, the present source, configured as a flat beam source, should be able to drive a compact Terahertz electron source based on the Smith-Purcell free-electron laser scheme [9].

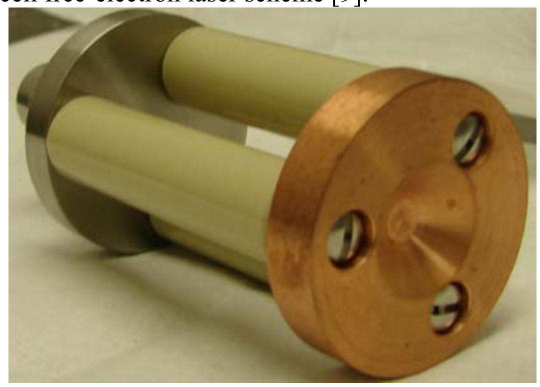

Figure 6. Assembled cathode on insulated holder.

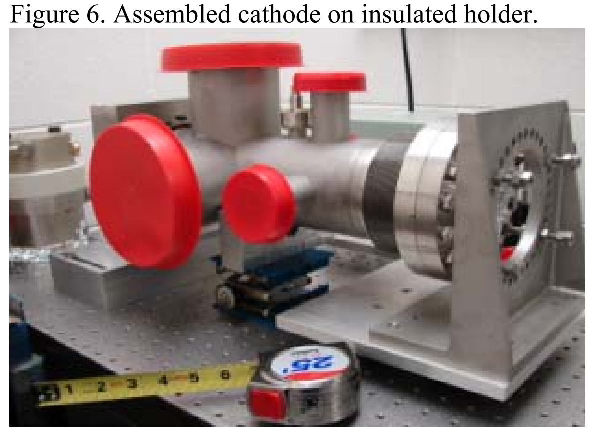

Figure 7. Assembled vacuum chamber on its fixture. The linear actuator with the cathode mounted on it is bolted to the backside flange through the hole at the right.

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