A 160 keV PHOTOCATHODE ELECTRON GUN TEST FACILITY

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Abstract

We propose the construction of a photocathode electron gun test facility for the characterisation of electron bunches emitted from a GaAs photocathode at room temperature and at LN_2 (77 K) temperature, offering diagnostic capabilities to measure beam emittance and photocathode response time as a function of quantum efficiency (*Q.E.*), based on DC photocathode and photoinjector technology.

INTRODUCTION

The ALICE[1] facility at Daresbury Laboratory is an ERL–driven free–electron laser light source operating at IR wavelengths. The ALICE ERL is also a powerful source of pulsed THz radiation. An upgrade to its DC photoinjector electron gun has been designed and partially–constructed [1], but due to the postponement of its installation on ALICE, the system will instead be used for photocathode and photoinjector physics experiments. A diagnostic beamline will be assembled providing a suite of diagnostics to measure the temporal and spatial properties of the emitted electron bunches. The ultimate aim of this research is the delivery of high–brightness electron beams based on GaAs technology.

Overview

The photocathode gun will operate at 160 keV, a level at which it is possible to operate without the complication of a pressure vessel using SF_6 (or similar) to achieve high–voltage insulation. The gun will incorporate cryogenic cooling, allowing photocathodes to be cooled with liquid nitrogen to temperatures as low as 77 K.

The gun is matched to a state–of–the–art external photocathode preparation facility (PPF) [2]. This combination permits the rapid exchange of photocathodes, supporting the testing of various different photocathode structures, and fine control of the cleaning and activation processes applied during their preparation in the PPF.

The diagnostics beamline will allow characterisation of the emitted electron bunches as a function of both *Q.E.* and temperature, with particular attention on the bunch emittance and photocathode response time. The anticipated layout is shown in Figures 2 and 4.

PHOTOCATHODE PREPARATION

The PPF was developed in collaboration with the Novosibirsk Institute of Semiconductor Physics (ISP), and has been operating at Daresbury Laboratory since June 2009. Its commissioning and performance are described elsewhere [2, 3].

Bespoke GaAs heterostructure photocathodes supplied by the ISP (shown in Figure 1) and prepared as described in [3] will be activated to a state of negative electron affinity (NEA) where their *Q.E.* is typically 15 % or more, transferred into the photocathode gun using a “load–lock” mechanism, and their performance studied as a function of cathode *Q.E.*

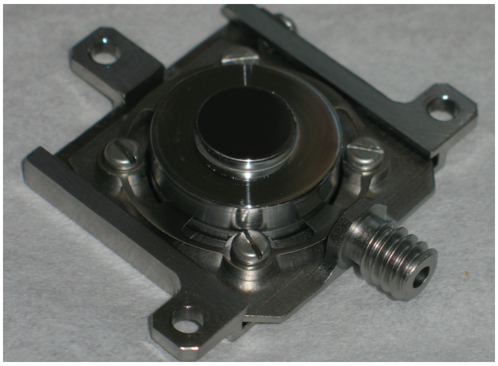

Figure 1: A GaAs photocathode with a 10 mm Ø active area on a molybdenum ‘puck’, mounted on a carrier plate.

The photocathode will be effectively *degraded* during the experiment by the addition of oxidant in a highly–controlled manner through a piezo–electric fine leak valve. During operation, the *Q.E.* will be varied between approximately 10 % and 0.1 %. This will take the photocathode from the NEA state into positive electron affinity (PEA), the transition from NEA to PEA occurring around the 7 % level at a wavelength of 532 nm [4]. It is expected that there will be a clear difference in the observed performance of the photocathode either side of this threshold point.

PHOTOCATHODE DRIVE LASER

The drive laser wavelength will be specified such that the photocathode response time defined by the electron diffusion model is significantly longer than the bunch lengthening predicted due to space–charge effects in the gun. The thickness of the photocathode active layer will be matched to this wavelengths under test. For example, the $\frac{1}{e}$ absorp-

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[1] Accelerators and Lasers In Combined Experiments

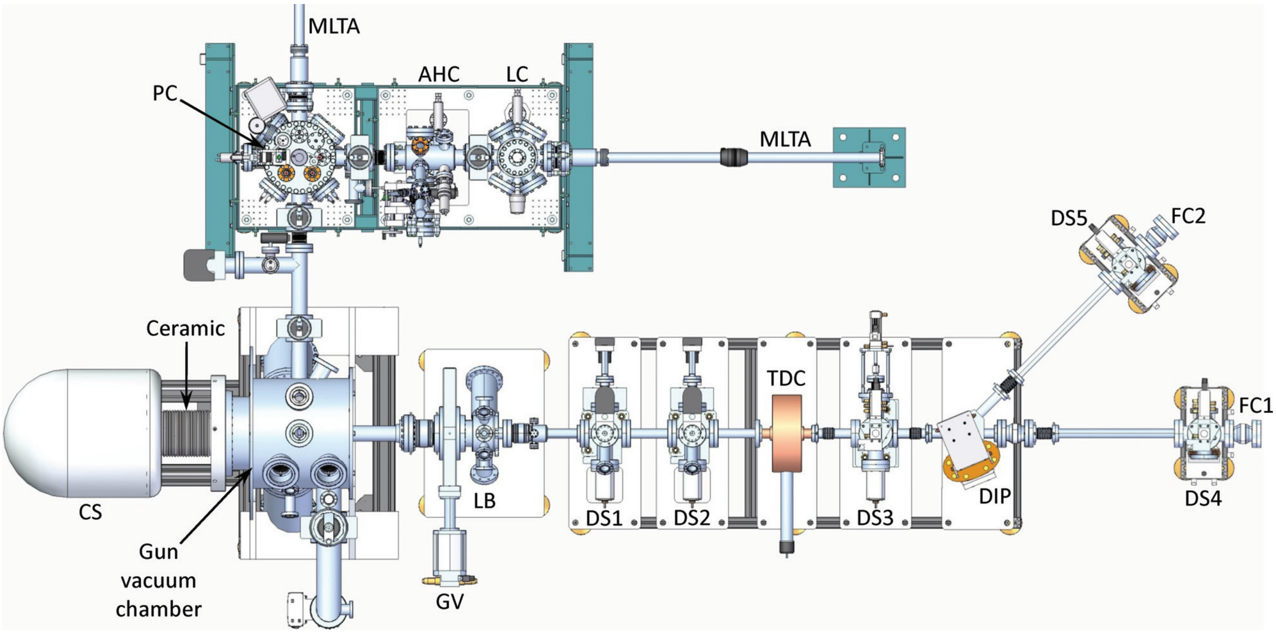

Figure 2: Plan showing a preliminary layout of the photocathode electron gun test facility. The key to the components is contained in the accompanying text.

tion length at 532 nm (2.33 eV) is 200 nm, though this increases to 330 nm for a 635 nm (1.95 eV) photon.

The fundamental pulse length will be less than the natural response time at this material thickness, and will be Gaussian in nature. This can be stacked to create a longer effective pulse length, as required. Simulations have shown that a laser pulse length of 1 ps (RMS) will generate an electron bunch 7 ps long for a 0.1 pC bunch charge.

The laser pulse energy will be controlled to ensure that the bunch charge extracted from the cathode remains at a constant level around 0.1 pC, thus compensating for the fall in *Q.E.* as the cathode is degraded.

The laser spot size will be around 8 mm Ø, so will be close to filling the active area of the photocathode surface, but is chosen to be large specifically to avoid the effects of space charge as much as possible.

GUN TEST FACILITY LAYOUT

Figure 2 shows a preliminary plan for the gun test facility layout. The upper part of the figure shows the 3–chamber PPF [2, 3], comprising (right–to–left): loading chamber (**LC**); atomic hydrogen cleaning chamber (**AHC**); photocathode preparation chamber (**PC**) which includes a storage carousel for up to 6 photocathodes. A magnetic linear transfer arm (**MLTA**, shown horizontally) allows photocathodes to be moved within the PPF. A second transfer arm (**MLTA**, shown vertically, truncated) allows photocathodes to be moved into and out–of the gun through a side–slot in the cathode HV electrode.

The mechanism shown in Figure 3 was designed for the ALICE upgrade, and provides a mount for the photocathode inside the HV electrode. It incorporates a worm–gear mechanism to move the photocathode forwards after insertion into an operational position, or backwards prior to extraction back into the PPF. The worm–gear will be operated by a handwheel located inside the corona shield (**CS**) at the back of the gun, shown in Figure 2.

The gun vacuum chamber will also include a piezo–electric fine leak valve to effectively degrade the cathode through over–oxidising, thereby controlling the *Q.E.*

The vacuum in the photocathode preparation chamber is typically in the 10^{-12} mbar regime, and will be in the 10^{-11} mbar regime in the gun chamber. The cryogenic cooling will further improve the gun vacuum and thus permit the low–temperature experiments to take place over longer timescales for a given *Q.E.* level. An all–metal gate

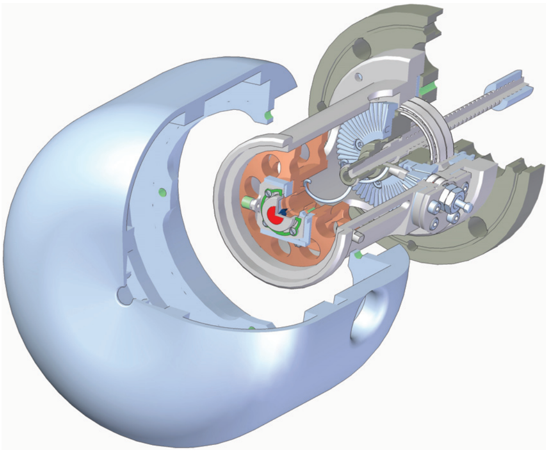

Figure 3: Photocathode mounting mechanism inside the HV electrode. The electrode is displaced and cut for clarity.

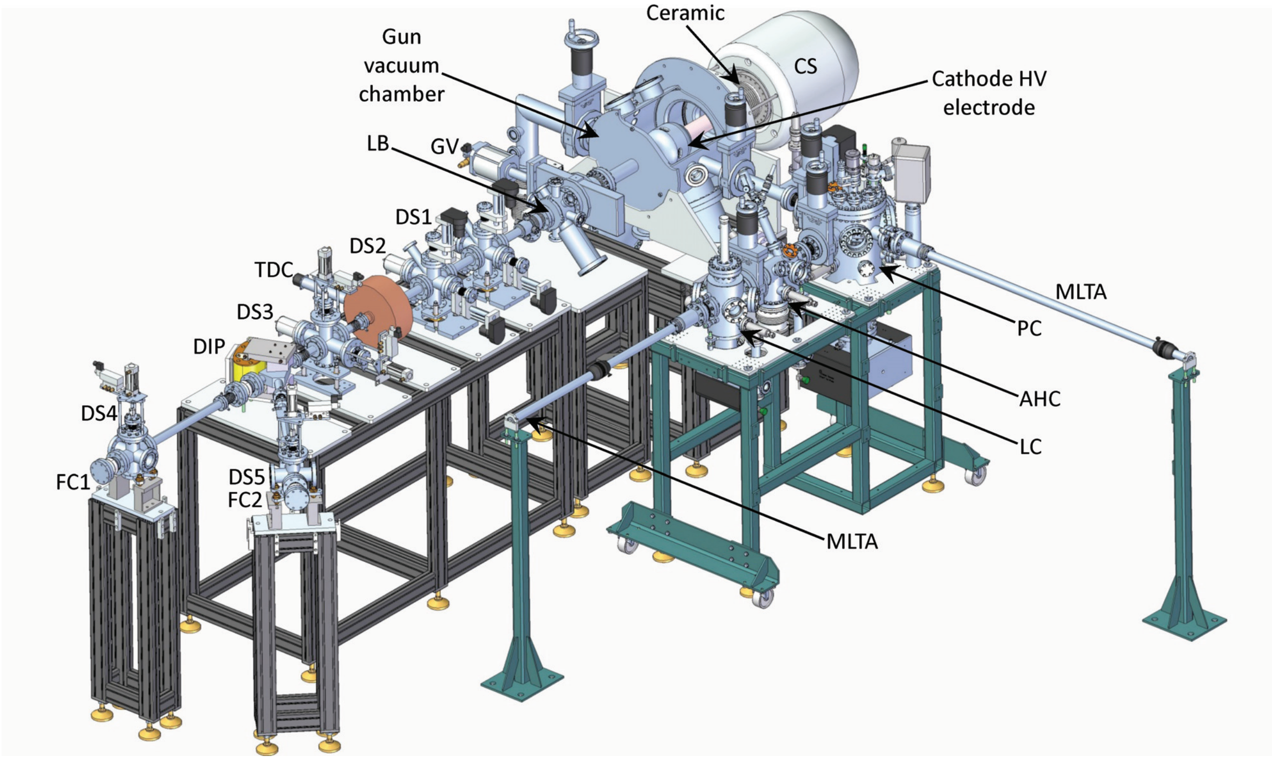

Figure 4: Preliminary schematic rendering of the anticipated photocathode electron gun test facility, with the vacuum vessel cut–away to show the cathode HV assembly. The key to the components is contained in the accompanying text.

valve (**GV**) will isolate the gun from the lightbox (**LB**, a mirror box which couples the drive laser beam into the vacuum system) and the diagnostics beamline itself.

Diagnostics Beamline

The diagnostics beamline will be based on that built for the initial commissioning of the ALICE (then known as the ERLP or *Energy Recovery Linac Prototype*) photocathode gun described in [5]. A solenoid for transverse focussing will be present immediately after the gun vacuum vessel, with a second solenoid expected further downstream.

The beamline will include a single–cell transverse deflecting cavity (**TDC**) operating at 1.3 GHz for bunch length measurements, and a dipole magnet (**DIP**) for beam energy and energy spread measurements. A pepperpot will allow rapid estimations of beam emittance, and a range of horizontal and vertical slit and screen assemblies will permit more accurate emittance measurement, so providing full 6–D characterisation of the electron bunches generated.

Up to five diagnostics vessels with YAG screens are under consideration (**DS1–DS5**), as shown in Figures 2 and 4. The DS1 to DS3 vessels shown downstream of the lightbox will also contain a range of horizontal and vertical slits, and a pepperpot for rapid estimation of beam emittance. The DS5 vessel will be in the 45° spur after the dipole magnet ro permit measurement of the energy spread and bunch length when the transverse kicker cavity is operated.

Faraday cups (**FC1** & **FC2**) placed at the end of both beamline stubs after DS4 and DS5 will support bunch charge measurements, and a current transformer may be included in the final scheme.

CONCLUSIONS

We plan to construct a photocathode test facility with a diagnostics beamline to characterise the performance of GaAs photocathodes at room and cryogenic temperatures. The measurements will focus on beam emittance and photocathode response time. This work is intended to deliver progress towards a high–current, short–pulse photoinjector electron source based on GaAs technology.

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