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Effects of Cathode Non-Uniformity on Emittance of an S-band Photocathode RF Gun[†]

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Abstract

The need for a high brightness electron beam for the proposed Linac Coherent Light Source (LCLS) project at SLAC has led to the development of the Gun Test Facility (GTF) at SSRL. The design requirements for the LCLS are 1 nC of charge in a micro-bunch of 10 ps or less with a normalized rms emittance of 1π mm mrad. Simulations of the GTF using a 1 nC bunch with 10 ps flat top temporal and uniform transverse distribution produce a simulated beam that meets the LCLS requirements. Initial measurements at the GTF with a micro-bunch containing 1 nC of charge with Gaussian longitudinal and transverse distributions, have shown that lengthening the laser pulse from 5 ps to 8 ps FWHM led to a reduction in the normalized emittance. In this paper, brief details of recent drive laser upgrades and results of emittance measurements - for which the photoemission from a Cu cathode is very non-uniform - are presented.

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ABSTRACT:

The need for a high brightness electron beam for the proposed Linac Coherent Light Source (LCLS) project at SLAC has led to the development of the Gun Test Facility (GTF) at SSRL. The design requirements for the LCLS are 1 nC of charge in a micro-bunch of 10 ps or less with a normalized rms emittance of 1π mm mrad. Simulations of the GTF using a 1 nC bunch with 10 ps flat top temporal and uniform transverse distribution produce a simulated beam that meets the LCLS requirements. Initial measurements at the GTF with a micro-bunch containing 1 nC of charge with Gaussian longitudinal and transverse distributions, have shown that lengthening the laser pulse from 5 ps to 8 ps FWHM led to a reduction in the normalized emittance. In this paper, brief details of recent drive laser upgrades and results of emittance measurements - for which the photoemission from a Cu cathode is very non-uniform - are presented.

Laser

The GTF drive laser system has undergone several upgrades during the past year. The original oscillator, on loan from ANL, has been replaced with an identical Lightwave 136 series ND:Glass diode-pumped mode-locked unit. The regenerative amplifier, on loan from the University of Rochester, has been replaced with a Positive Light model RGN-5 ND:Glass single head system designed to produce 3 mJ pulses at 2.5 Hz. In order to produce additional energy another head was placed after the regen as a single pass amplifier. This combination was capable of producing 6-7 mJ of IR. Due to the low damage threshold of the glass rods, the output was limited to 4-5 mJ. Maximum conversion efficiency from IR to UV of 5-10% was obtained for the shortest pulses from the compressor, 1.4 ps (FWHM). These pulses produced 3.5 ps (FWHM) UV pulses measured with a Hadland model FS300 streak camera. With the limited regen output energy, lower compressor and IR to UV conversion efficiencies and transport losses, the maximum available UV energy at the cathode was limited to 100-150μJ.

Electron Beam

The laser spot at the cathode had σ_{radial}=1.0 mm and was clipped at one σ_{radial} in order to minimise the non-linear space charge effects from the radial tails of the electron beam. The emittance of the electron beam was measured using a quadrupole doublet and normal incidence YAG screen after the linac. Additional details of the accelerator are presented in a previous paper [1]. Due to the combination of low laser energy at the cathode and low quantum efficiency of the copper cathode, $1 \cdot 10^{-5}$, only 200 pC of charge was produced. Despite the low charge the measured normalized emittance of the beam was relatively large, 3.38±0.04π mm mrad at 25 MeV for 3.5 ps (FWHM) laser pulses. Results from a series of solenoid scans are presented in Fig. 1. Simulations using PARMELA produced emittances of 1.0π mm mrad.

For certain settings of the solenoid and quadrupoles, the image of the electron beam from the YAG screen exhibited regions of missing charge, Fig 2. The regions of missing charge could be made to vary by steering the drive laser on the cathode. Examination of the laser spot immediately before entry into the vacuum system did not reveal any visible non-uniformity. By placing a 200μm wire across an aperture in the laser room that is relay imaged to the cathode, the image of the wire formed by the lack of charge from the cathode could be clearly seen on the YAG screen. This indicated non-uniform emission from the cathode. Part of the discrepancy between the simulations and the measurements is due to the non-uniformity in the electron beam, which gives rise to non-linear space charge forces that cannot be compensated by the solenoid.

The non-uniform emission from the cathode was not unexpected. However, the degree of non-uniformity was surprising. The cathode had been cleaned during the previous run by rastering a high intensity laser pulse (~$2 \cdot 10^{9}$ W/cm^2) across a 3mm high by 5mm wide area of the cathode in the presence of ~100MV/m fields in the gun. Before the laser cleaning the cathode non-uniformity was 100% with a QE of $5 \cdot 10^{-6}$; after the laser cleaning the QE was 2-$3 \cdot 10^{-5}$and the cathode uniformity improved to ~10%. While this increased the QE of the cathode it also increased the dark current. A SEM examination of the cathode after it was replaced revealed 100μm craters as shown in Fig. 3 below. Also evident was the uneven distribution of "cleaned" areas. Future plans are to perform emittance measurements with a new cathode and investigate less destructive cleaning methods.

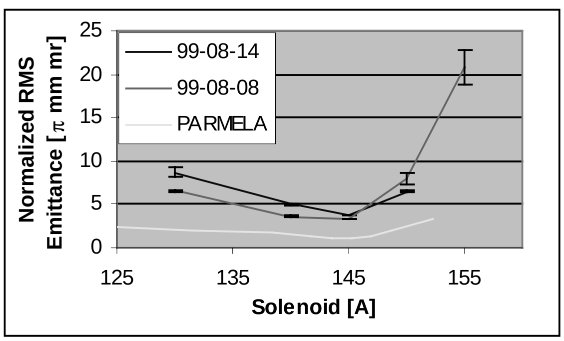

Fig. 1. Emittance as a function of solenoid strength.

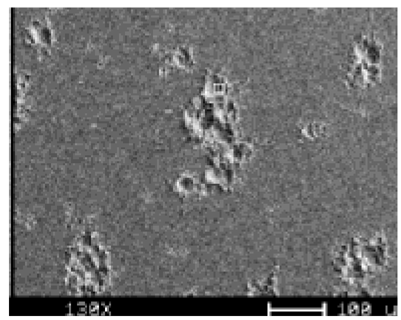

Fig. 2. Image of YAG screen with regions of missing charge, white line is 250μm.

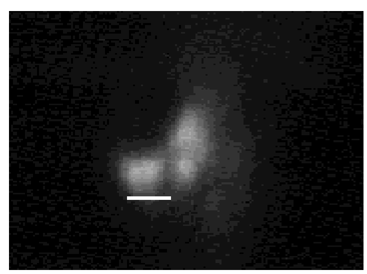

Fig. 3. SEM of laser cleaned cathode scale at lower right is 100μm.

References

[1] D.A. REIS ET AL.,TRANSVERSE EMITTANCE MEASUREMENTS FROM A PHOTOCATHODE RF GUN WITH VARIABLE LASER PULSE LENGTH, NUCL. INSTR. AND METH. A 429 (1999) 341-346.