OBSERVATIONS ON FIELD-EMISSION ELECTRONS FROM THE LOS ALAMOS FEL PHOTOINJECTOR*

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Abstract

A background source of electrons from the photoelectric injector (PEI) of the Los Alamos FEL experiment has been identified. This source is present without the drive laser irradiation and when the rf power is applied to the injector accelerator. Using intensified cameras and a synchroscan streak camera, these electrons have been imaged via optical transition radiation and Cherenkov radiation and characterized. The basic questions of location (photocathode), timing (~40 to 90° of the RF cycle), magnitude (2.2 nC per μs of rf power at 26 MV/m at the photocathode), and parameter sensitivity (accelerator A field's duration and magnitude) have been answered. The properties are consistent with a field-emission mechanism.

I. INTRODUCTION

The Los Alamos FEL facility incorporates a photoelectric injector (PEI) as a source of low-emittance electrons [1]. During the initial accelerator commissioning phase for beam energies of 14-17 MeV, electrons were accelerated, transported, and detected even when the PEI drive laser beam was blocked and only the RF power was on. This low power beam was initially detected with x-ray detectors and intensified television cameras that viewed intercepting beam-profile screens [2]. Using optical transition radiation (OTR) and Cherenkov radiation (CR) conversion mechanisms, the electron beam information was converted into visible light that was recorded by the intensified cameras and synchroscan streak camera, respectively. Several transport conditions were then used to image the background source and determine its location, spatial extent, timing, and parameter sensitivity. The characterizations led to the identification of the CsK_2Sb photocathode material as the source and field emission as the most probable mechanism. These results are some of the first to be reported from a high quantum efficiency (QE) photocathode/photoinjector.

II. EXPERIMENTAL PROCEDURES

The commissioning experiments began in the summer of 1989 and ended in May 1990. The beamline diagnostics used for the majority of this time are schematically shown in Fig. 1. No intercepting diagnostics or even wall current monitors (WCM) were allowed by the designers in the beamline until after the second accelerator tank. The electrons were transported about 7 m from the photocathode to the front-surface, aluminized fused-silica screen at position #3. The screen was oriented at 45° to the beam direction so that OTR was viewed at 90° to the beam direction and CR was viewed at 46° to the downstream beam direction. The beam position and profile were determined from the front surface (OTR) source and the CR from the fused silica substrate was optically relayed to a synchroscan streak camera several meters away from this screen. The Hamamatsu C1587 streak camera was phase-locked to the 108.3 MHz reference frequency, which is a subharmonic of the master 1300 MHz accelerator frequency. This technique allows the synchronous summing or integration of signals from many micropulses with relatively low jitter, 4 ps (FWHM), and reasonable temporal resolution, 5 ps (FWHM). In the case of this low current source we integrated the whole rf macropulse time at the 108.3 MHz repetition frequency [3].

III. EXPERIMENTAL OBSERVATIONS

As reported earlier [3] there was a strong dependence of the background source intensity on the photoinjector accelerator (A) field amplitude and duration. Starting at 26 MV/m, a 20% reduction in field resulted in a factor of 5 decrease in the box-average peak intensity of the field-emission image. Under some conditions a single laser-generated micropulse was comparable to the "field emission" electrons from about 50 μs of rf power. A synchroscan streak image exhibited a triplet temporal structure, which was attributed to a

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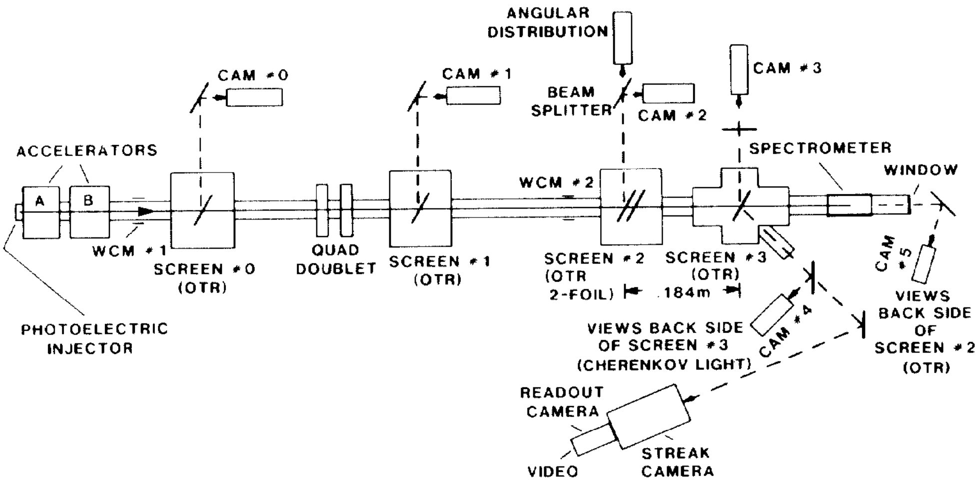

Fig. 1. Schematic of the accelerator beamline and diagnostics.

successful transport of electrons on only part of the rf phase, the partial sampling by the streak camera's entrance slit of the Cherenkov image, and the overlap of two pairs of time doublets via the display of deflections from both sides of the 108-MHz rf deflection in the streak camera. The latter effect was further proven when a change of 42 ps on the Narda phase shifter in the line between the rf source and the streak's synchroscan input moved the doublets in opposite "time directions."

Figure 2 shows the simultaneous imaging of PEI and field-emission injector (FEI) electrons with the synchroscan-streak camera. In this case, the drive-laser phase was at 20° to zero rf phase, and the FE electrons appear about 30 ps later and extend for ~30 to 40 ps (there is, thus, a several percent-energy spread). Due to transit-time effects in the first cell, the FE electrons can be generated from 40 to 90° of phase and arrive in this temporal window. In this case, beam transport seems to have included more of the differently phased electrons than in the March 20 data with the "doublet" structure.

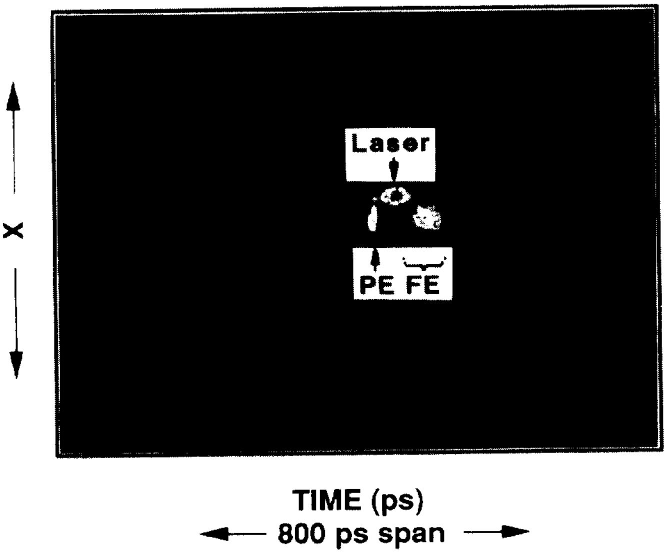

Fig. 2. "Simultaneous" synchroscan image of the drive laser, (PE) and FE sources.

Verification of the importance of the photocathode material's presence is illustrated in Figs. 3 and 4. In Fig. 3a, the quadrupole focus was adjusted to preserve the PEI electron beamlet pattern from the photocathode on the downstream screen. The same transport then allows the "imaging" of the background emission source distribution in Fig. 3b when the drive laser is blocked and higher camera gain is used. The swirling scene on the source (Fig. 3b) may be due partly to machining grooves on the MOLY substrate of the photocathode. Such edges could lead to enhanced local field gradients and, hence, emission of electrons from the lower work-function photocathode. Figure 4 shows an even more graphic result of the source before (upper) and after (lower) the photocathode material was baked off the plug. The halo remaining is larger than the plug diameter, and the camera gain had to be increased to see it. The absence of electrons from the central region is evidently because the photocathode material had been removed. Some photocathode material may be on the accelerator cell wall around the plug. The next day we also pulled the PC back about 2 mm in its slot, and the FE source strength decreased dramatically (10-20) with the reduction in rf field.

Subsequently, we performed a cross-comparison of integrated intensities under field-emission

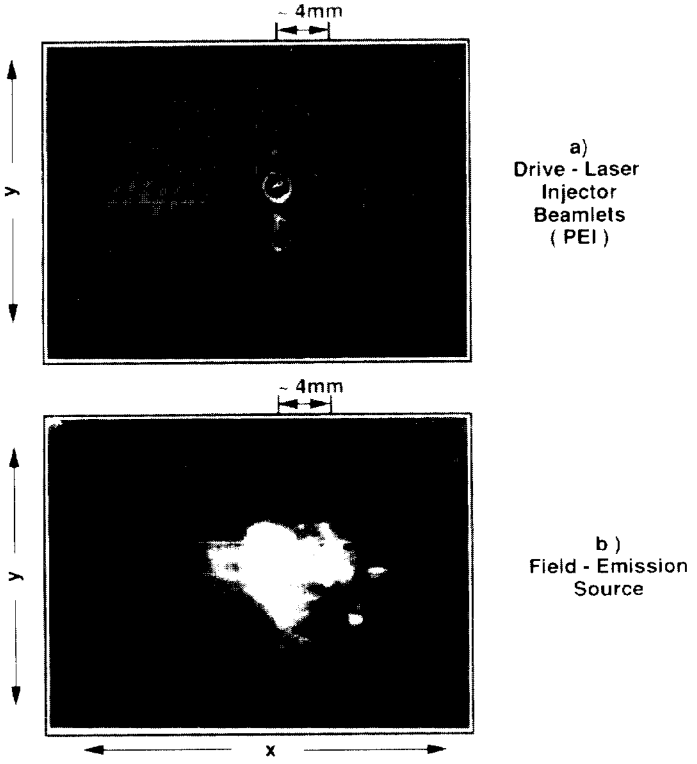

Fig. 3. Beam transport adjusted to preserve (a) PE beamlet pattern and (b) FE source distribution.

electron images and PEI electron-beam spot images and referenced the charge via a WCM. This comparison implied the FEI emission source strength of about 2.2 nC per microsecond of rf power for a field gradient of 26 MV/m. A plot of FE-electron intensity versus accelerator A field gradient showed an almost exponential dependence. It should be noted that one was only measuring those electrons transported through both accelerators and to this particular diagnostic station.

IV. SUMMARY

In summary, the background source of electrons in our photoinjector has been characterized. These electrons are generated from the photocathode material, depend nonlinearly (exponentially) on the injector accelerator field, depend linearly on the injector accelerator field duration, depend on the mechanical roughness of the photocathode substrate, and had a temporal extent of tens of picoseconds in our tests. Further experiments are planned at 6 MeV and ~40 MeV on our facility. This phenomenon is sufficient in strength to interfere with single micropulse beam parameter studies but not single macropulse studies. It would need to be addressed in PEI applications with high-duty factor rf power.

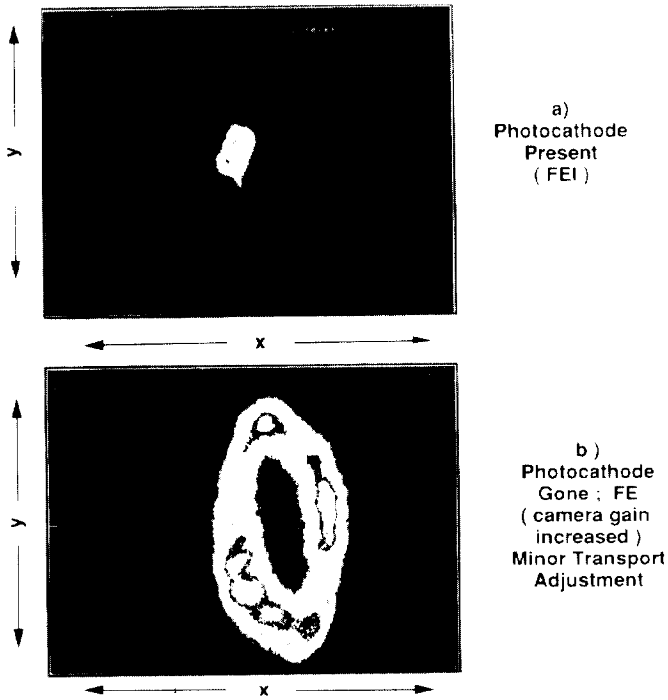

Fig. 4. Images (via OTR) of the photocathode source (a) before and (b) after bake off of the CsK_2Sb.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

[1] J. S. Fraser and R. L. Sheffield, IEEE J. of Quant. Elect., Vol. QE-23, p. 1489, September 1987.

[2] A. H. Lumpkin, et al., NIM. A 296, p. 769, 1990.

[3] Alex H. Lumpkin, Bruce E. Carlsten, and Renee B. Feldman, "First Measurements of Electron-Beam Transit Time and Micropulse Elongation in a Photoelectric Injector," in *Proceedings of the 12th International FEL Conference*, Paris, France, September 17-21, 1990.