COMBINED THERMIONIC AND PHOTOELECTRIC EMISSION FROM DISPENSER CATHODES

D. W. Feldman, A. Valfells, J. Neumann, J. Harris, B. Beaudoin, P.G. O'Shea
Institute Research in Electronics and Applied Physics, Energy Research Building, University of Maryland College Park, MD 20742-3511

Abstract

Photoelectric emission from dispenser cathodes has been studied earlier [1]. Photoelectric emission in conjunction with thermionic emission can provide a convenient and flexible means of modulating emission from thermionic cathodes with programmable formats and high bandwidth. This may be useful for experimental studies the beam dynamics of space charge dominated beams, such as in the University of Maryland Electron Ring (UMER). We have studied combined photoelectric and thermionic emission from a dispenser cathode using a Nitrogen laser operating at 337 nm. Results will be presented for the effect on emission of laser intensity, cathode temperature, and accelerating voltage.

1 EMISSION FROM DISPENSER CATHODES

Electron photoinjectors have gained acceptance as the source of choice for high-brightness electron accelerators. One of the main areas of difficulty is the short lifetime of the photoelectric cathode. The vacuum requirements of the cathode typically call for operation with ultra-high vacuum. The goal of the research described here is to study the properties of a common dispenser cathode as a candidate for use as a robust photocathode. This work is related to previous research we have done on LaB_6 cathodes [2].

Dispenser cathodes(W-Ba-Ca) are most commonly used as thermionic electron sources, but recent work[1,3] has shown that they have desirable characteristics as photo emitters, with higher quantum efficiencies than commonly used metals and reasonable lifetimes. We have examined some characteristics of a cathode as a photo and thermionic emitter and report the current results here.

1.1Combined Thermo and Photo Emission

Combining photoelectric excitation with thermionic emission provides some unique opportunities for the study of electron beam physics in machines such as the University of Maryland Electron Ring(UMER). The spatial and temporal agility of laser sources permit the superposition of current pulses of adjustable geometry and timing onto DC or quasi-DC thermionic currents. Observation of the evolution of these perturbations in the UMER ring should be a powerful tool for the study of electron interactions in the extreme space charge regime.

1.2 Dispenser Cathodes for Photoinjectors

For photoinjectors operating with macro pulses of the order of microseconds, with micro pulse repetition rates of 10-100 MHz, quantum efficiencies(QE) must be high enough to obtain micro pulse charges of 0.1-1 nC with reasonably obtainable excitation lasers. In addition, the lifetimes at reasonably attainable pressures must either be very long(days) or be of the order of a workday with simple rejuvenation techniques.

The work in references 1and 3 indicate that dispenser cathodes have QE's an order of magnitude or more higher than metal cathodes[4], that at somewhat elevated temperatures, they have lifetimes of many hours, and that after depreciation, they can be easily rejuvenated.

Because dispenser cathodes appear to have such promising characteristics, we decided to revisit the question with components that were readily available to us in our laboratory,

2 EXPERIMENTAL ARRANGEMENT

1.1 Cathode

The cathode that we used was one that was several years old and that had been used in a variety of experiments. Its thermionic emission is about one half of that which was measured when the cathode was originally activated. Therefore it was assumed that the emission, both thermionic and photoelectric would be less than that of a fresh cathode. Figure 1 shows schematically the configuration of the cathode housing.

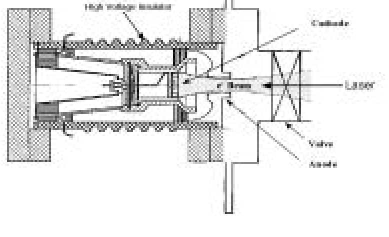

Figure.1 Thermionic Gun Assembly

The anode-cathode gap is 2,54 cm, the cathode diameter is 2,54cm, and the maximum accelerating voltage was 9kV. The current was measured with Bergoz current transformer with a temporal resolution of 200ps.

The signals were read out on a 4Gs/sec LeCroy oscilloscope and digitized.

1.2 Laser

The laser used was a PAR LN1000 nitrogen laser operating at 337 nm. The laser had an output energy of one mJ at 3pps and a temporal width of 1.25ns with at least one small subsidiary peak. The output beam was apertured down to 300µJ and the spot size on the cathode could be changed with focusing optics. The laser intensity was adjusted by inserting thin plastic sheets into the beam.

3 EXPERIMENTAL RESULTS

3.1 QE and Lifetime

At the laser wavelength of 337nm, the measured QE was 7.4×10^{-5} electrons/photon. This is approximately one half that to be expected from the data of ref 3. Considering the fact that the thermionic emission from the cathode is less than that observed when the cathode was fresh, this is not surprising. This should be revisited with a newly activated cathode.

The 1/e lifetime of the QE was about one hour at room temperature. At 700c and a background pressure of about 5×10^{-8}, the 1/e lifetime was measured to be about 30 hours. After depreciation, the QE could be restored by heating the cathode to 1020C.

Over the range of accelerating voltages that we were able to use, we did not observe any appreciable Schottky effect.

3.2 Beam Kinetics

The most interesting, and in part, unexpected findings from this study were effects of beam dynamics. There were two types of effects; variation in field saturation limits resulting from changing the emission density in a finite area (Child-Langmuir limit) and pulse shape instabilities.

3.2.1 Current Limitations

The classical Child-Langmuir treatment [5] of current limitation due to field saturation is based on a one-dimensional model of infinite, parallel electrodes. Recently, simulations with a two dimensional model was developed by Luginsland et al [6] and theoretical work by Lau [7] which showed a Child-Langmuir limit which was a function of the ratio of the inter-electrode gap to the width of the emitting strip. Our analysis when the emitting surface is circular shows a similar qualitative behavior.

Figure. 2 shows the variation of the total charge in the current pulse as a function of laser intensity.,

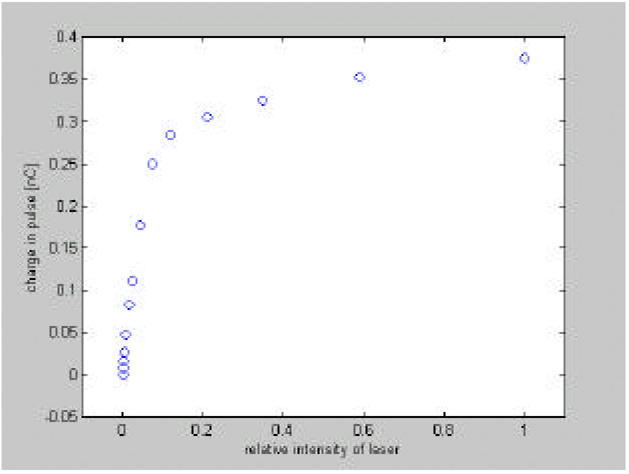

Figure 2 Charge vs. Laser Intensity

An interesting point is that there is not a hard limit for the amount of charge that may de drawn from the cathode but there is a transition region where the emission becomes space charge limited.

Figure 3 shows the variation of the space charge limited average current density as a function of the emitter size.

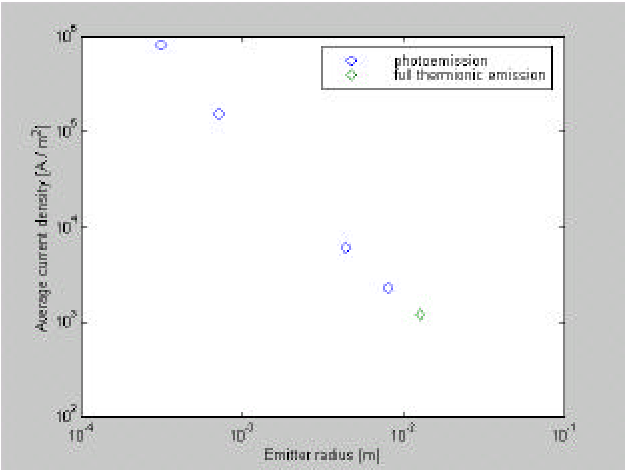

Figure 3 Space Charge Limit vs. Spot Size

The ordinate gives the value of the ratio of the radius of the emitter to the gap spacing, which we call F_D, and the abscissa gives the ratio of the averaged current density to the Child-Langmuir current density, which we call F_J. We observe a scaling law of $F_J \sim F_D^{-1.8}$, whereas Luginsland and Lau predict that F_J be inversely proportional to F_D. There is a significant difference between their theory and our experiment. The model of Lau and Luginsland looks for the maximum current density that may be drawn before virtual cathode formation in front of the center of the emitting area takes place. We are measuring the average current density across the entire emitter area. This is expected to be higher since virtual cathode formation at the edge of the emitter occurs at higher current densities than at the center.

In these experiments, we did not have good control over the shape of the focused beam so that it was not perfectly circular. There is also some uncertainty about the effective inter-electrode gap, since the anode has a hole in it while the theories and simulations assume parallel planar electrodes with no holes

.3.2.1 Beam Instabilities

Figure 4 shows a comparison of the laser pulse shape with the photocurrent pulse shape at laser intensities below and above the space charge limit.

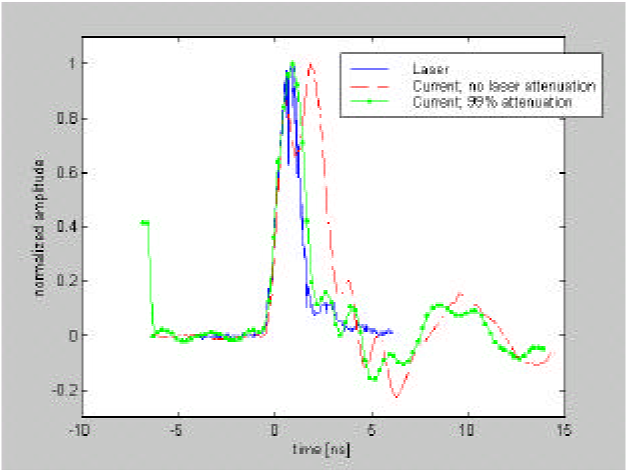

Figure 4 Laser and Beam Pulse shapes

The pulse amplitudes are normalized. At low beam current, the temporal beam profile basically mimics the laser excitation. As the beam current increases, the pulse broadens and splits into two peaks.

Figure 5 illustrates the effect of varying the acceleration voltage while keeping the laser intensity constant.

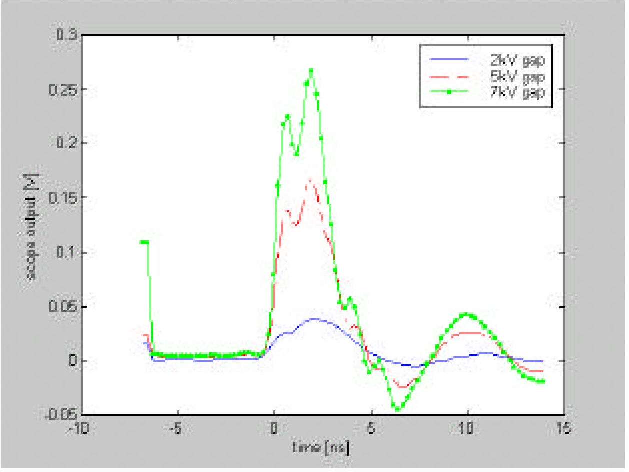

Figure 5 Current Pulse at Different Accelerating Voltages

Clearly, we are seeing the initiation of instabilities and formation of virtual cathodes. Similar phenomena have been observed in high current rf photo injectors [8] and in lower voltage microwave devices [9], although we are operating at lower current densities and lower field gradients than most devices, and with a range of pulse length to transit times, all of which may affect the observed behavior. We are at present developing a relevant model for our conditions.

2 CONCLUSIONS

Tungsten dispenser cathodes may be used as reasonably efficient photoelectric as well as thermionic emitters. Both processes can be used simultaneously to produce fast perturbations and patterns onto thermionic beams for basic beam behavior studies.

Dispenser cathodes also appear to be candidates for cathodes for photo injectors. They have quantum efficiencies well above most metal surfaces, useful lifetimes at moderate temperatures and pressures, and can be easily rejuvenated.

The classic Child-Langmuir limit for current density can be exceeded for emission from finite areas. We are currently working to reconcile the difference between the model and the experimental results.

We plan to develop the model to include the excitation pulse shape and to repeat our experiments with a fresh cathode, an improved structure to allow higher field gradients, and to study the quantum efficiency at other excitation wavelengths.

REFERENCES

[1] B. Leblond,"Short Pulse Photoemission From A Dispenser Cathode Under the 2nd, 3rd and 4th of a Picosecond Nd: YAG Laser,", Nucl. Instr. And MethA317 (1992) 365-372

[2] P.G. O'Shea et al, " RF Photoinjector Using a LaB_6 Cathode and a Nitrogen Drive Laser" Appl. Phys Lett. 73, 411 (1998)

[3] H. Bergeret et al, "Short Pulse Photoemission From A Dispenser Cathode", Nucl. Instr. And Meth A301 (1991) 389

[4] E. Chevallay, J. Durand, S. hutcins, G. Suberlucq, and M. Wurgel, CERN/PS 93-22(LP) CLIC Note 203

[5] C. D. Child, Phys. Rev. **32** , 492 (1911); I. Langmuir, *ibid*. **21**, 419 (1923)

[6] J. W. Lugensland, Y. Y. Lau, and R. M. Gilgenbach, PRL, **77**, 22, 25 Nov. (1996)

[7] Y.Y. Lau, A simple theory on the two-dimensional Child-Langmuir law, preprint.

[8] D. H. Dowell et al, "Observation of Space-Charge Driven Beam Instabilities in a Radio Frequency Photoinjector", Phys. Plasmas **4** (9) September 1997

[9] R. B. Miller,"An Introduction to the Physics of Intense Charged Particle Beams" (Plenum, New York, 1985)pp 97-105.