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A LASER HEATED THERMIONIC CATHODE *

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Abstract

There is increasing interest in developing accelerator technologies for space missions, particularly for fundamental science. In order to meet these mission needs, key accelerator technologies must be redesigned to be able to function more reliably and efficiently in a remote and harsh environment. In this work we focus on a modest electron injector system, specifically the traditional thermionic cathode. Typically such cathodes are resistively heated by a power supply that is floated at the cathode accelerating negative high voltage. This can increase engineering complexity and add a significant load to the accelerating voltage supply. We pursue laser heating a thermionic cathode in order to remove the heater power supply from the injector system, allowing for reduced engineering complexity and power requirements for the injector. To date we have shown that a simple tantalum disk cathode can be heated by a laser with similar emission performance to the same disk resistively heated.

INTRODUCTION

Thermionic cathodes are widely used as electron sources in everything from microwave tubes to RF and DC injectors [1–3] and were once ubiquitous in CRT displays. These cathodes are generally regarded as robust, straightforward to operate, and not well suited to high-brightness applications. The fundamental mechanism for electron emission is heating the cathode material to a temperate on the order of 1500 K to 2200 K by means of resistive heating. This requires an external heater power supply to be floated at the high-voltage used to accelerate the emitted electrons. Generally the resistive heater power supply is connected through an isolation transformer to regular 120 V facility power, however, such a set up usually requires a significant amount of space for the high-voltage insulators and often the transformer. It is also possible to achieve the same result powering the heater power supply from batteries. For applications requiring compact systems, low power consumption, and overall robustness, we propose to remove the resistive heater power supply from the system and heat the thermionic cathode using a laser. In addition to eliminating potentially bulky hardware, this approach also allows increased flexibility for the high-voltage accelerating power supply.

EXPERIMENT SET-UP

To perform a proof-of-concept demonstration we designed the simple parallel plate system with cathode holder, annular anode, and Faraday cup shown in Fig. 1. The cathode plate, anode, and Faraday cup are made of stainless steel, each mounted to a larger frame, and electrically isolated from each other by PEEK or ceramic spacers. This apparatus was inserted into a vacuum chamber with a pumping port, a laser viewport, a regular viewport, a vacuum diagnostics port, and an electrical feedthrough port. The chamber could be pumped down to about 10^{-8} Torr in about 1-2 days without baking on a small turbo-pump station. We only required 10^{-6} Torr pressure range for cathode operation.

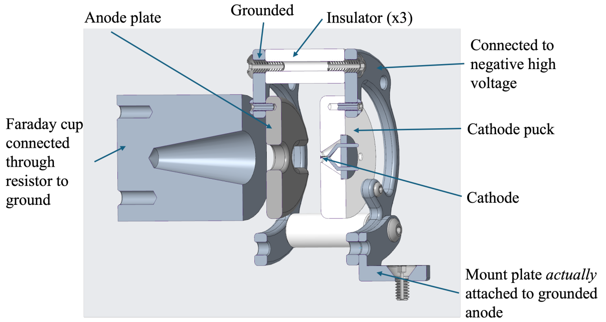

Figure 1: A mechanical drawing of the core test apparatus. The cathode holder is on the right, the annular anode in the middle and Faraday cup to the left. The main mount is actually on the anode holder, allowing the cathode to be held at negative high voltage. The insulators are either PEEK or ceramic. The Faraday cup is isolated from the anode and connected to ground through an ammeter.

Figure 2 shows a picture of the core experiment hardware assembled and ready to be mounted in the vacuum chamber.

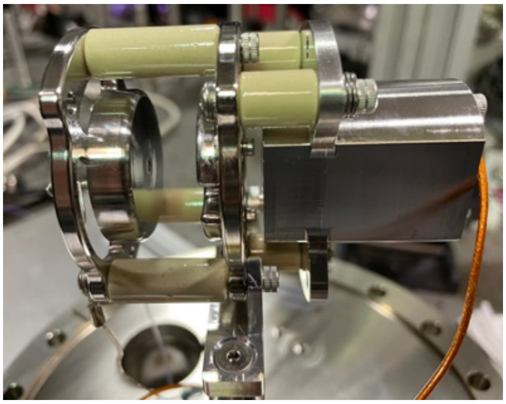

Figure 2: This is a picture of the core test apparatus, with the cathode holder on the left, annular anode in the middle and Faraday cup on the right. The orange cable on the back of the Faraday cup carries the measured current.

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Our high voltage power supply is an SRS +/-5 kV supply sourcing up to 5 mA. The polarity switching feature was invaluable since we had to switch the high-voltage from the anode for resistive heating, to the cathode for laser heating. We did not have the means to float the heater power supply, so instead had to swap how we applied the accelerating voltage.

Cathode

The cathode holder (see Fig.1 has a recess in the back that holds the cathode. We used a Kimball Physics ES-046 tantalum disk cathode mounted on an AEI standard scanning electron microscope base [4]. The cathode parameters are shown in Table 1. For laser heating tests we drilled a hole in the alumina insulator of the AEI base to allow the laser to illuminate the back of the tantalum disk.

Table 1: Cathode Specifications

Material	tantalum
operating temperature	2200 K
diameter	1.5 mm
thickness	0.1 mm
emission area	19.5×10^{-3} cm^2
typical emission	5 mA

Laser

The laser used in this project is an Agiltron HPSL-121111111 fiber-coupled diode laser, capable of outputting up to 20 W CW power at 1060 nm. In this case the wavelength is not particularly important because we are not yet concerned with optimizing photon absorption. The laser had a collimator at the end of the fiber pigtail producing a 4.5 mm diameter spot. The laser was directed thought the chamber laser viewport, through the hole in the insulator of the AEI base, and focused on to the back of the cathode by an off-axis paraboloid mirror. Figure 3 shows the built-in red alignment laser illuminating the back of the tantalum disk. The larger white circle is the alumina insulator of the AEI base. For the laser heating configuration we attached a wire from the heating lead of the AEI base to the cathode frame to provide the cathode with the necessary electrical connection.

Figure 3: This shows the built-in alignment laser illuminating the back side of the cathode. The large white disk is the insulator in the AEI base that hold the cathode.

Measurements

First we measured the emitted current using resistive heating. We put the heater power supply in voltage control mode to protect the cathode. We began with the recommended conditioning process, essentially ramping up the temperature very slowly while monitoring the vacuum level. If the vacuum crossed in to the 10^{-6} Torr range we shut off the heater and waited for the cathode to cool and the vacuum level to recover.

To collect data we turned the heater voltage up slowly with the accelerating voltage fixed at 1.5 kV, recording the voltage and current shown on the heating power supply front panel. We measured current in this configuration by recording the voltage drop across a current-viewing resistor of 28.9 kOhms that connected the accelerating voltage power supply to the Faraday cup, in parallel with the accelerating voltage to the anode. This configuration yielded high fidelity current data and ensured a zero-field region between the anode and Faraday cup. We also mounted an uncalibrated infrared camera aiming at the back of the cathode disk to measure relative temperature of the cathode.

To measure the emitted current in the laser heating configuration we incrementally turned up the laser power while the accelerating voltage was fixed at 1.5 kV. At each increment we intercepted the laser beam, before it entered the chamber, with a power meter. We often recorded data incrementally turning the laser power down as well. Emitted current was measured by running a cable from the Faraday cup directly into a Keithley 6485 Picoammeter.

During these experiments we monitored the vacuum level, but we rarely saw any levels higher than the mid-10^{-7} Torr range.

RESULTS

The data we collected from both the resistive heater emission and laser heating emission are plotted in Figs. 4 and 5. These are plotted on both a linear and log scale to emphasize different features.

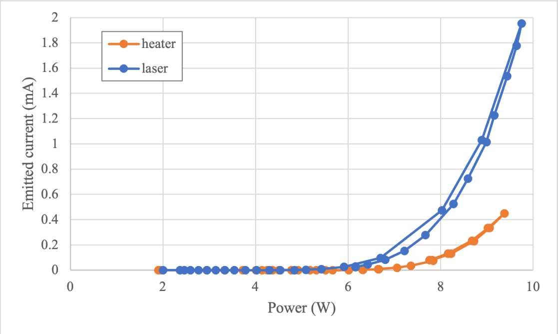

Figure 4: Emitted current plotted versus incident power, either measured on the power supply front panel or by an optical power meter before the laser enters the vacuum chamber. The linear scale emphasizes the high-current data.

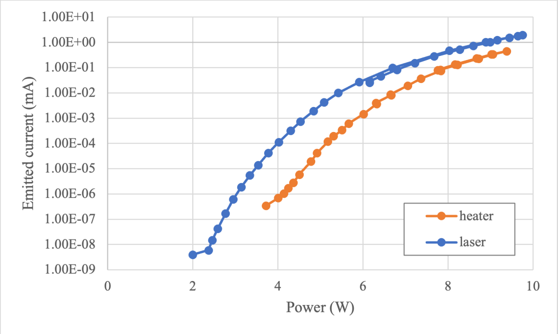

Figure 5: Emitted current plotted versus incident power, either measured on the power supply front panel (orange) or by an optical power meter before the laser enters the vacuum chamber (blue). The log scale emphasizes the low-current data.

The heater data is shown in orange and the laser data is shown in blue. The emitted current is slightly higher for the same incident power for the laser heating than for the resistive heating method. There are a number of factors for which we could not account in this presentation: resistive losses in the circuit between the heater power supply and the cathode, thermal losses, optical loss at the vacuum chamber viewport, optical losses due to poor photon absorption at the cathode surface, and laser spot size.

Figure 6 shows the emitted current as a function of observed relative temperature of the cathode during heating. Theoretically these should be co-linear, however, we observed that the temperature reading on the IR camera was very sensitive to the alignment of the camera. We assume that the difference in these plots is due to the uncertainty in the camera measurements. However, this very slight difference is not sufficient to explain the data shown in the next figure. Figure 7 shows the observed relative temperature of the cathode during emission for both resistive heating and laser heating. this plot indicates that for the same incident power, laser heating raises the cathode to a slightly higher temperature than resistive heating. This is a bit surprising because we estimate that the resistive losses in the wiring between the heating power supply and the cathode are low compared to the optical losses due to material reflection.

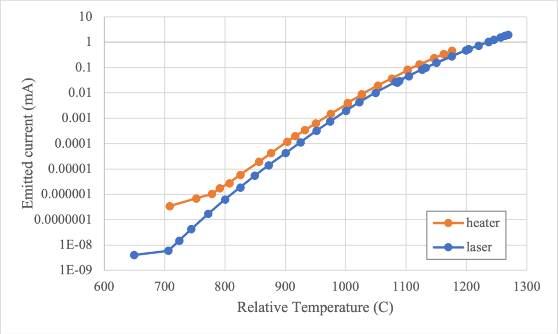

Figure 6: This shows the emission current from each heating method as a function of the observed relative temperature of the cathode during emission. This plot suggests that there are some slight discrepancies in the temperature measurement, which is what the researchers observed.

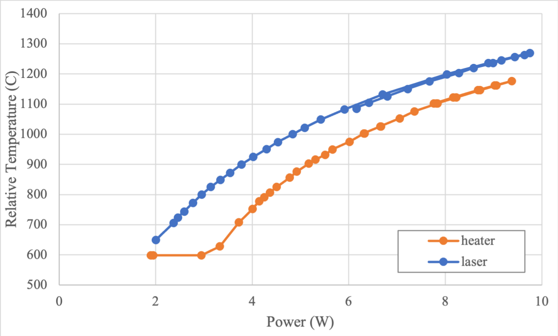

Figure 7: This shows the relative temperature as a function of incident power either from the resistive heater or the laser. For the same power, the laser appears to heat the cathode to a higher temperature than the heater.

CONCLUSION

We have compared emission current from a tantalum disk cathode driven either by resistive heating or by laser heating. The results show that it is possible to heat a modest size cathode to emission temperatures using only a CW laser, and that the laser heating method may be slightly more efficient than resistive heating. Future work will include investigating laser heating with various cathode materials and increasing photon absorption.

ACKNOWLEDGMENTS

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