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Title : Influence of Power throughout Heaterless Hollow Cathode Ignition

Theme :

Attached documents :

SP2016_Abstract Submission_Daykin-Iliopoulos_final.pdf

Resume :

Hollow cathodes typically operate through the use of low work function emitters to deliver thermionic current. To achieve high thermionic current the emitters require heating to around 1500 K for barium oxide cathodes and over 1900 K for lanthanum hexaboride cathodes. Conventionally a heater component is utilised to raise the emitter to the required thermionic temperatures for ignition, however this has drawbacks: firstly additional mass and volume for the heater component is required, secondly there are reliability issues due to thermal cycling and high temperature variation, and finally there are long ignition times, up to 10 minutes, due to indirect heating of the insert. Thus replacing the heater component with a simpler and potentially faster ignition system will be highly advantageous. Conventional hollow cathodes can be cold started, though this leads to high voltages combined with unacceptable mass flow rates (order of magnitude higher).

We are investigating an alternative approach to ignition by developing dedicated heaterless hollow cathodes (HHC) that meet the internal pressures required at nominal mass flow rates. In which the emitter heating is driven by a discharge between the keeper and the emitter. This method allows for direct heating of the emitter, lowering the overall HHC ignition time to as low as 2 seconds, without requiring additional components.

Though to date HHC's have only demonstrated lifetimes of hundreds of hours. This is primarily due to the absence of thermionic emission during the breakdown stage, such that higher breakdown potentials are used compared with conventional ignition. Hence the sputter erosion yields can be higher due to the higher energy ion bombardment and in addition cathodic spots can form through ignition, due to over powering, thus causing high localised erosion.

This study investigates a novel power switching sequence to ignite the heaterless hollow cathode, which can enable repeatable ignition at relatively low voltages (<500V) and flow rates (<20 sccm), thus resulting in low erosion. This is achieved though adapting the voltage and current though through ignition to understand their influence on repeatability and erosion. This is examined through an experimental campaign conducted on the 20A heaterless hollow cathode under development at the University of Southampton. Results have shown that discharge stability can be increased by limiting current though the use of electrical ballasts due to the plasmas negative resistance characteristics observed. Erosion analysis is being conducted though the following diagnostics: scanning electron microscope for erosion detection, spectroscopy for species identification and periodic mass measurements for erosion quantification.

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An Investigation into the glow discharge phase of an LaB6 heaterless hollow cathode

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Presentation Overview

Introduction

- Motivation of research
- Research aims and objectives

Design and experimental set-up

- Experimental apparatus

Results and discussion

- Pressure influence
- Electrode distance influence

Conclusions and future research

- Conclusions
- Future research

Motivation of the research

Why develop heaterless hollow cathodes?

Hollow cathode heater reliability issues

- High thermal cycling
- Large temperature variations up to1650℃
- Survival of launch vehicle vibration environment

Mass, volume, and power savings

- Dual heaters have been used due to the known reliability issues

Reduction in ignition time

- Direct heating of the insert region

Design simplicity

- Reduction in hollow cathode cost
- Simplified design with fewer components

Research aims and objectives

Aims

- Heaterless ignition comprises of three main stages: breakdown, heating and nominal operation.

- Such that the investigation and evaluation of each stage of the start-up, as well as the transition between stages will enable the design of a reliable and low erosive high powered heaterless hollow cathode

- In this study the aim is to investigate the glow discharge stage of the heaterless ignition, and study of the characteristics of the glow discharge and relation to classical theory for designing of HHCs

Objectives

- This will be done through a simulated experiment in a backfilled chamber that reproduces most aspects of the HHC including: cathode and keeper material and geometries though it will not be enclosed enclosed to allow for better diagnostics of the phenomena hence the thermal and gas conditions will not be in common.

- This study involves investigating the laB_6 glow discharge and the influence of:
  - Electrode separation on the glow discharge characteristics
  - Pressure influence on the glow discharge characteristics

Experimental apparatus

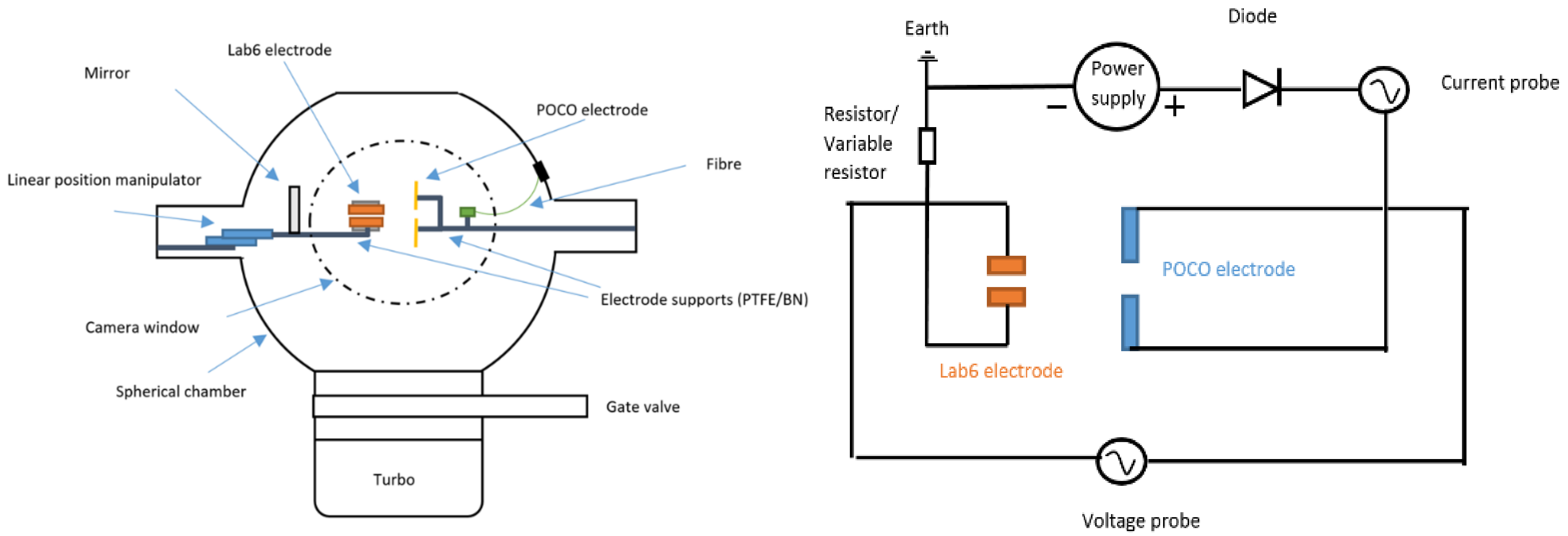


Figure 1: Overview of experimental and the electrical setup

- 35 cm diameter spherical stainless steel vacuum chamber, ~ 2 × 10-5 mbar prior to backfilling.
- Backfilled by two Bronkhurst EL-FLOW mass flow controllers (MFCs) with 0-10 sccm and 0-20 sccm flow rate ranges

LaB6 experimental setup

- LaB_6 Cathode: L = 15 mm, ID=2 mm, OD = 4.5 mm
  - Electrical contact through POCO graphite
  - Boron nitride dielectric sleeve over the graphite
- POCO Anode: ID= 1mm, thickness = 2 mm
  - Macor sleeve to the anode to reduce the edge effects
- Position manipulator to alter the electrode separation
- Dielectric Macor mount to enable testing within the left (low pd) region of the Paschen curve without unintentional discharges

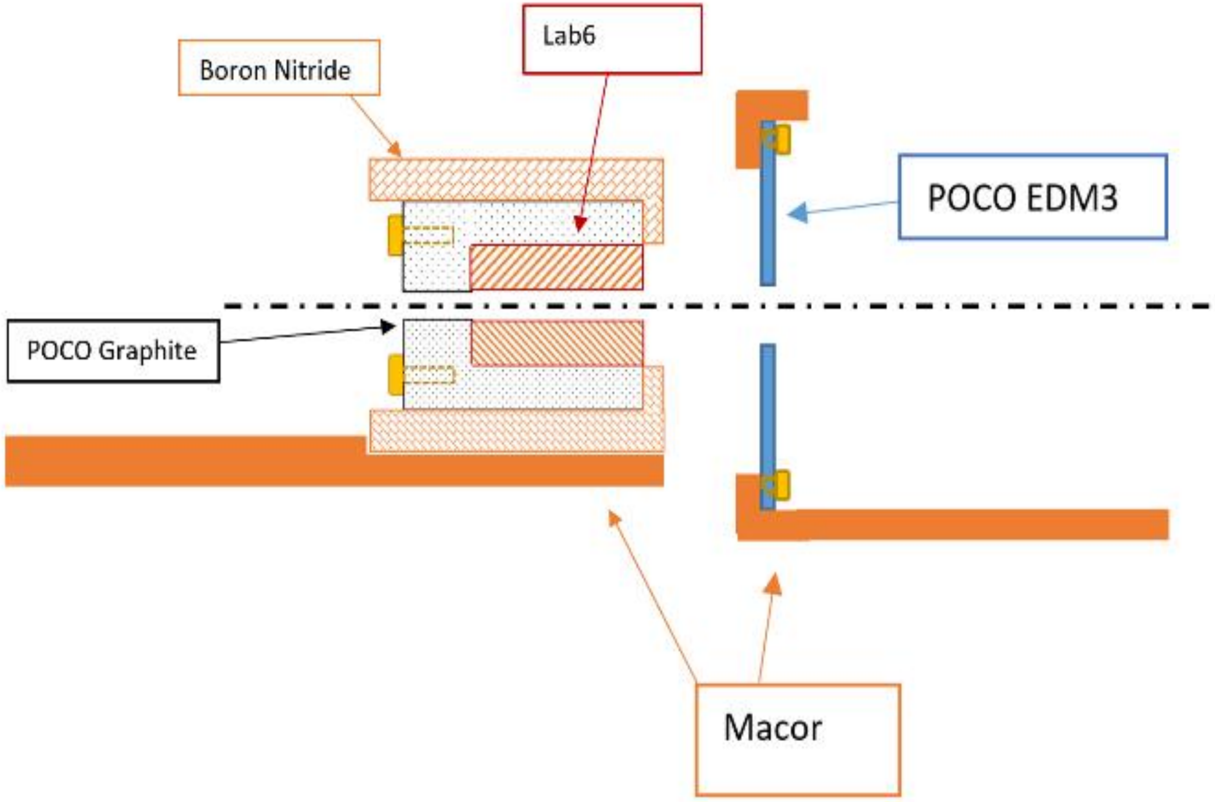
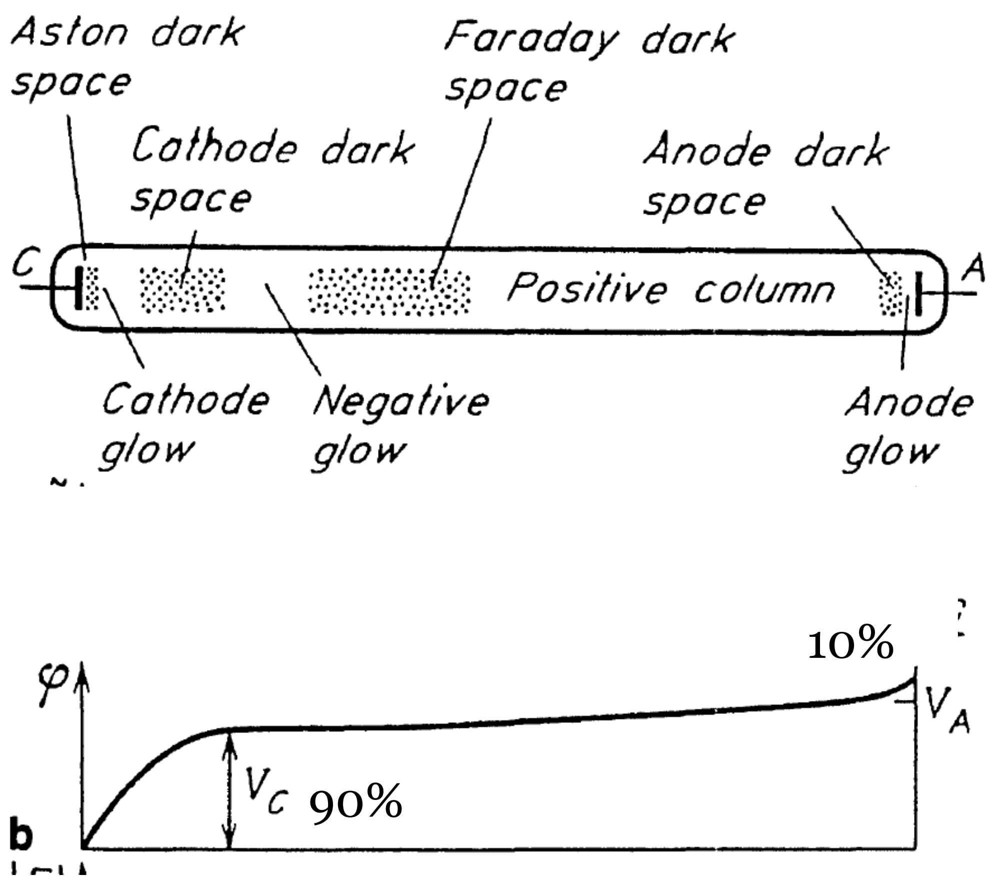


Figure 2: LaB_6 *and POCO electrode mounts*

Theoretical considerations



- The cathode fall is substantial portion of the total voltage drop [Gas discharge Physics]

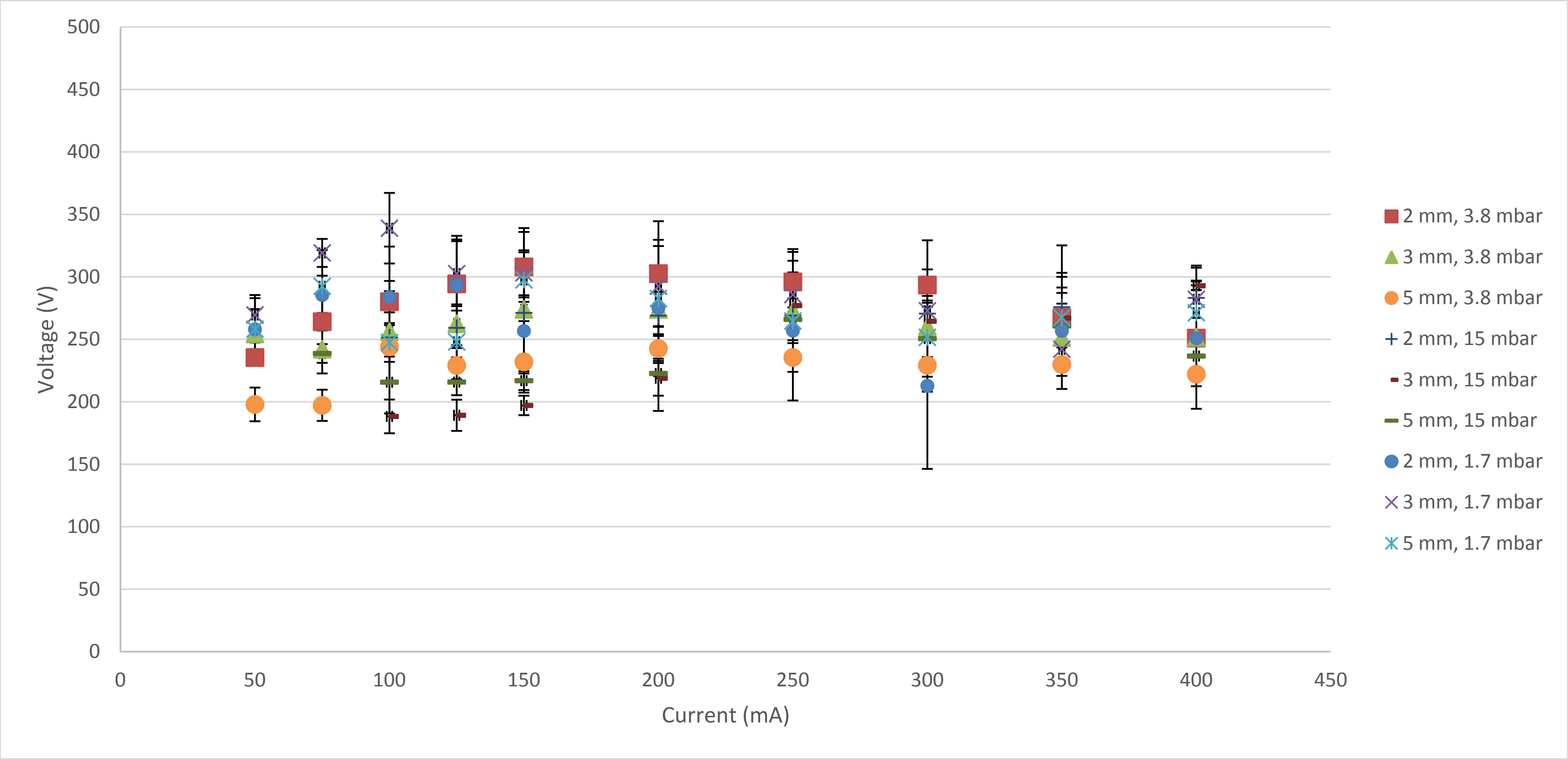
- The following equations five the relationship of the cathode fall V_C with respect to the normal cathode layer thickness pd

$$V_C = \frac{Bpd}{C + \ln pd}, \qquad C = ln \frac{A}{\ln\left(1 + \frac{1}{\gamma}\right)}$$

- For the normal glow discharge the cathode fall and cathode layer thickness are found to be close to that of the $V_{\min}$ and $(pd)_{\min}$

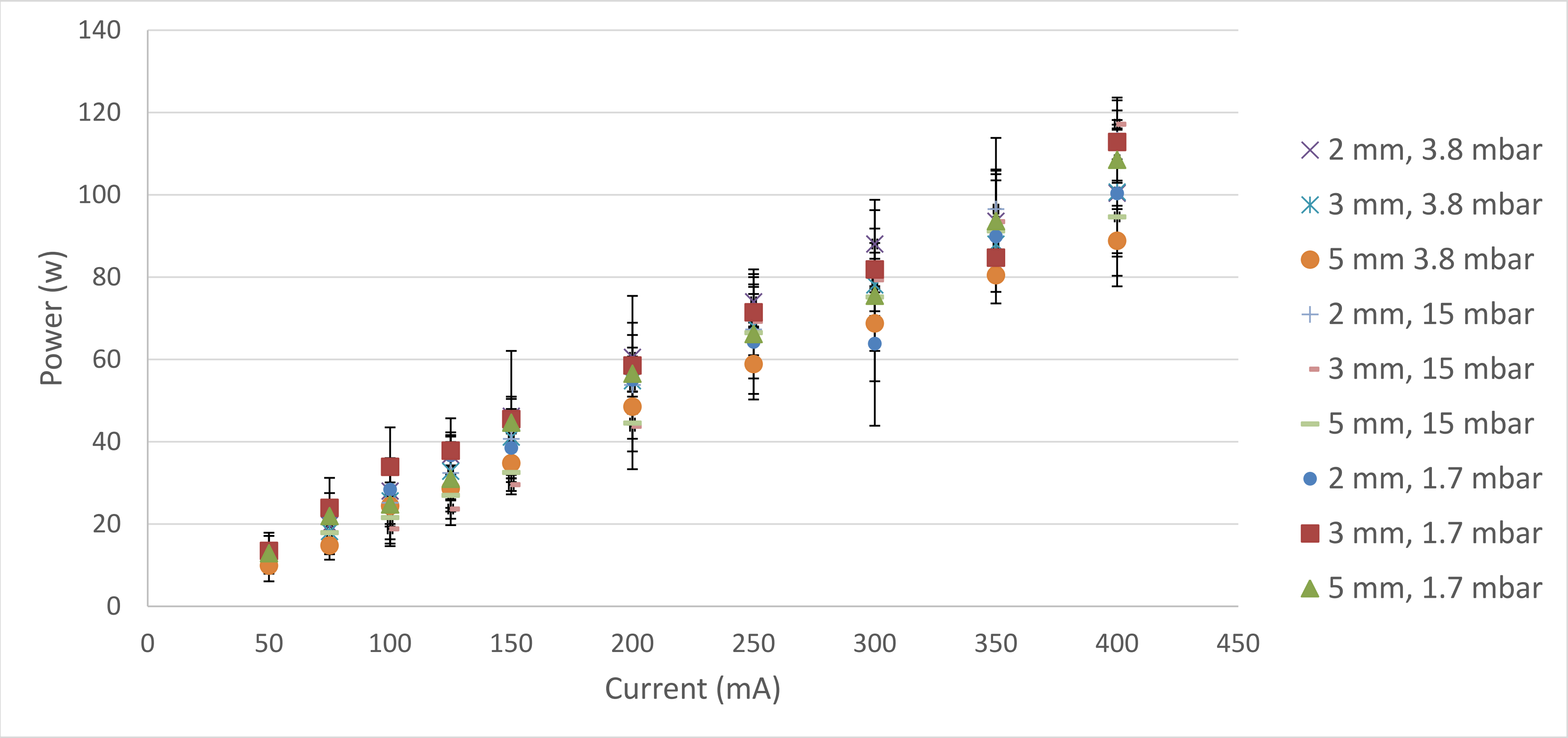
- $(pd)_{\min} = \frac{2.72}{A} \ln\left(1 + \frac{1}{\gamma}\right)$, $V_{\min} = \frac{2.72B}{A} \ln\left(1 + \frac{1}{\gamma}\right)$

Results – pressure and electrode separations



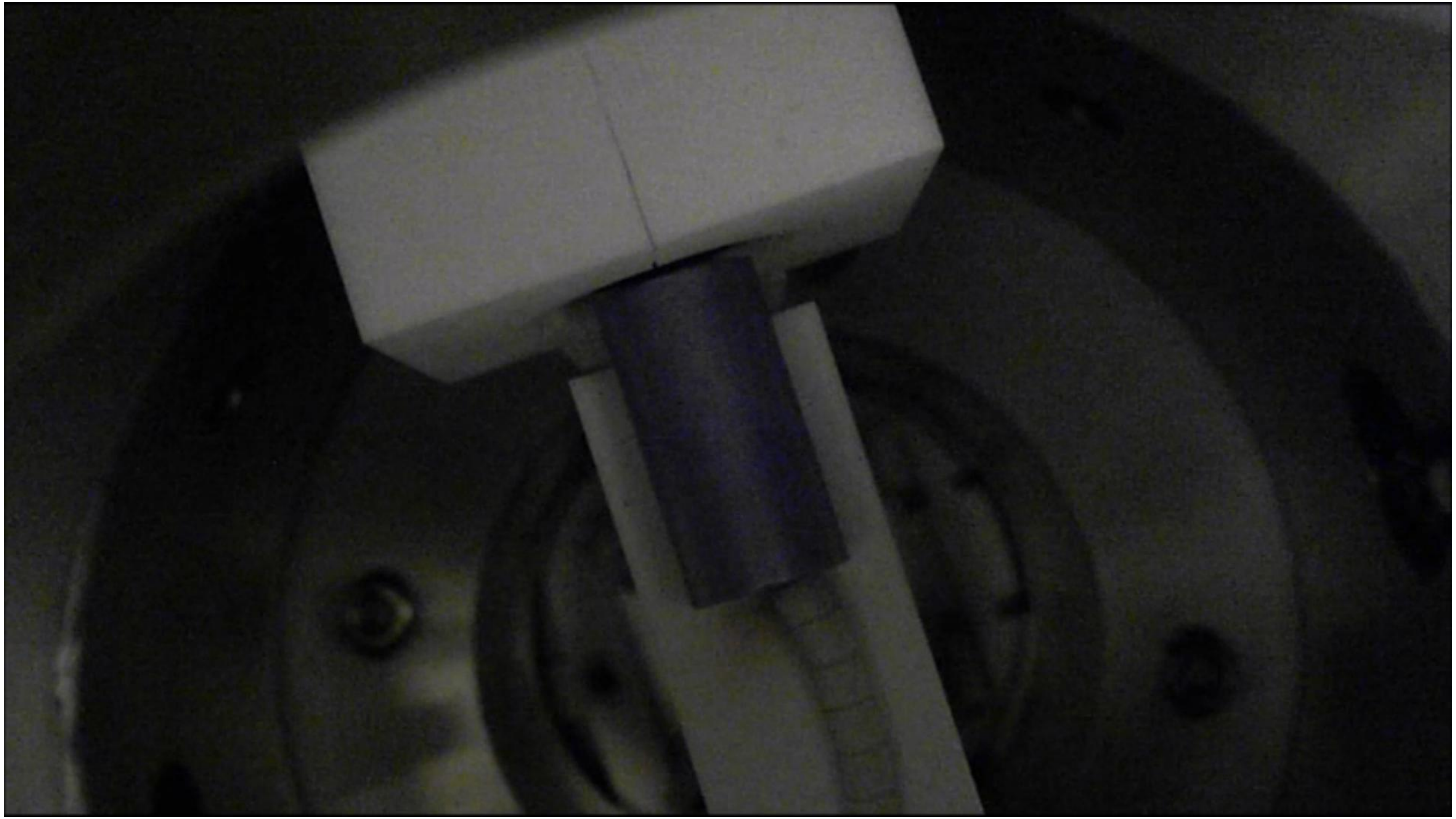
- Pressures from 1.7 – 15 mbar and 1 to 5 mm electrode separation
- Initial data is very noisy, though it shows no significate voltage change with current as would be expected in normal glow
- Pressure and electrode separations do not appear to have a significate effect on the discharge characteristics – though more testing is needed to clarify this

Results – discharge power characteristics



- Again data is very noisy, but this initial data does indicate that pressure and gap size do not have a significant the heating.

Video of operation 400 mA, 3 mm gap



Conclusions and Future work

Conclusions

- A LaB_6 hollow cathode glow discharge have been examined and initial V-I characteristics follow that of conventional glow discharge theory
- The initial results so far indicate that standard glow discharge theory is applicable to the design of HHCs and these initial results indicate that the pressure and electrode separation do not significantly alter the heating rate of the of the cathode – though more data is required to support this

Future Work

- Heating times at various power rates will be investigated for the stable transition to the thermionic discharge stage.
- Further tests will be conducted to determine the erosion levels at various operational conditions through spectrographic data and SEM post analysis.
- Heaterless hollow cathodes can undergo substantial erosion during the ignition stages from discharge localization, thus the parameters influencing this discharge localization are of high importance to investigate

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