



Emittance Studies of Novel Cathodes

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UNIVERSITY OF WISCONSIN SYSTEM

07/30/2018
Final Report

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Abstract

This project began as an investigation into novel carbon fiber cathodes and the emittance associated with surface features, with a mind toward providing experimental data to compare to recent theoretical developments. In the course of the project, we quickly realized that an entirely new type of electron microscope was required to pursue this research, which we have dubbed the FFEEM, or Focusing Field Electron Emission Microscope. This microscope is the field emission analog of photoemission and thermal emission electron microscopes already present in the literature, but with several crucial differences. In this project, we began by investigating the challenges inherent to designing an emission electron microscope around a field emission source. We proceeded to design a FFEEM using field emission models from the literature and an electron optics software. Finally, we have constructed the FFEEM in an ultra-high vacuum chamber, obtained an initial focused image of an etched tungsten fiber field emission cathode, and reproduced the experimental image in simulation.

Research Summary

The original objectives of this research grant were:

1. We would investigate the relationship between surface morphology of field emission cathodes and beam emittance. This would be accomplished in the following ways:
 - a. Emission sites would be imaged using an emission electron microscope and microchannel plate (MCP) detector.
 - b. Emittance would be measured using a pepper-pot mask and MCP detector.
 - c. Emittance sites would be correlated to surface features by comparing scanning electron micrographs to emission images.
2. We would compare our experimental results of emittance and surface structure to recently published theoretical models.

In pursuing these goals, it became clear early on that a new type of emission electron microscope was needed to pursue this project, owing to the unique nature of field emission. To the above, we added the following objective:

3. Develop, construct, and test an emission electron microscope capable of forming focused images of the emission surface of a field emission cathode.

We succeeded in completing objective 1a and the related objective three for a simple field emission fiber cathode. We assembled the tools necessary to complete objective 1b but did not have an opportunity to employ them. Similarly, we did not complete objectives 1c or 2 due to time constraints. Key accomplishments in this effort included:

- Acquiring a comprehensive understanding of emission electron microscopes, including an understanding as to why focused imaging of field emission cathodes poses such a challenge and has not been attempted before.
- Pursuing an alternate microscope design path to overcome the challenges posed by field emission focused imaging and developing the Focused Field Emission Electron Microscope, or FFEEM.
- Simulating a novel microscope design with a physically relevant field emission model.

- Constructing the FFEEM and the necessary peripheral experimental apparatus to measure the current emitted at the cathode and to move and monitor the cathode's position relative to the microscope.
- Acquiring an initial FFEEM image of an etched tungsten field emission fiber cathode and comparing the experimental result to simulation.
- Designing a pepper-pot mask for low-emittance cathodes.

A list of key personnel involved in or supported by this research grant includes:

Professors John Booske (Electrical and Computer Engineering) and Nader Behdad (Electrical and Computer Engineering).

D. Enderich (graduate student)

Archival Publications:

[1] D. Enderich, J. Booske, N. Behdad, "Surface morphology and field emitter cathode quality", 2016 29th International Vacuum Nanoelectronics Conference (IVNC), (full length conference paper), Vancouver, Canada, July 2016.

[2] D. Enderich, J. Booske, N. Behdad, "Field-emission electron microscope development and cathode emittance", 2017 30th International Vacuum Nanoelectronics Conference (IVNC), (full length conference paper), Regensburg, Germany, July 2017.

Conference Abstracts and Talks

[3] D. Enderich, J. Booske, N. Behdad, "Field-emission electron microscope development and cathode emittance", 45th IEEE International Conference on Plasma Science, Denver, USA, 2018.

In Preparation

[4] D. Enderich, J. Booske, N. Behdad, "Focusing field-emission electron microscope for cathode study".

Ph.D. Thesis

[5] D. Enderich, "A Novel Emission Electron Microscope for the Study of Field Emission Cathodes and their Emittance", Ph.D. thesis, University of Wisconsin-Madison, 2018.

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John Booske

Program Officer

The AFOSR Program Officer currently assigned to the award

Jason Marshall

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Abstract

This project began as an investigation into novel carbon fiber cathodes and the emittance associated with surface features, with a mind toward providing experimental data to compare to recent theoretical developments. In the course of the project, we quickly realized that an entirely new type of electron microscope was required to pursue this research, which we have dubbed the FFEEM, or Focusing Field Electron Emission Microscope. This microscope is the field emission analog of photoemission and thermal emission electron microscopes already present in the literature, but with several crucial differences. In this project, we began by investigating the challenges inherent to designing an emission electron microscope around a field emission source. We proceeded to design a FFEEM using field emission models from the literature and an electron optics software. Finally, we have constructed the FFEEM in an ultra-high vacuum chamber, obtained an initial focused image of an etched tungsten fiber field emission cathode, and reproduced the experimental image in simulation.

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Archival Publications (published) during reporting period:

[1] D. Enderich, J. Booske, N. Behdad, "Surface morphology and field emitter cathode quality", 2016 29th International Vacuum Nanoelectronics Conference (IVNC), (full length conference paper), Vancouver, Canada, July 2016.

[2] D. Enderich, J. Booske, N. Behdad, "Field-emission electron microscope development and cathode emittance", 2017 30th International Vacuum Nanoelectronics Conference (IVNC), (full length conference paper), Regensburg, Germany, July 2017.

New discoveries, inventions, or patent disclosures:

Do you have any discoveries, inventions, or patent disclosures to report for this period?

No

Please describe and include any notable dates

Do you plan to pursue a claim for personal or organizational intellectual property?

Changes in research objectives (if any):

Added development of novel emission electron microscope as a necessary step in pursuing the original research goals.

Change in AFOSR Program Officer, if any:

N/A

Extensions granted or milestones slipped, if any:

When we realized that existing FEEM design principles would not work for our project, we re-strategized and came to the determination that our basic microscope approach was going to be a new research effort in its own right. The time it took to develop, construct, and test the new FFEEM was more ambitious than originally anticipated and as a result, we did not measure the emittance of any cathodes.

AFOSR LRIR Number**LRIR Title****Reporting Period****Laboratory Task Manager****Program Officer****Research Objectives****Technical Summary****Funding Summary by Cost Category (by FY, \$K)**

	Starting FY	FY+1	FY+2
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