AFRL-AFOSR-VA-TR-2018-0355

Emittance Studies of Novel Cathodes

John Booske
UNIVERSITY OF WISCONSIN SYSTEM

07/30/2018
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB1
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
29-07-2018	Final Technical Performance Report	May 1, 2015 to April 30, 2018

4. TITLE AND SUBTITLE
Emittance Studies of Novel Cathodes

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-15-1-0206

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Enderich, Daniel A.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Wisconsin-Madison
Research and Sponsored Programs
21 N. Park St STE 6401
Madison WI 53715-1218; (608) 262-3822

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
875 N. Randolph Ste.325
Arlington, VA 22203
Jason Marshall 703-696-7721
AFOSR/RTB1

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This project began as an investigation into novel carbon fiber cathodes and their emittance, 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 developed and dubbed the FFEEM, or Focused 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.

15. SUBJECT TERMS
Field emission cathodes, beam emittance, electron optics, field emission electron microscope

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Professor John H. Booske
			UU		**19b. TELEPHONE NUMBER** *(Include area code)* 608-890-0804

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18
Adobe Professional 7.0

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

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.

AFOSR Deliverables Submission Survey

Response ID:10137 Data

1.

Report Type

Final Report

Primary Contact Email

Contact email if there is a problem with the report.

daniel.enderich@gmail.com

Primary Contact Phone Number

Contact phone number if there is a problem with the report

608-575-1030

Organization / Institution name

University of Wisconsin-Madison

Grant/Contract Title

The full title of the funded effort.

Emittance Studies of Novel Cathodes

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-15-1-0206

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

John Booske

Program Officer

The AFOSR Program Officer currently assigned to the award

Jason Marshall

Reporting Period Start Date

05/01/2015

Reporting Period End Date

04/30/2018

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.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF The maximum file size for an SF298 is 50MB.

SF298.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.

Final_Report.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

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 that originally anticipate 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
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Jul 30, 2018 14:27:48 Success: Email Sent to: daniel.enderich@gmail.com