DIODE STUDIES FOR HPM APPLICATIONS AT AFRL

NRL Cathode Workshop – 10 MAY 01

Ryan Umstattd

Don Shiffler, John Luginsland, Michael Haworth

Air Force Research Laboratory
Directed Energy Directorate
High Power Microwave Division
Kirtland AFB, NM

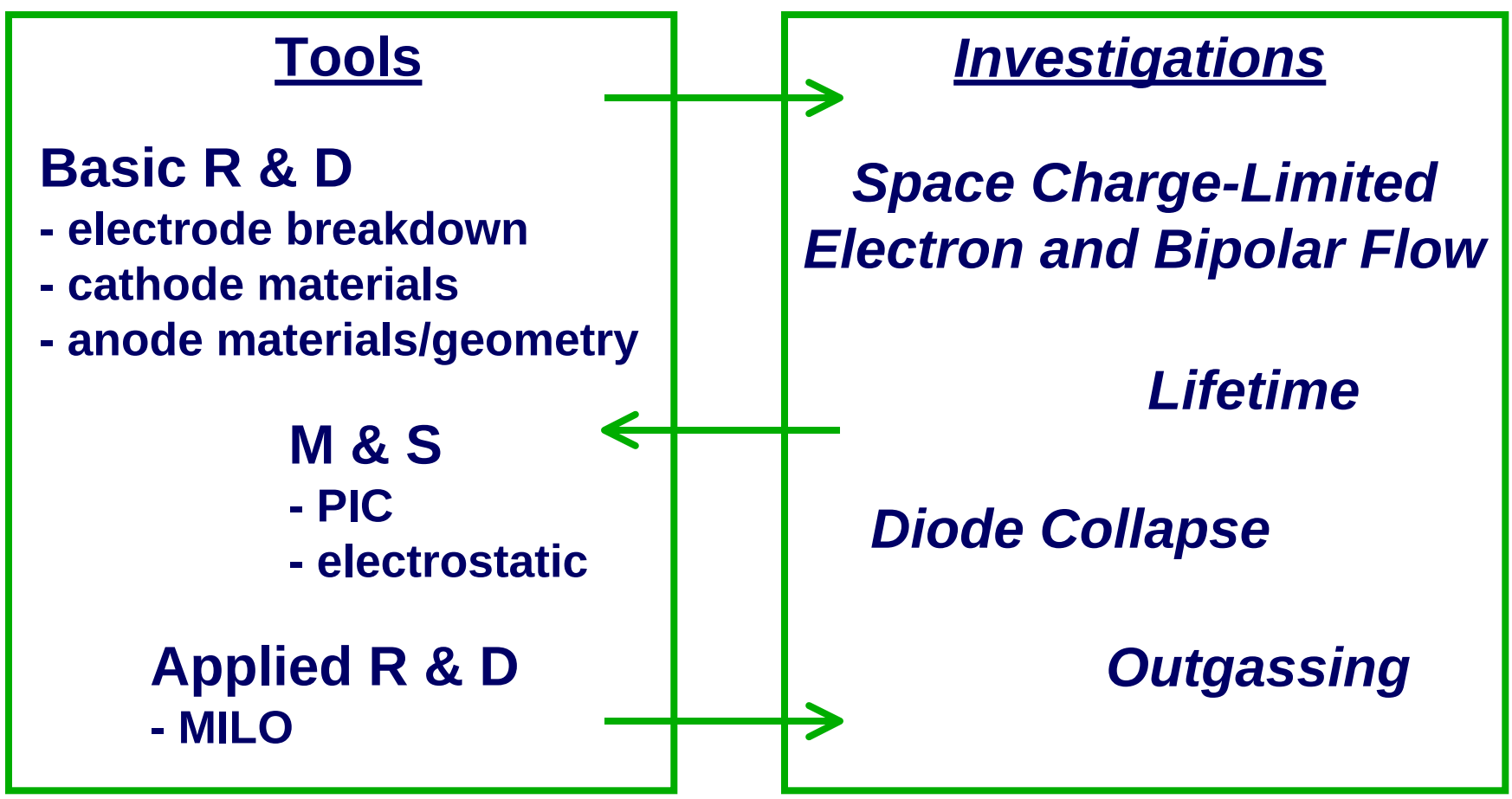
Outline

- Why AFRL studies diode physics…
- Our available resources
- Some cathode considerations / materials
- Effects seen in both simulation and experiment
  - Bipolar flow
  - 2-D current density enhancements
- Future plans

Motivation for Diode Research

- **Goal: increase the RF energy available by increasing...**
  - **Output power**
  - **Pulse duration**
  - **Repetition rate**
- **Modus Operandi: control the emission**
  - **Must consider all species (electrons, ions, and neutrals)**
  - **Desirable vs. undesirable emission**

Experiments & Concerns

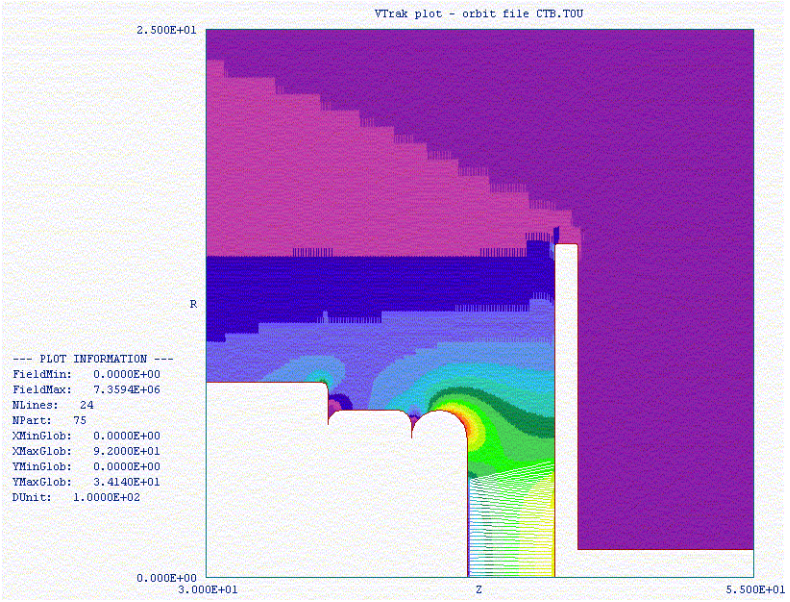


Basic R & D Test Beds

- **Rep-rate Test Pulser (RTP)**
  - **500 kV, 100 Ω, 2 Hz, 1 μs pulse**
  - **Vacuum range from 3.5 x 10^{-8} to 1 x 10^{-4} Torr**
  - **Upgrades to 10+ Hz**
- **GRUMP**
  - **350 kV, 5 Ω, 15 Hz, 50 ns pulse**
  - **Vacuum range from 1 x 10^{-7} to 1 x 10^{-4} Torr**
  - **Upgrades to 30 Hz**
- **Threshold Cathode Test Facility (TCTF)**
  - **200 kV, var. impedance, var. duration, ≤ 1 Hz**
  - **Vacuum range from 4 x 10^{-9} to 1 x 10^{-5} Torr**

Why Velvet?

- An explosive emission standard for ~ 15 years (R. Adler et al., RSI, 1985)
  - Emits at relatively low field strengths (~ 10 kV/cm)
    - Fast turn-on
  - Insulating nature of fibers provides built-in ballast



  - Wide range of vacuum compatibility
    - Base pressures from 10^{-3} to 10^{-8} Torr
  - Inexpensive, COTS, widely available
  - It works!

Why Not Velvet?

- Outgassing limits functionality
  - Increased pressure inside HPM device leads to breakdown thereby terminating RF output
- Lifetime strongly dependent on cathode loading
  - Single shot up to ~ 10^4 shots
  - Possibly correlated with silicon content as determined by collaboration with AFRL/ML
- Variability in performance due to lack of control over manufacturing
  - Proprietary formulae
  - Not reproducible from one fabric roll to the next

Cathode Study Findings

Material	*Emission Threshold*	*Lifetime (# of shots)*	*Outgassing (# of neutrals per electron)*
CsI-Carbon Microfibers	**< 3 kV/cm**	**> 72,000**	**4 – 6.5 (substrate)**
"Sandia Red" Velvet	8 kV/cm	~ 8,000	10
"MILO Green" Velvet	10 kV/cm	~ 4,000	10 - 14
Velveteen	Low	< 600	> 12
F-Velvet	Low	< 100	> 12
Ceramic Cloth	> 120 kV/cm	---	---
Ceramic Felt	> 100 kV/cm	---	---
Carbon Pyramids	> 80 kV/cm	---	---
Carbon Nanotubes	20-50 kV/cm	Arc rate of ~ 2%	~ 4
Bare Carbon Microfiber	15-40 kV/cm (packing density)	> 36,000	4.3 – 6.5 (substrate)
CsI-Carbon Fiber Tufts	< 3 kV/cm	> 200,000	~ 4
Metal / Ceramic	95 kV/cm (diode collapse unless > 150 kV/cm)	---	8

Data courtesy of D. A. Shiffler

Why CsI-Coated Carbon Fibers?*

- High atomic mass
  - Slows plasma expansion relative to hydrogen
- Good UV/X-ray photocathode
  - Improved flashover at turn-on
- Long-lived
  - No deterioration seen under any tested pulse conditions (as long as cathode is not coated with anode blow-back)

*H. Kosai and A. Fisher, RSI, 1990

New MILO Cathode Material

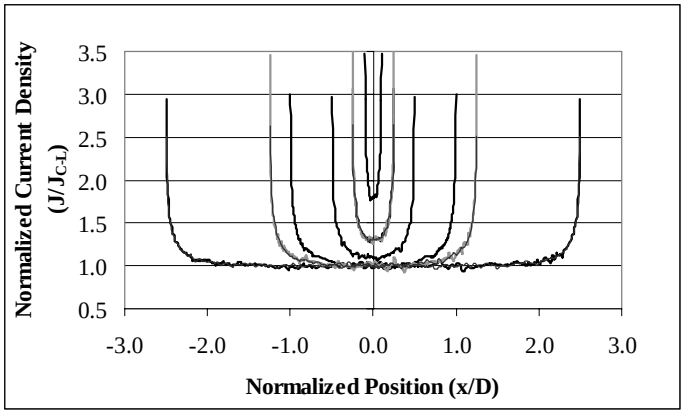
- New carbon fiber-based cathode developed for MILO based upon recent carbon fiber cathode RTP results
- Testing both uncoated and CsI-coated versions:
  - CsI helps lower emission threshold
  - Carbon fibers outgas less than velvet

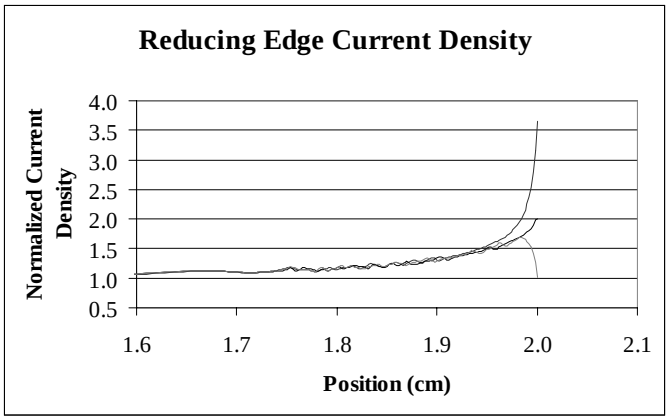
Controlling Bipolar Flow

- Experimental current ~ twice that of both electrostatic and PIC electron current simulations (1.6 kA vs. 780 A)
  - Seen on both 1 μsec and 50 nsec experiments
  - Use of mesh anode reduced current to space charge-limited electron current
  - Solid anode can be conditioned to space charge-limited flow in 32 min at 2 Hz (1μs pulse duration)
  - Bipolar flow returns after 20 min pause under vacuum and hot (redeposit due to vacuum or diffusion?)
- Identical current results for both 80% transparent brass and 90% transparent stainless steel meshes
- Heating a solid anode produces the same effect as having a mesh screen
- Directly related to performance of MILO (power, impedance, frequency content, x-ray signals)

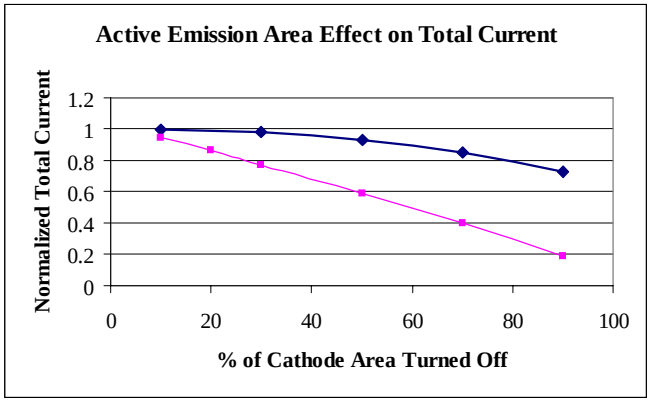
2-D Space Charge-Limited Emission

- **Significant current density enhancement is seen at the edges of a planar cathode**





- **Can be controlled by adjustments to the vacuum electric field**



- **Relevant to description of cathode "death" mechanism**

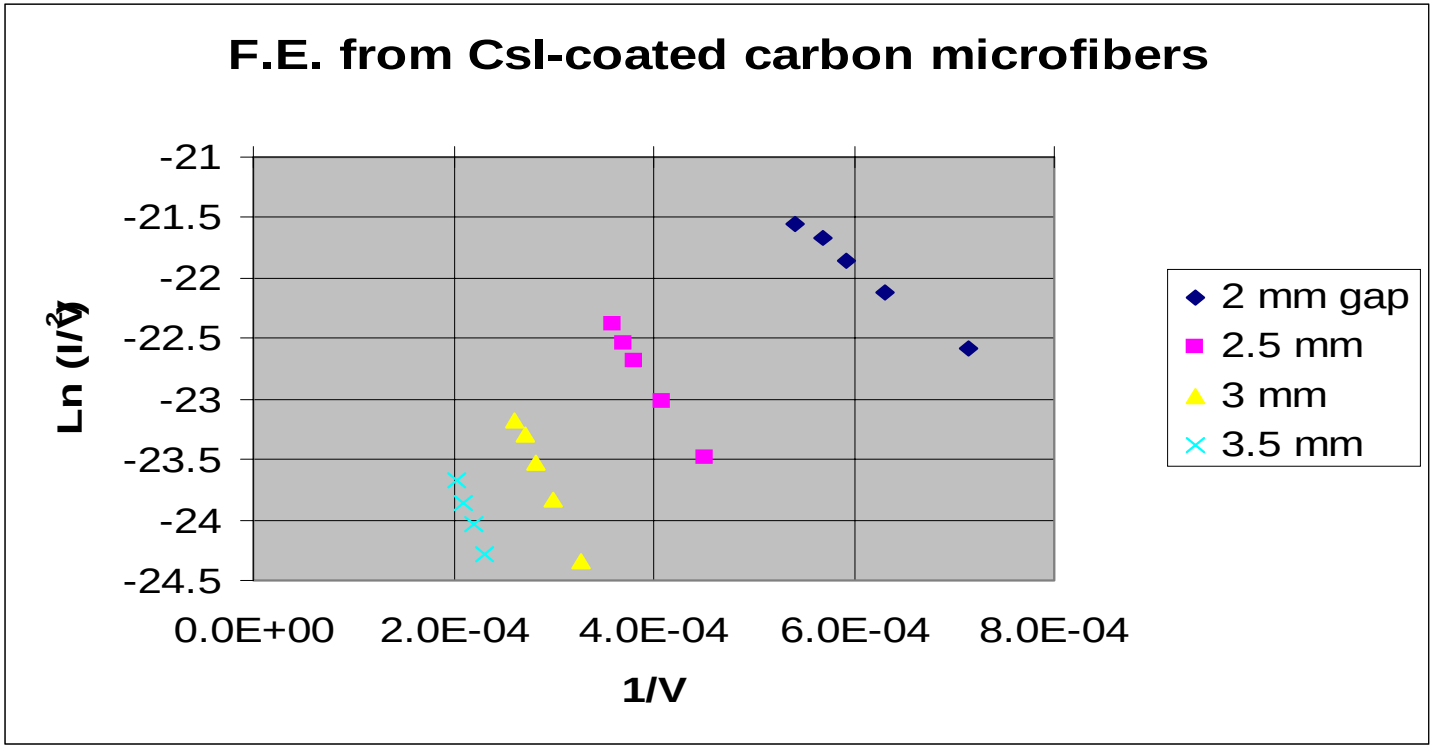
Summary

- **Still looking for “holy grail” cathode while developing relevant physical models that will improve predictive capability and extrapolation to other regimes…**

Related Publications

- R. J. Umstattd and J. W. Luginsland, "Two-Dimensional Space Charge-Limited Emission: Beam Edge Characteristics and Applications," submitted to *PRL*, March 2001.
- D. A. Shiffler, et al., "Comparison of Velvet and Cesium Iodide Coated Carbon Fiber Cathodes," to be published in *IEEE Trans. Plasma Sci.*, June 2001.
- M. D. Haworth, et al., "Evidence of a New Pulse-Shortening Mechanism in a Load-Limited MILO," *IEEE Trans. Plasma Sci.*, v.28, pp. 511-516, June 2000.
- D. A. Shiffler, et al., "Comparison of Carbon Fiber and Cesium Iodide Coated Carbon Fiber Cathodes," *IEEE Trans. Plasma Sci.*, v.28, pp. 517-522, June 2000.
- R. J. Umstattd, et al., "Design and Implementation of a New UHV Threshold Cathode Test Facility," *Proc. SPIE Intense Microwave Pulses VII*, v.4031, pp.185-194, April 2000.

Non-explosive Emission



- **Initial DC field emission results from a 3 cm dia. cathode disk of CsI-coated carbon microfibers**
  - **Maximum stable current ~ 1.6 mA**
  - **Background pressure ~ mid 10^{-8} Torr**