Carbon Velvet Cathodes

NRL Workshop on Cathodes for Relativistic Electron Beams

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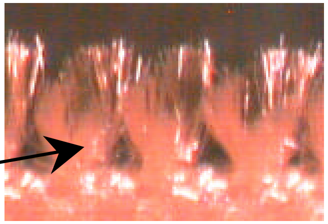
Contents

- Heritage
- Design Considerations
- Cathode Types Fabricated
  - NRL, PLK
- Materials Options
- Benefits

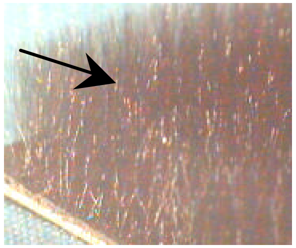
Velvet Cathode Heritage

- Explosive emission cathodes for HPM, HEL
  - Conditions: 0.1-1 MV, ~kA/cm2, ~0.1 μs, <1 Hz
  - Requirements: high current, fast turn on, uniformity, long pulse duration, long cycle life, (large, conformal, lightweight)



- Heritage
  - 1980's: carbon felts, carbon fibers, cloth velvets

    Prohaskar&Fisher, Eden&Epp, Erickson&Mace, Adler&Voss, …
    - Achieved uniform fast current … but duration, lifetime, consistency of velvet, were lacking
  - 1990's: carbon tufts, photoemitting salts, carbon velvets
    - Garate et al., Benford, Bekefi&ESLI
    - Achieving better duration, uniformity, cycle life



Design Consideration

- Provide field enhancement
  - Two enhancement effects
    - Velvet field concentration

      $$ß_{velvet} = 1/f$$

    - Fiber field enhancement

      $$ß_{fiber} = 2L / D$$

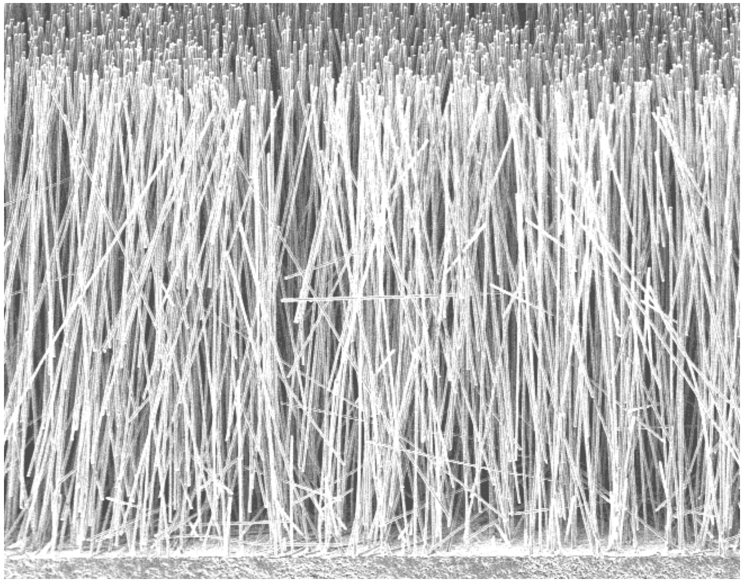
Examples	units		
field strength required	V/m	**1.00E+09**	**1.00E+10**
voltage	V	5.00E+05	5.00E+05
gap	m	2.00E-02	2.00E-02
gap field strength	V/m	2.50E+07	2.50E+07
enhancement required	-	**40**	**400**
maximum fiber packging	-	**2.50%**	**0.25%**
minimum fiber aspect ratio	-	20	200
fiber diameter	m	7.00E-06	7.00E-06
minimum fiber length	m	**1.40E-04**	**1.40E-03**

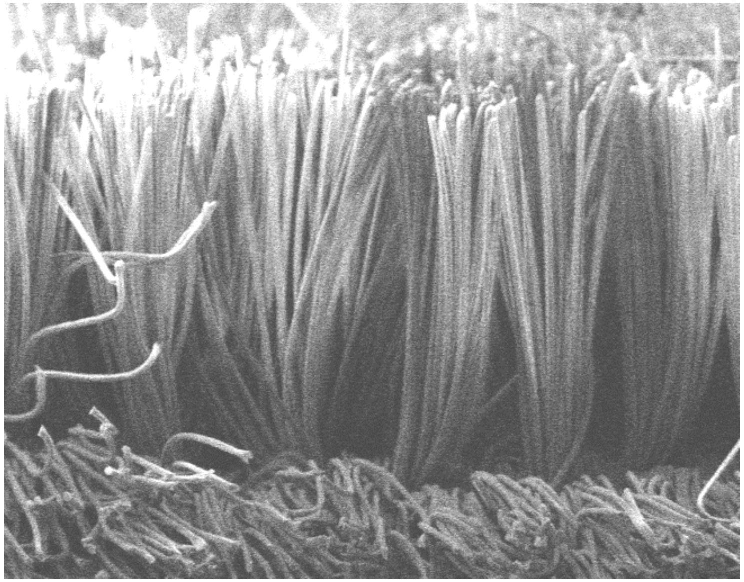
β	field enhancement factor
ϕ	fiber packing fraction
L	fiber length
D	fiber diameter

- Balanced design requires
  - Velvet not too dense
  - Fibers not too short
- But … really relevant to explosive emission?

Compare Velvet Structures

- ESLI Carbon-Carbon
  - 7-mu dia @ 2.0%
- NRL Green Polymer
  - 18-mu dia. @ 4.4%



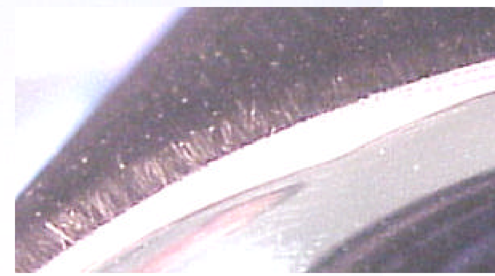


Carbon Velvet Cathodes (1999)

- Flexible fabric configuration with vinyl substrate
  - Substrate options: epoxy; metal?
- Discrete PAN Carbon Fiber, Ag-epoxy, on Al substrate
  - Investigated fiber packing densities 0.1 - 2.0 %
  - 2.5e5 shots @ 330 kV, 3.3 kA, 1 μs (D. Shiffler, 2Feb01)

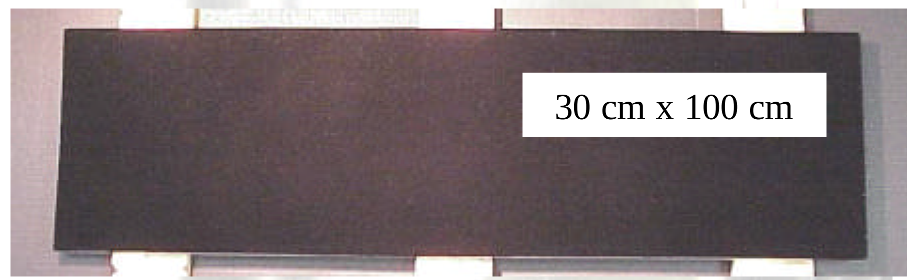
MILO Cathodes (2000)

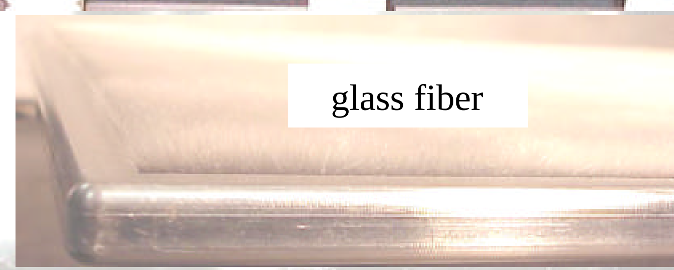
- ESLI Carbon Fiber/Epoxy/Aluminum
  - 1.5-mm velvet at 0.4%(vol); 1 kA/cm^2 @500 kV



ELECTRA Cathodes (2000)

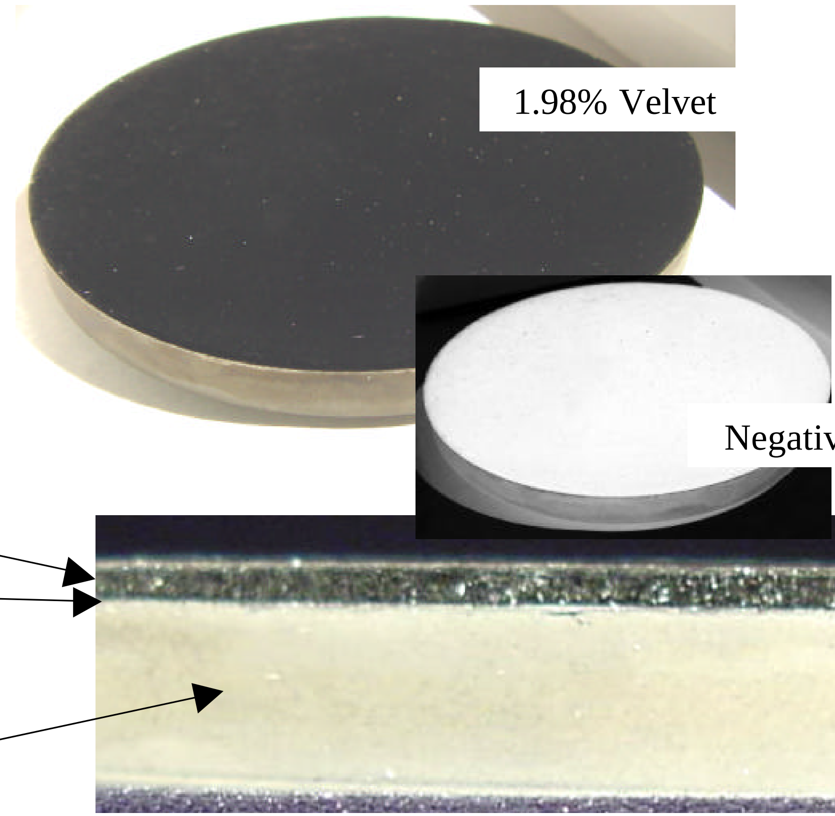
- Carbon Fiber/Epoxy/Aluminum
  - 1.5-mm high-k PAN @2.0% and @1.6%
  - Best uniformity of all cathodes
  - Good turn-on time
  - Limited lift testing OK
  - Minimal debris





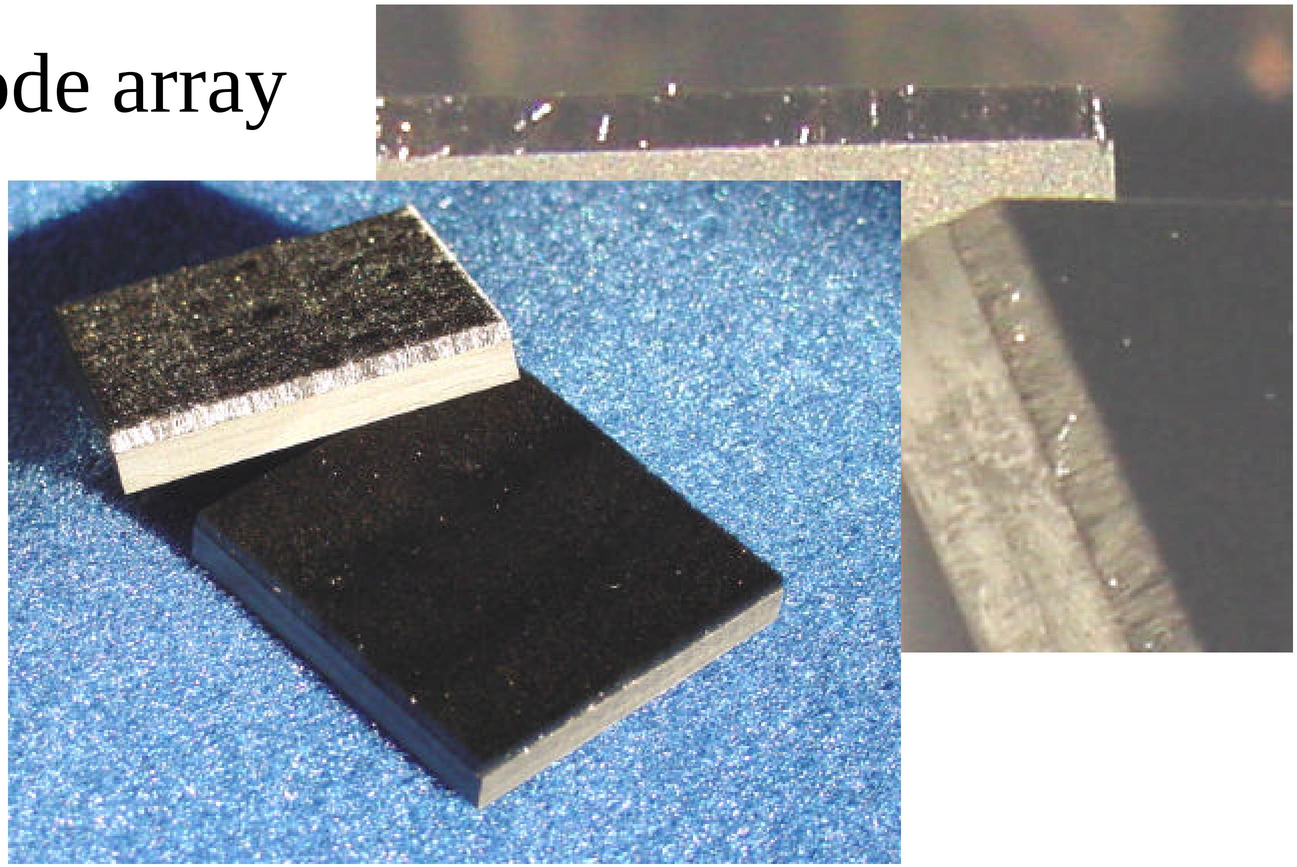
CC Cathodes for PLK (2001)

- High-T processing
  - No outgassing
  - Non-melting
- Carbon-carbon
  - Carbon fiber
  - Carbon adhesive
    - Pyrolyzed, CVD
  - Carbon substrate
    - Pyrocarbon coating



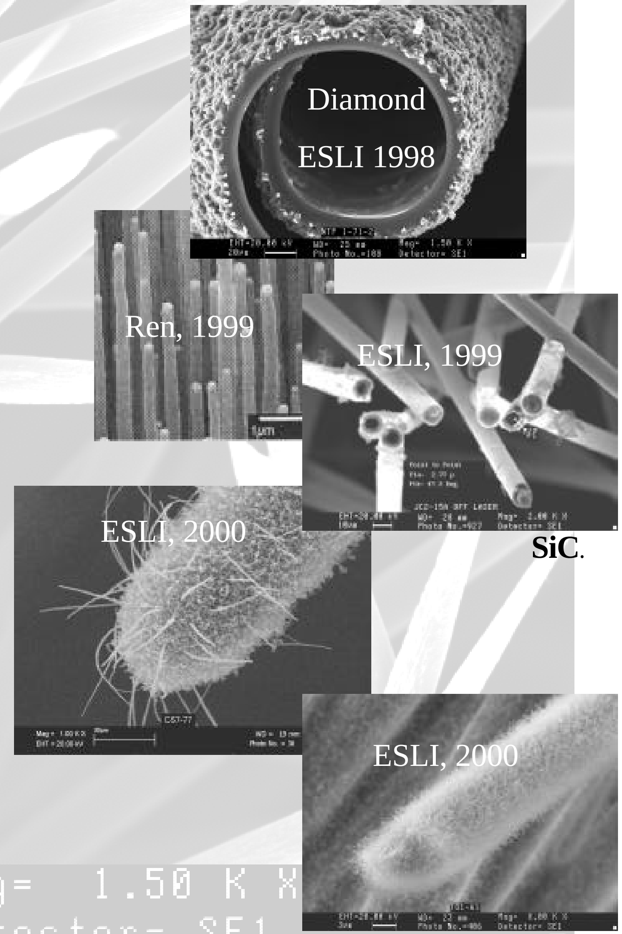
CC Cathodes for NRL (2001)

9-cathode array



ESLI Processing Options

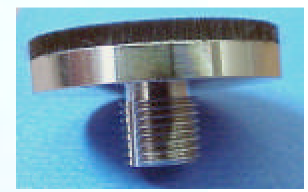
- Materials
  - Bondline (epoxy, C, braze)
  - Substrate (metal, carbon, ceramic)
  - Fiber type (C, glass, SiC, metal, polymer…)
  - Surface treatments (CVD, salts, activation)
- Texture
  - Fiber length, packing density
  - Tip shape
  - Uniformity of array (random, ordered)
  - Uniformity of surface (flat, bimodal)
  - Diverse scales (fiber, whisker, nanotube)



Cathode Study - 2001

- Joint effort to better understand explosive emission
  - ESLI prepares cathode configuration
    - Different fiber types, substrates, bondlines, coatings
  - PLK (Ryan Umstattd) measures performance
    - Validate V-I characteristics, closure, uniformity, life
    - Identify & quantify outgassing constituents
- Overall objectives
  - Better understanding of explosive emission
    - Role of ambient gas, cathode vaporization/redeposition
    - Microscopic model?
  - Higher performance electrodes
    - Higher repetition rate, higher average power

POCO Graphite



304 S Steel

Benefits of Carbon

- Clean, conductive, refractory material
  - Cathodes survive 2500^{o}C in vacuum or inert gas
  - Can be coated or infiltrated (eg. molten salts)
- Wide range of configurations
  - Materials and textures (uniformity, order?)
- Can fabricate large-area contoured shapes
  - ESLI fiber handling techniques
  - High-T processing, CVD