Carbon Velvet

Dry Chamber Wall

Timothy R. Knowles
Energy Science Laboratories,Inc.

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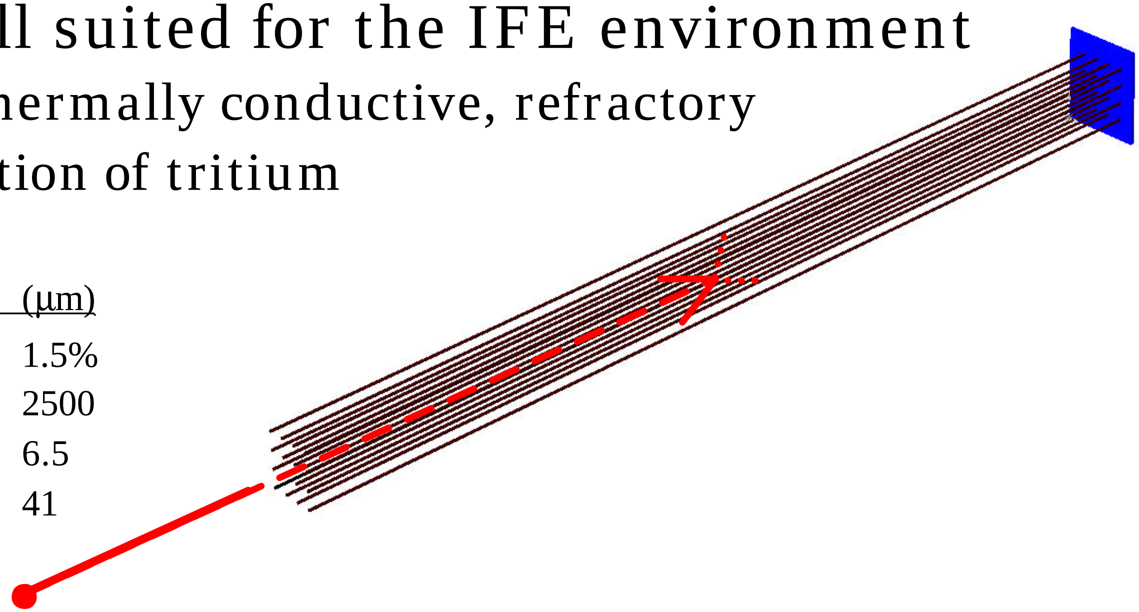
Contents

Carbon Velvet Chamber Concept

- Define “velvet” as array of well-oriented, straight, high aspect ratio fibers at modest packing density (<10 vol%)
  - Normally incident beams then penetrate deeply over a large effective surface area at greatly reduced incident flux
  - Sputtered material is trapped and potentially recycled
  - Sharpened fiber tips can be electrostatically shielded
- Carbon fibers are well suited for the IFE environment
  - Clean, strong, stiff, thermally conductive, refractory
  - Potentially low retention of tritium

Typical Carbon Fiber Velvet	(μm)
Fiber packing fraction	1.5%
Fiber length	2500
Fiber diameter	6.5
Fiber separation	41



Velvet Chamber Wall Design

Configure carbon velvet so that…

- Effective surface area is increased ~50x
- Ion beam penetration depth ~½ velvet height
- Ions impinge on fiber shafts at near-grazing incidence
- Effective thermal conductance is adequate
- Fiber tips are sharpened to reduce tip erosion

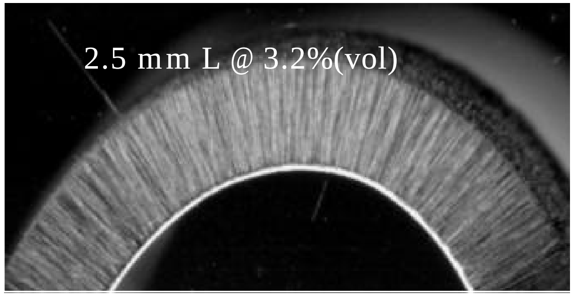
Suitable carbon velvet is: 6-μm *x* 4-mm, 5% packing fraction, fiber k=200 W/m-K, fiber tilt = 0.1 rad; then…

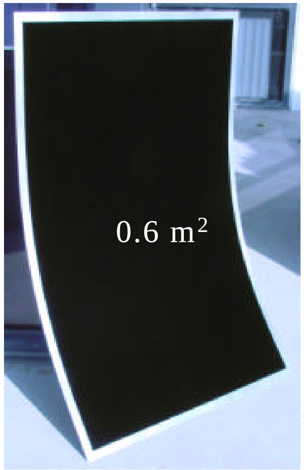
- DelT = 200 K, for 1 MW/m2 average thermal flux
- Surface area enhancement = 133
- Beam penetration length = 2 mm

Carbon Velvet Examples

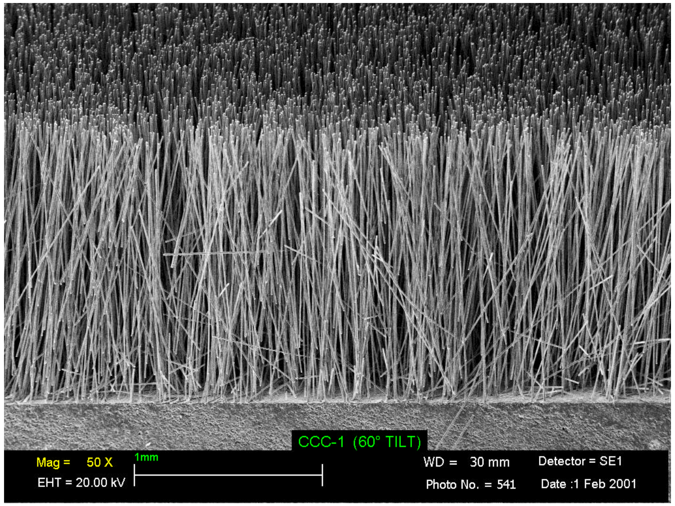
ESLI carbon velvets

Packing fractions	0.1 - 10%
Fiber diameter	5 - 10 mm
Fiber length	0.1 - 5 mm

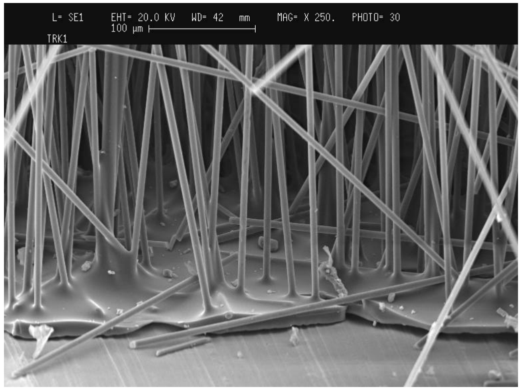




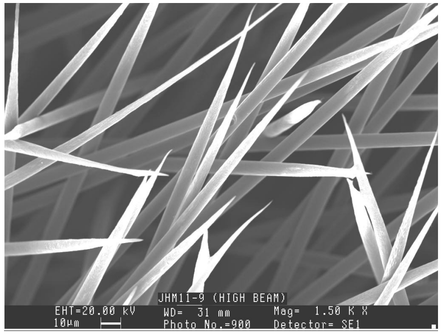
Carbon-Fiber/Epoxy/
Aluminum



Carbon-Carbon



Bondline



Sharpened Tips

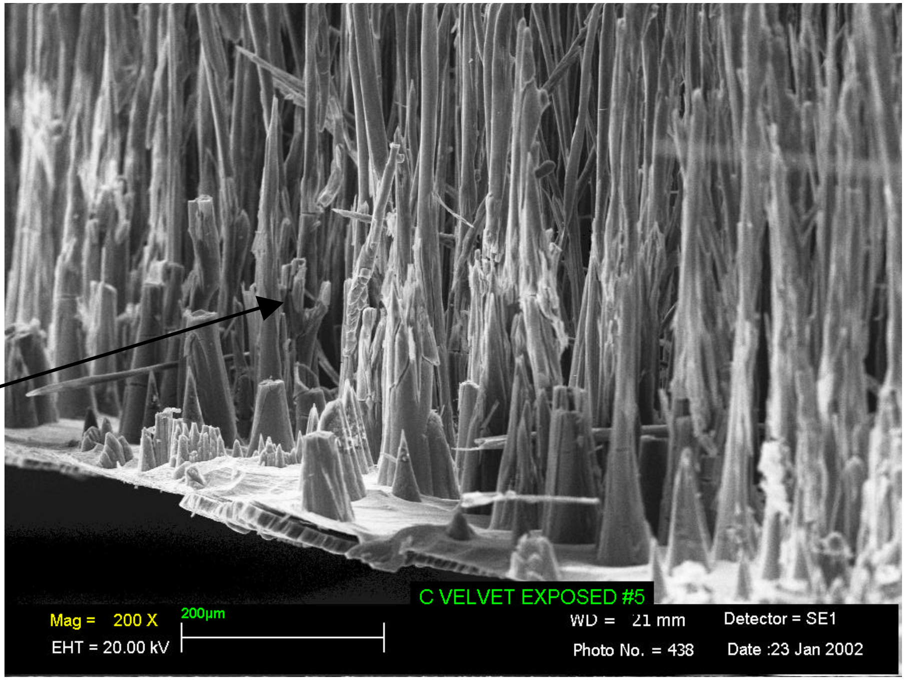
High Fluence Sputter Exposure*

Exposure to ungridded Ion Source (Hall-Effect Thruster)

- 400 V Xe+ ions at 65 μA/cm2 for 200 hours (10^{-6} torr chamber pressure)
- 5×10^{-9} higher particle fluence than one RHEPP pulse (3-m range)

Velvet loses 10x less mass than Poco graphite that receded 25 μm

- Clear evidence of carbon redeposited at base of velvet



* *Exposure of ESLI velvet by D. King, General Dynamics, Dec 2001*

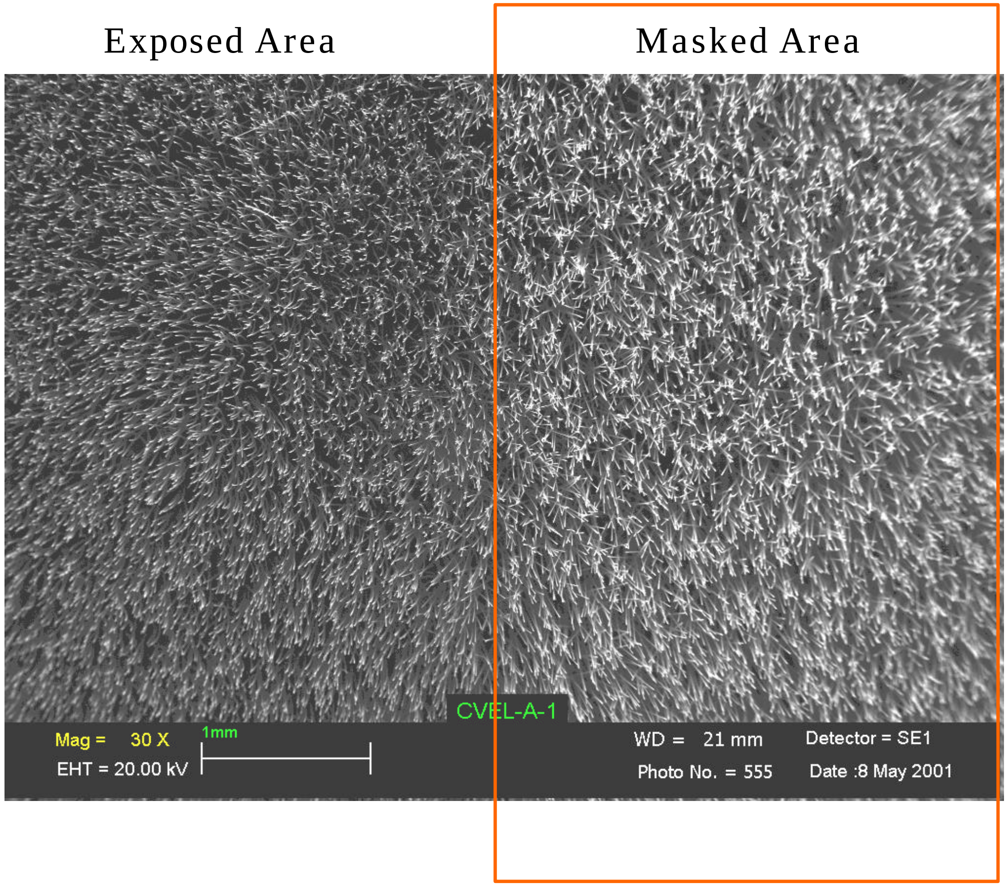
Results of RHEPP Exposure

(SNL, T. Renk, April ‘01)

Carbon Velvet in RHEPP

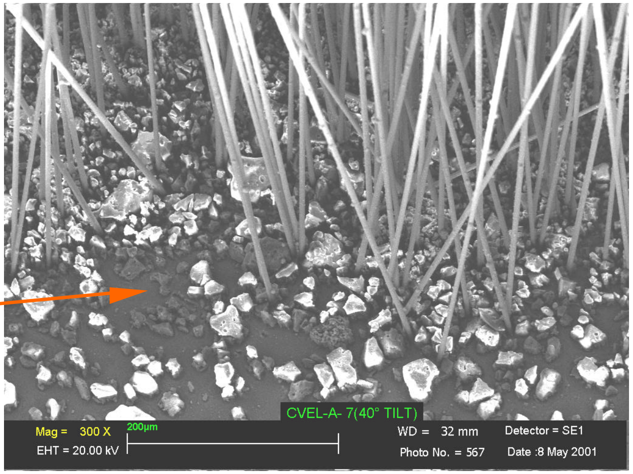
RHEPP Test

- Horizontal fibers (6-μm diameter) eroded completely
- Vertical fiber shafts show no erosion
- Qualitatively lower mass erosion than POCO graphite

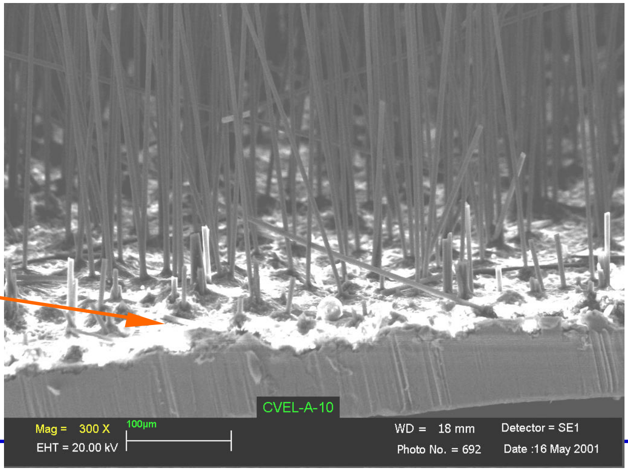


Velvet Protects the Substrate

At the boundary of the velvet, the exposed substrate is heavily eroded (epoxy totally etched, alumina grains exposed, aluminum partly etched)

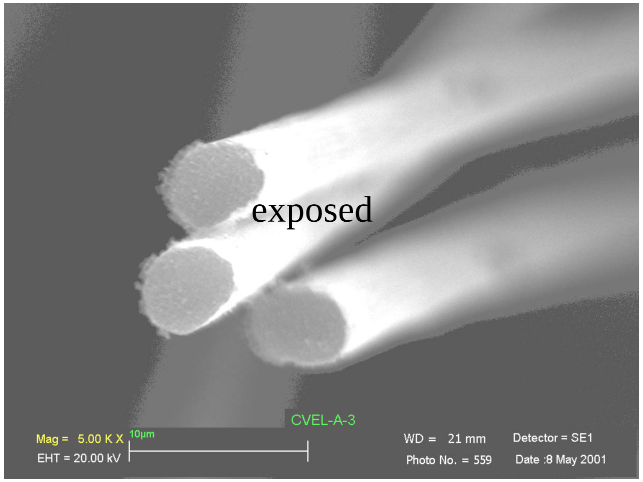


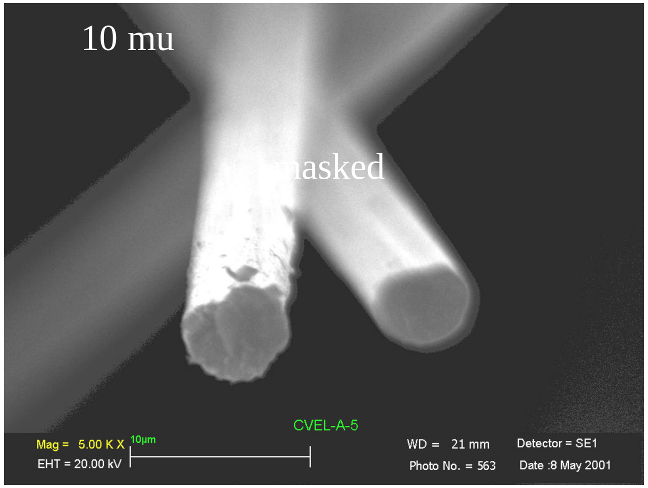
Under the velvet pile, the substrate shows little erosion (epoxy coating over aluminum survives)



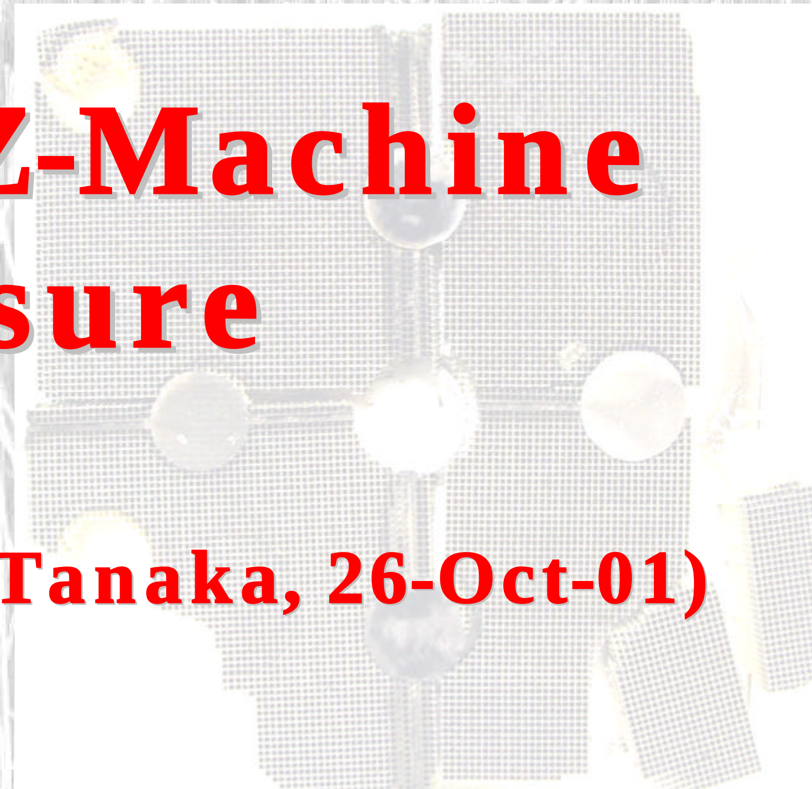
Carbon Fiber Erosion

- Horizontal fibers completely eroded
- Some fiber tip damage evident
  - No chipping; no rounding
  - Blunt tip recession could be many microns, but no length change diagnostic applied in this test
- Fiber shaft damage appears slight
  - No apparent thermal ablation, even though horizontal fibers and the exposed substrate erode strongly
  - No evidence of sputter redeposition, but it is difficult to resolve thin carbon redeposition on carbon!





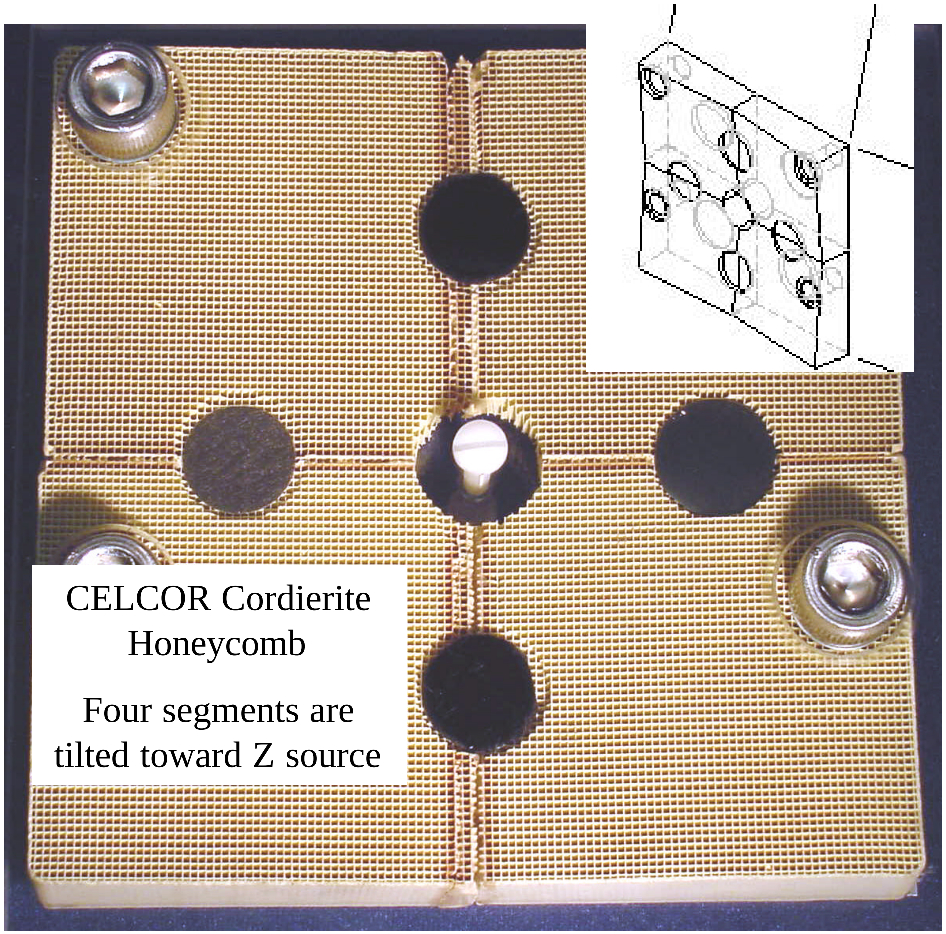
Results of Z-Machine Exposure



Z Shot #817 (SNL, T. Tanaka, 26-Oct-01)

Collimator Plate Before Z-Shot

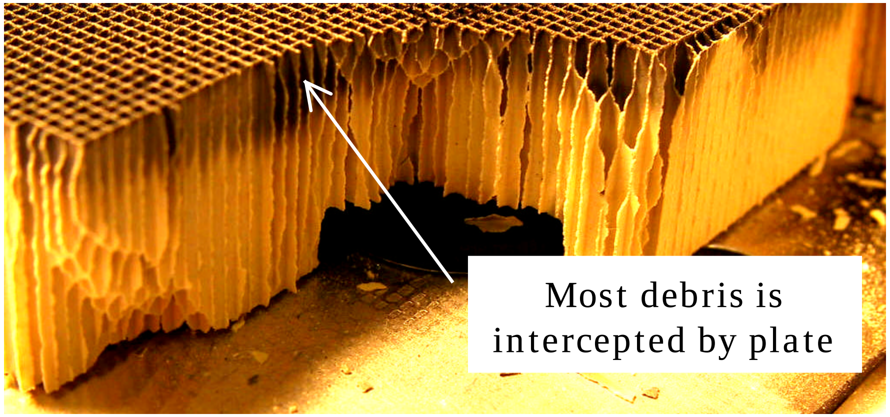
- ESLI collimator plate fabricated to permit eight test specimens to be mounted in front of MPRS* target holder
  - Four in front (uncollimated)
  - Four in back (collimated)
- Rear specimens sample a range of intensities from ~300 cells, each with 0.6 mm^2 area
  - Velvets have hundreds of fibers per 0.6-mm^2 cell

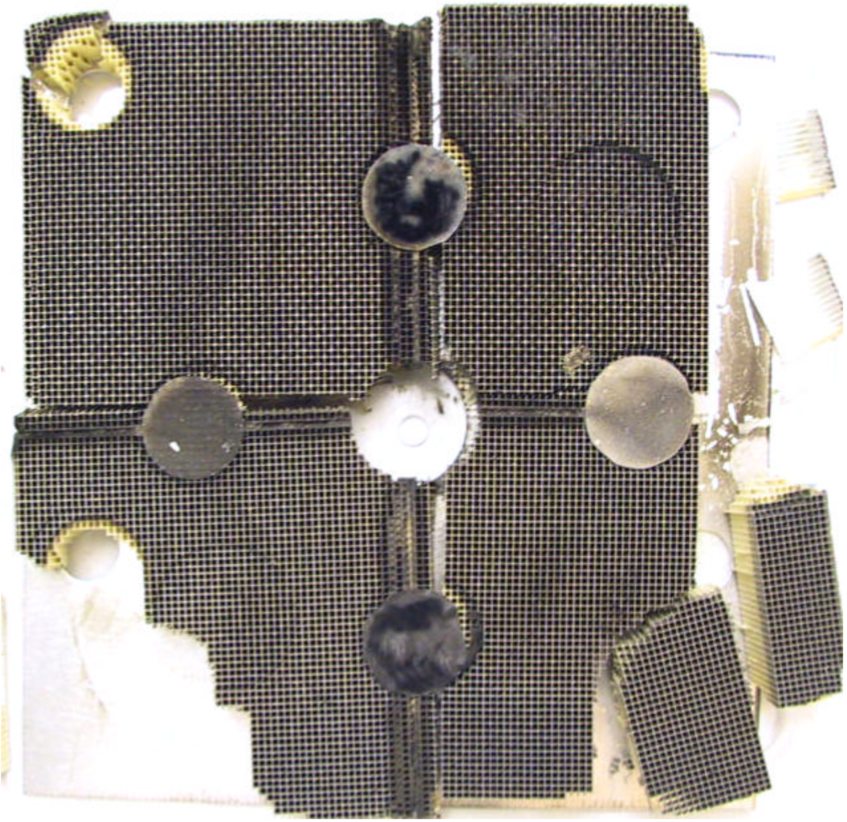


** MPRS = Multi-Purpose Radiation Shield*

Collimator Plate After Z-Shot

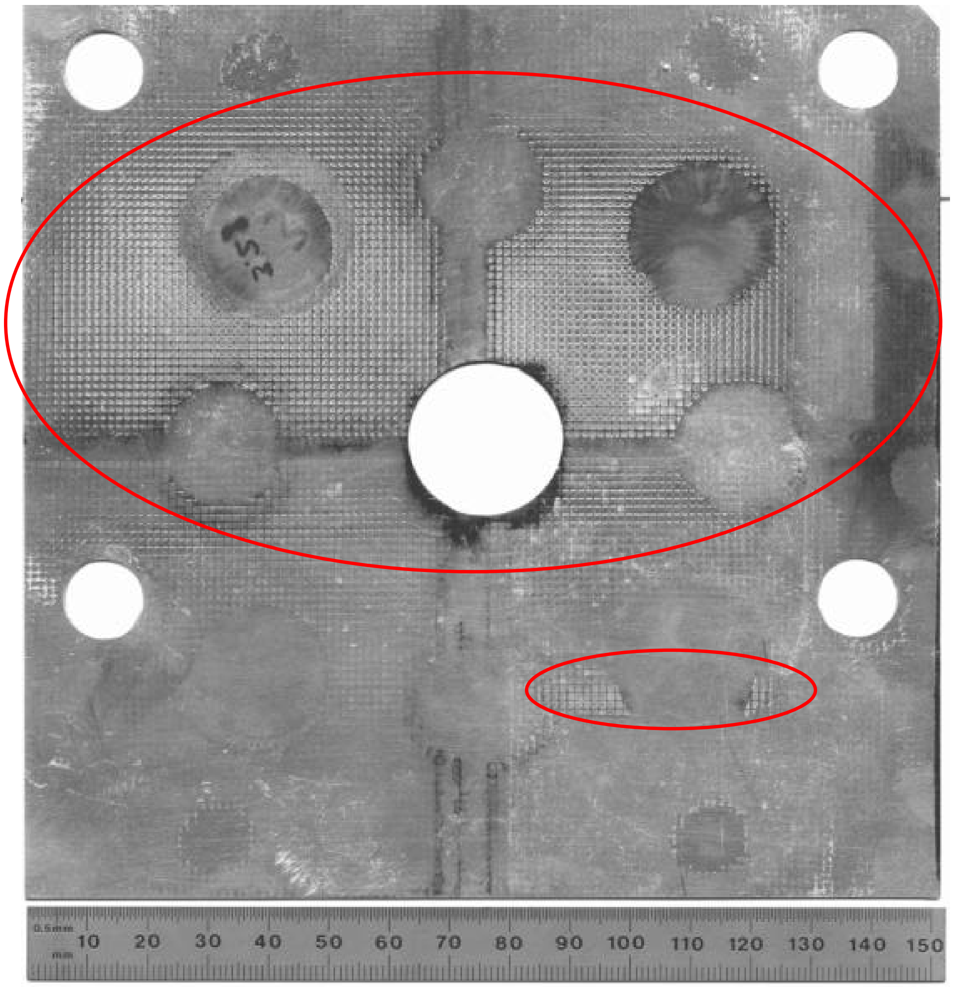
- Collimator plate served well at filtering debris and enabling simultaneous test of multiple specimens
- Front specimens were heavily damaged by debris; back specimens were not





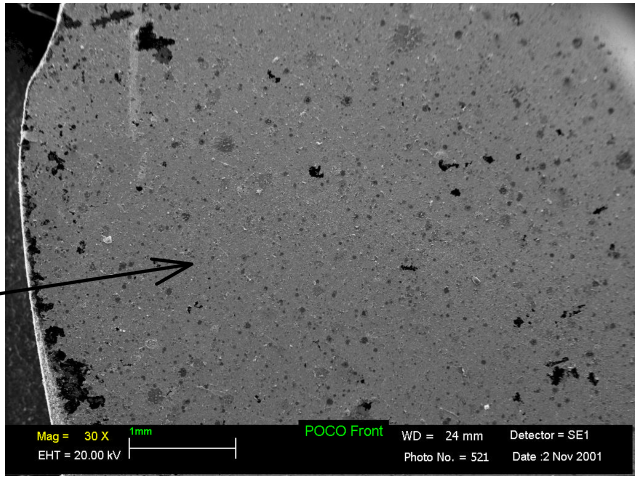
High X-Ray Fluence Regions

- Erosion of a backing plate provides witness for the X-ray fluence pattern
- Revealed here that only the upper portion of the sample holder received high fluence
  - It was later confirmed that the MPRS sample holder was partially blocked by other components in the Z Machine

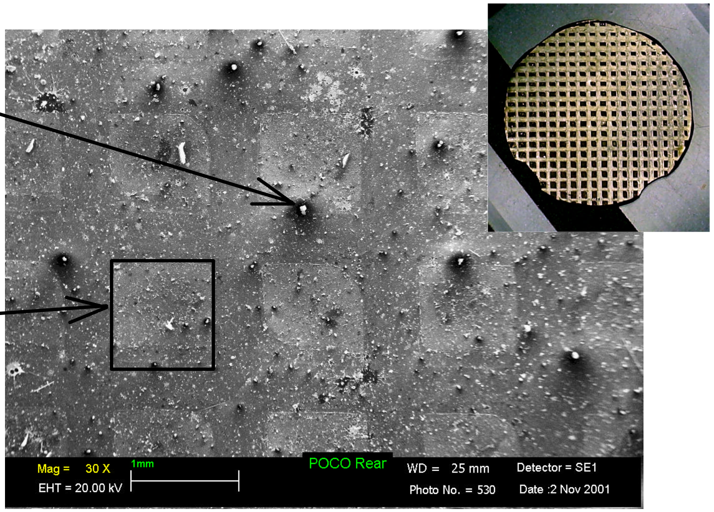


Carbon Mirror Specimens

- ESLI carbon mirrors consist of pyrocoated polished graphite
- The exposed front mirror specimen is covered with metallic debris from Z



- The rear mirror specimen is only lightly sprinkled with particulate debris, both metallic and ceramic
- The X-ray erosion patterns are clearly resolved

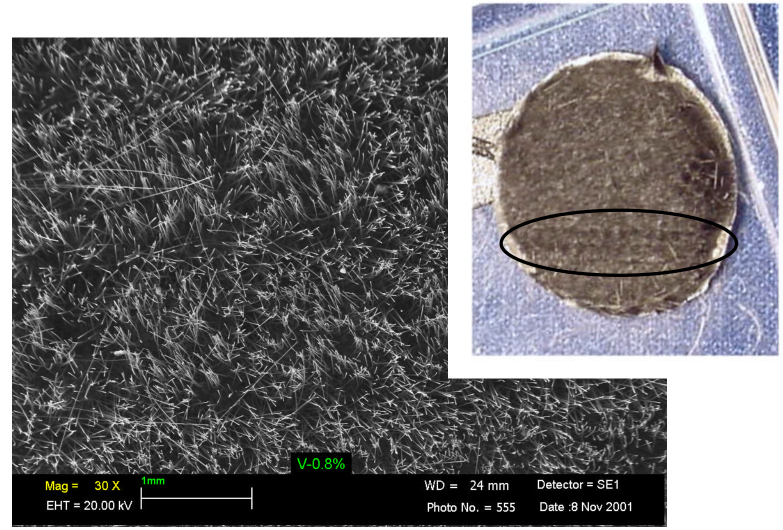


Low Density Velvet (0.8%)

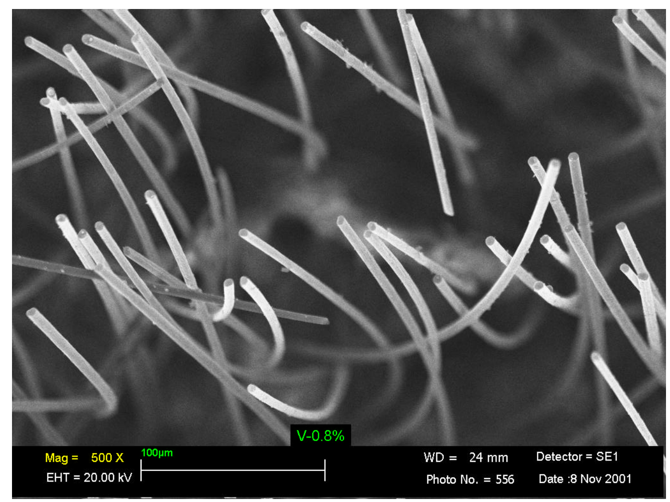
Rear specimen with little particulate debris

Exposed cells are blacker

As if non-vertical fibers have been vaporized ?

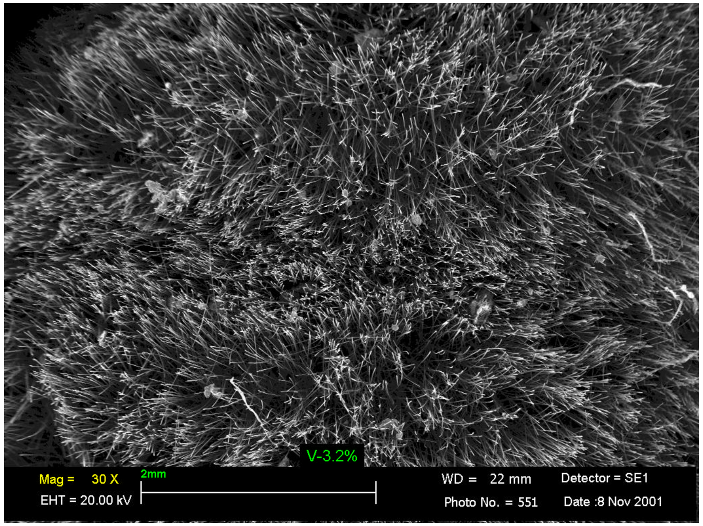


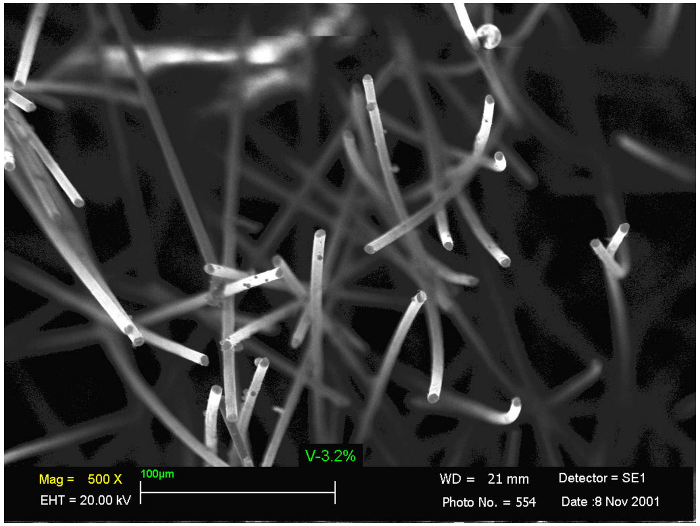
Fibers exposed to X-ray pulse appear curved



High Density Velvet (3.2%)

- Rear specimen with little particulate debris
- This denser velvet appears more “disheveled”
  - Possibly horizontal fibers have been “propelled” into the velvet, parting it
- Fibers exposed to X-ray pulse appear curved





FY01 Conclusions

FY02 Plans

Conclusions

- Initial (FY01) exposure of carbon velvets on RHEPP show expected behavior
  - Vertical fibers survive with little fiber shaft erosion
  - Horizontal and leaning fibers erode completely
  - No evidence of roughening of the fiber shafts or the substrate below the velvet
- Initial (FY01) exposure on Z
  - Compact ceramic collimator provides large-area high X-ray fluence (unfiltered) with minimal debris
  - Velvets specimens disheveled as if horizontal fibers were propelled into the velvet by pulsed ablation
    - But such high fluence (unfiltered) exposure is not relevant to direct drive IFE

FY02 Test Plan

- RHEPP testing aiming at quantitative data on carbon fiber tip recession and shaft erosion
- Test specimens planned for FY02 include:
  1. Polished carbon velvet having all fiber tips in the same plane, to help resolve few-micron erosion
     - Measure tip recession in SEM for ~50-shot RHEPP exposure
     - Control specimens: carbon mirror, carbon fabric, metal
  2. Metallized carbon velvet (eg. Au plasma coating)
     - Use high-contrast SEM to identify where RHEPP beam erodes the thin metallic film
     - Compare data with beam penetration modeling