UT-BATTELLE

SNS ASAC Review 2009

SNS Foil Development Program

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SNS SPALLATION NEUTRON SOURCE

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

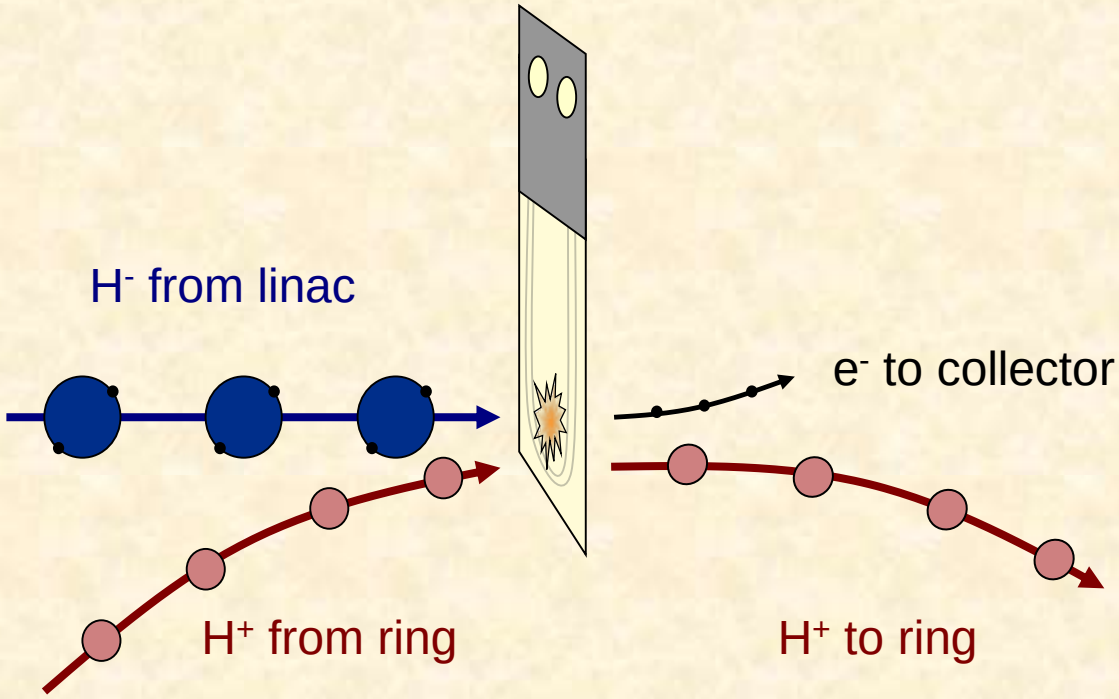
Outline

- Foil requirements for the SNS.
- Corrugated, nanocrystalline diamond foils.
- Alpha ranging for foil thickness determination.
- Diamond foil performance at SNS and PSR.
- 30 keV electron beam foil test stand.
- New directions.

Corrugated, Nanocrystalline Diamond Foils

- Prepared by plasma-assisted Chemical Vapor Deposition (CVD) on pre-patterned silicon wafers.
- A portion of the silicon is removed by chemical etching to create a foil-on-a-handle.
- 4 μm carbon fibers are not required for mounting (corrugations instead).
- Foils are in use at SNS and PSR.

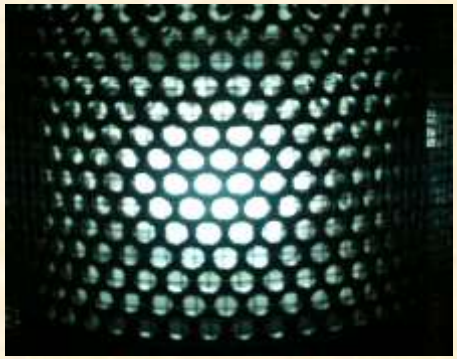
SNS Foil Requirements



- Withstand peak temperatures up to 2500 K ???
- Stripping efficiency of 97% (of intercepted beam)
- Foil set of 11 foils must last 90 day cycle --> 200 hr each
- 20 mm x 12 mm (25 x 17) freestanding foil, single edge support
- Uniform thickness of 280 μg/cm^2 (~0.8 μm for diamond)

Diamond Film Growth

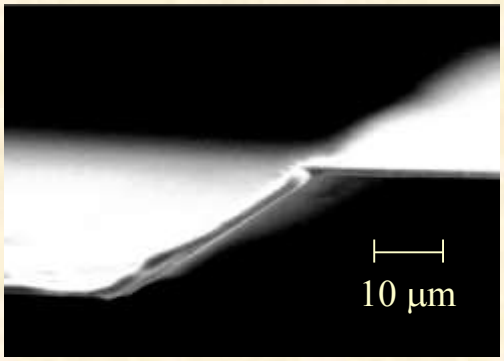
- **Nucleation density is critical due to 1 μm foil thickness ⇒ Nano-seeding**
- **Microwave plasma CVD**
  - **Microcrystalline films:**
    - **2% CH_4, 98%H_2; 50 torr**
    - **~110 minutes @ 1300 W; Ts = 750 °C**
  - **Nanocrystalline films:**
    - **90% Ar, 1-2% CH_4, 8-9% H_2; 130 torr**
    - **~55-90 minutes @ 1000 W; Ts = 650 °C**

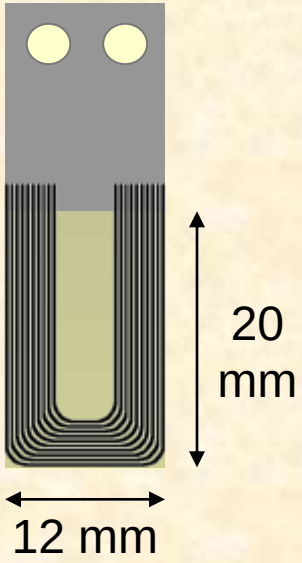


Microwave CVD growth chamber (left) and the plasma ball during 98% H_2 1300 W microcrystalline (center)and 90% Ar, 9% H_2 1000 W nanocrystalline growth (right).

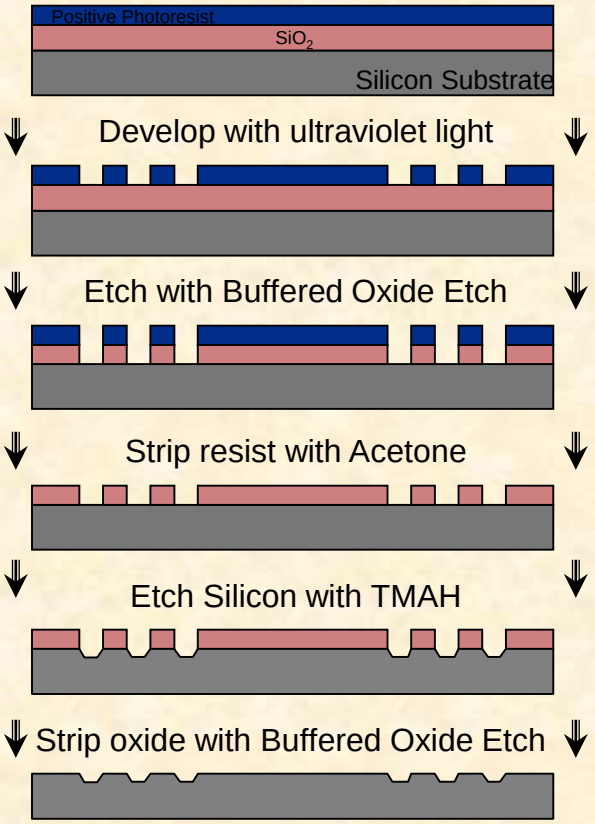
Corrugated Diamond Foils for Flatness

- Thermal expansion mismatch diamond vs silicon
- Foils scroll upon release from Si wafer
- Foil corrugation method developed

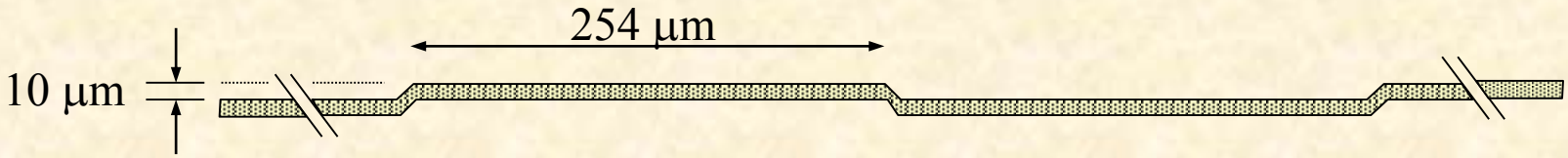




Patterning Process

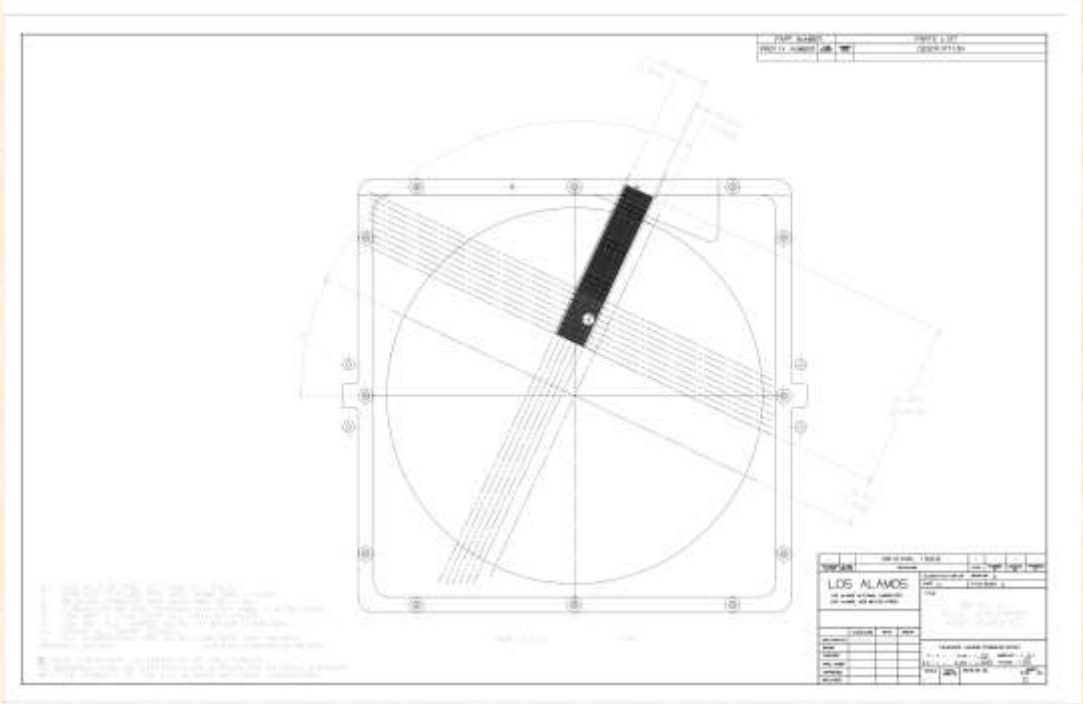


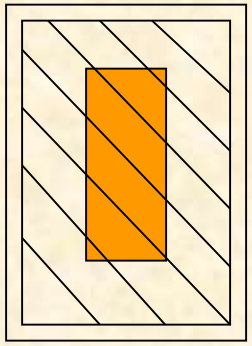
50 Line/inch Foil:



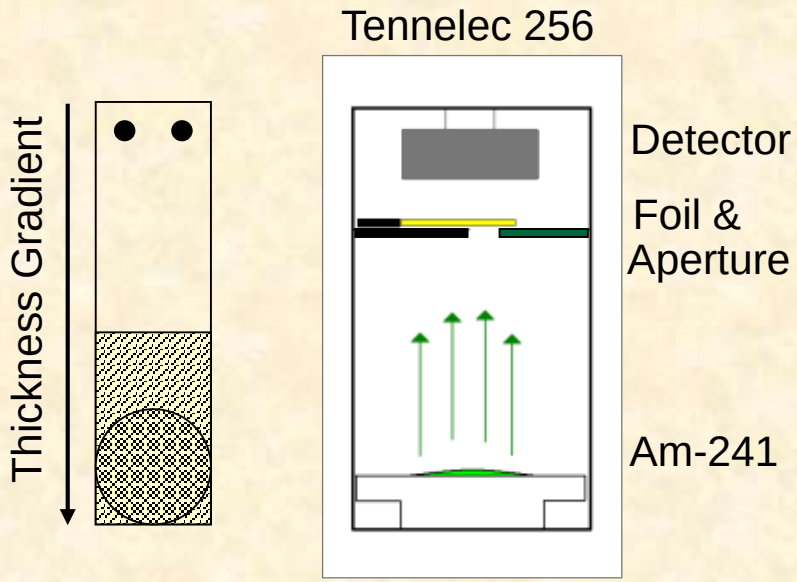
Corrugated foils avoid the need for carbon fiber support

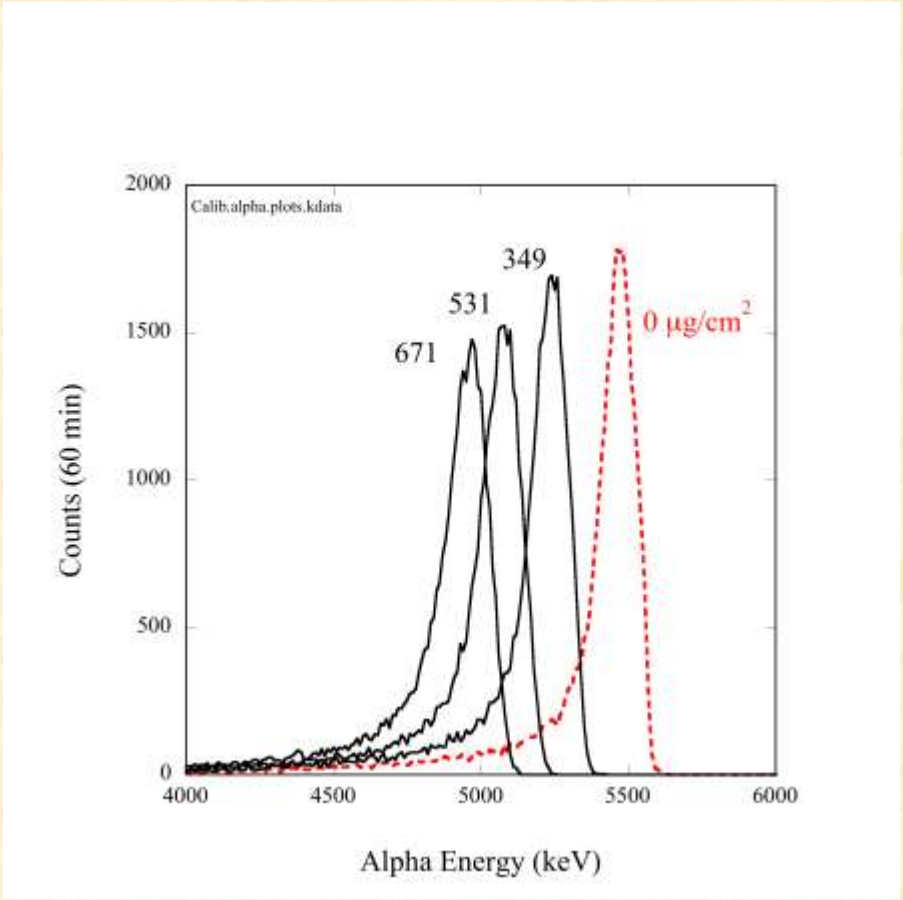
LANL/PSR Foil Mount





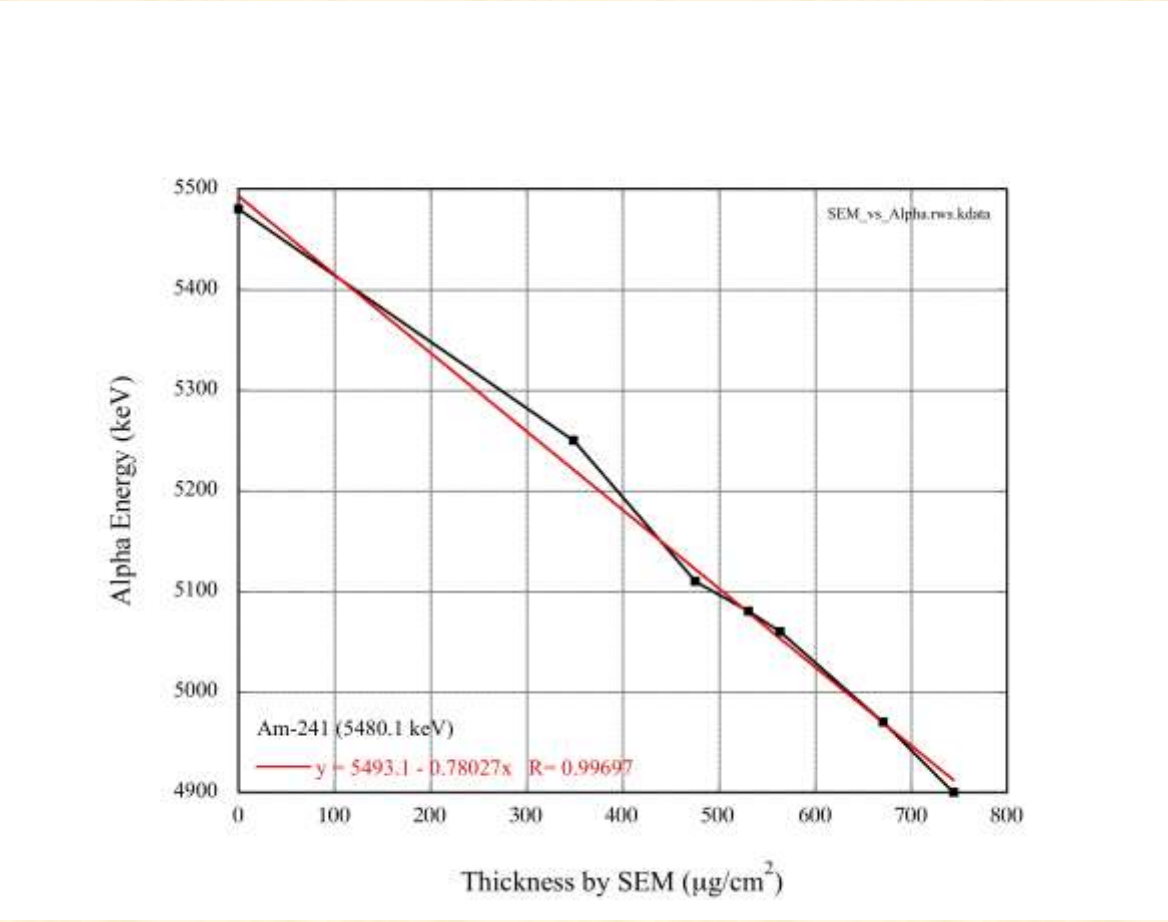
Foil Thickness from Alpha Ranging





Am-241 alpha spectra upon passage through nanocrystalline diamond foils.
The indicated thickness values were determined using SEM images.

Foil Thickness Correlation

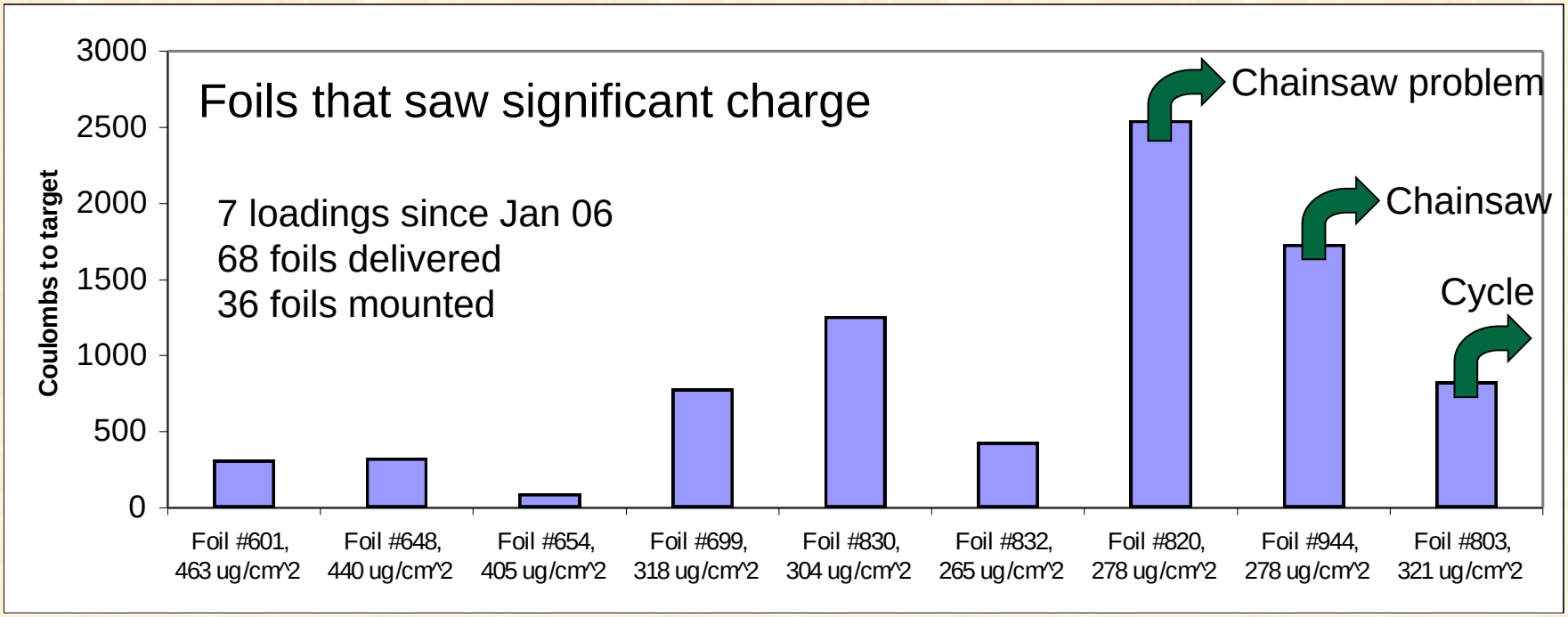


Thickness:
± 3% precision

Correlation between diamond foil thickness as determined using SEM images and the energy shift of transmitted Am-241 alpha particles.

SNS Diamond Foil Experience

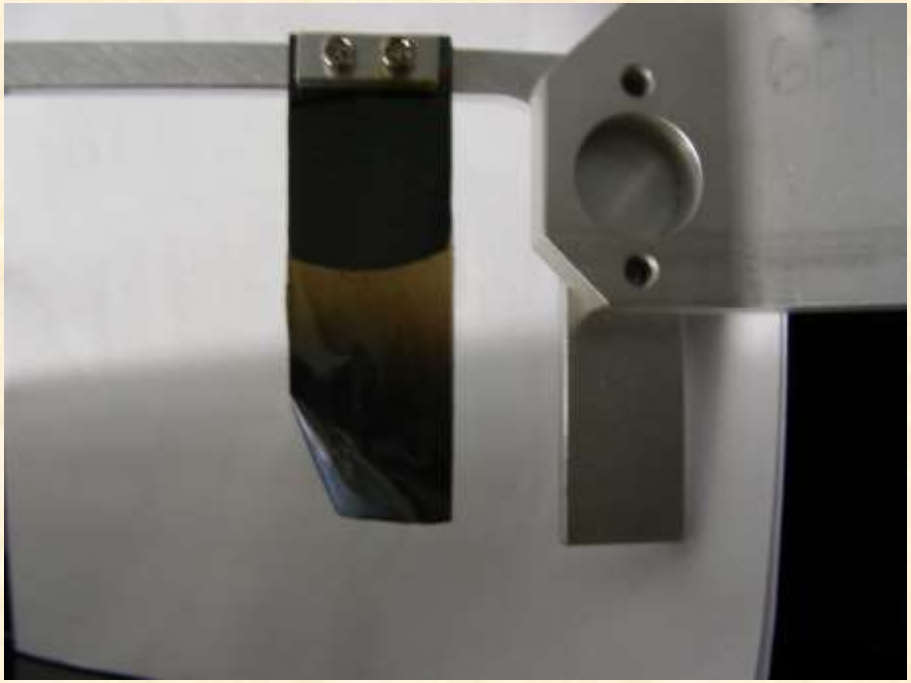
Integrated SNS charge delivered to target before removal from service for nanocrystalline diamond foils.



<Foil_statistics.xls>

- We have not observed any catastrophic foil losses in production mode.
- 2500 Coulombs represents about 1 month at design power (but currently only operating at about 700 kW).

Photograph of a nanocrystalline SNS foil (#601; 463 ug/cm2 avg) after experiencing 300 C of injected charge. The lower left corner is curled away from the camera from interaction with the injected and circulating ion beam.



<601 looking upstream.jpg>

SNS Foil 699 after 783 C

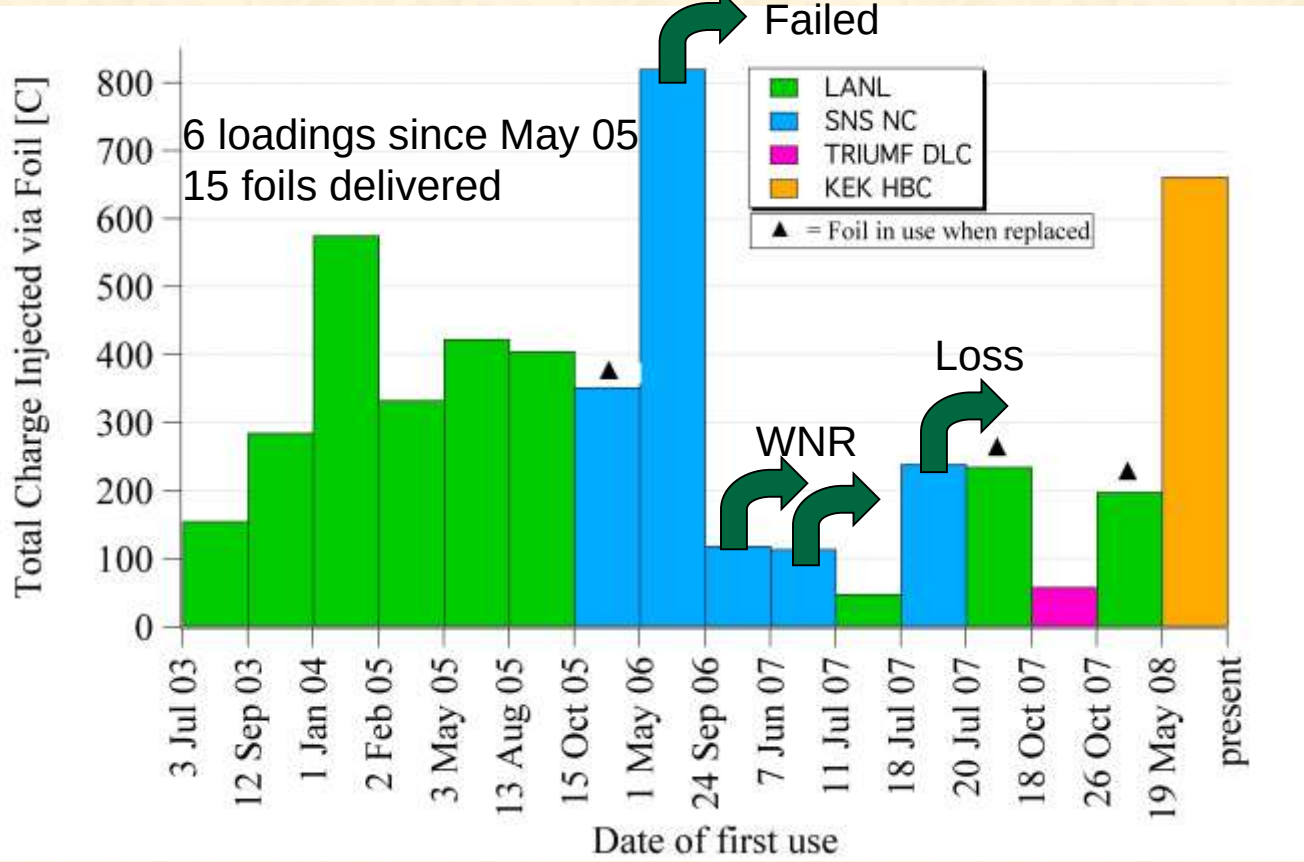
Comparison of SNS and PSR

- PSR: **20 Hz, 3.1x10^{13} ppp, 50-70 foil hits/proton, 400 μg/cm^2**
  - **ca. 1.9x10^{15} hits/pulse,**
  - **ca. 3.6x10^{16} hits/sec**

- SNS: **60 Hz, 1.5x10^{14} ppp, 7-10 foil hits/proton, 330 μg/cm^2**
  - **ca. 1.3x10^{15} hits/pulse,**
  - **ca. 7.7x10^{16} hits/sec**

⇒ PSR has comparable hits/pulse and about 1/2 hits/sec of SNS, and is a good surrogate for foil testing.

PSR Foil Experience



Current assessment is that nano-diamond foils perform well in production (without fiber support), but fail catastrophically at high current density.

30 keV Electron Test Stand

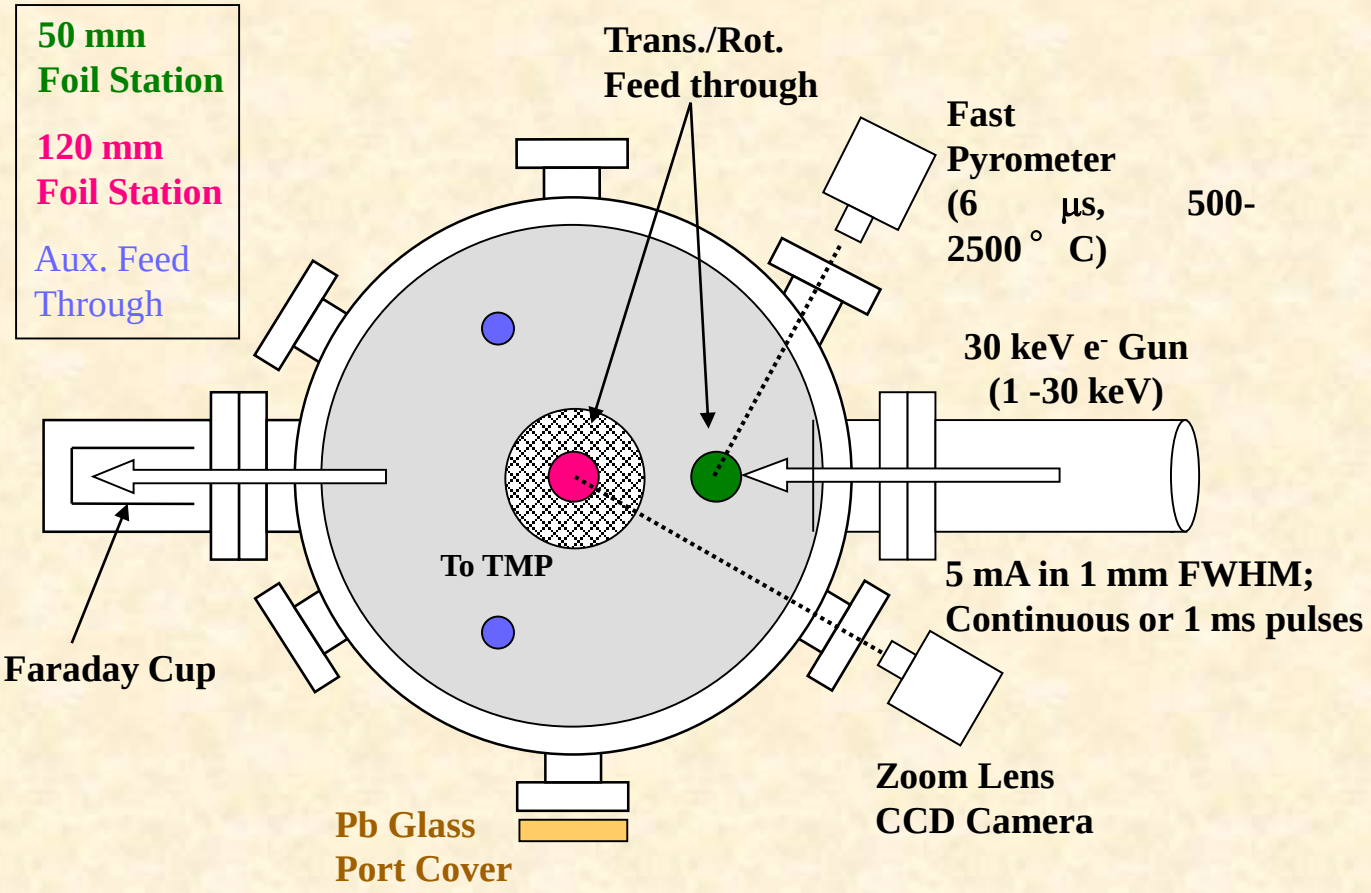
- Foil testing has always been a bottle neck, as we needed to rely on commissioned accelerators without disrupting operations
  - Diamond foils, Doped diamond foils
  - Diamondlike Carbon Foils (TRIUMF)
  - Hybrid Boron Carbon Foils (Sugai)
  - Carbon Nanotube Foils

- This instrument was designed to match the foil heating for the SNS base design
  - Injected and circulating beams considered
  - H^- pulse length and repetition rate considered
  - Convoy electrons considered

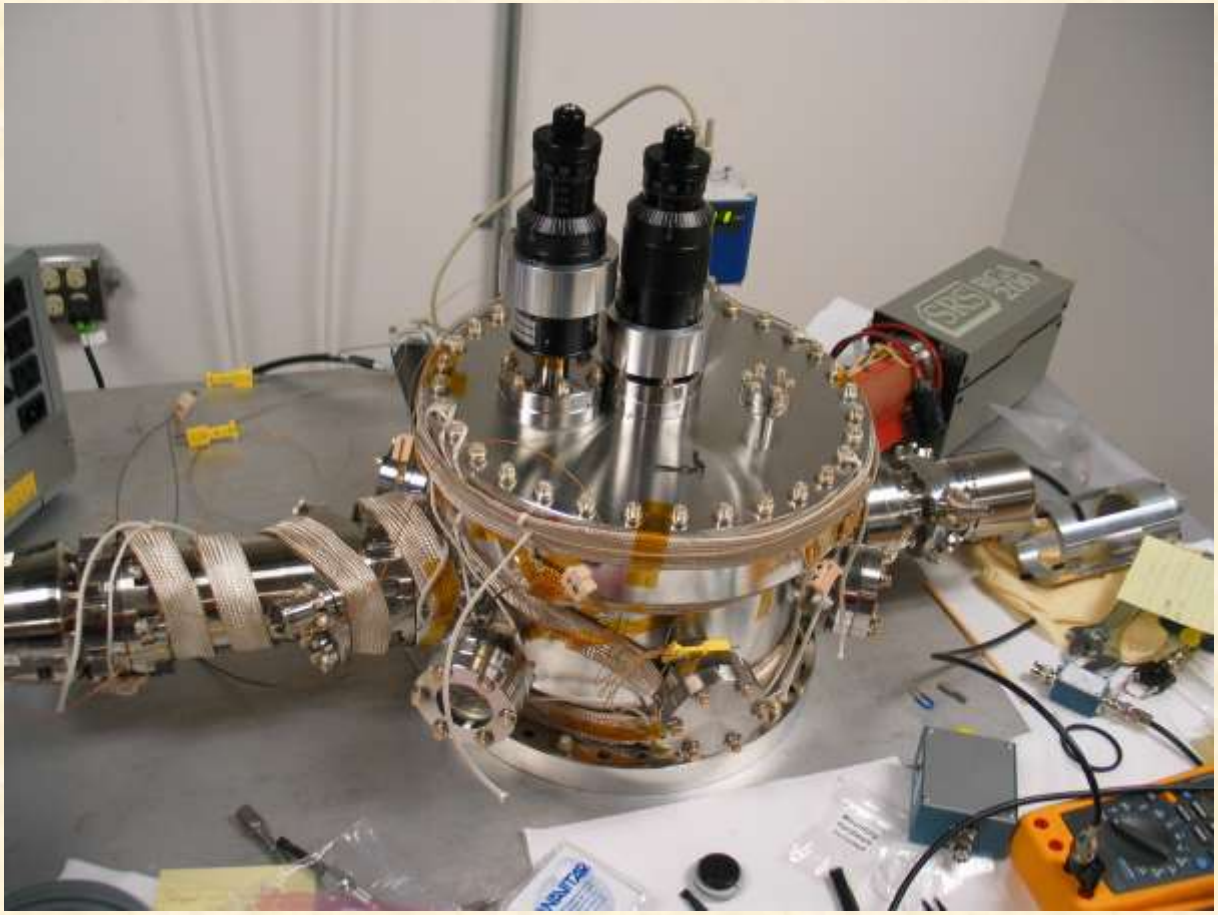
1.6 mA/mm^2 (peak) current required
5 mA in a 1 mm spot capability

- Impractical to match the 27 mm^2 (rms) SNS injection spot
- Design allows for photography and pyrometry

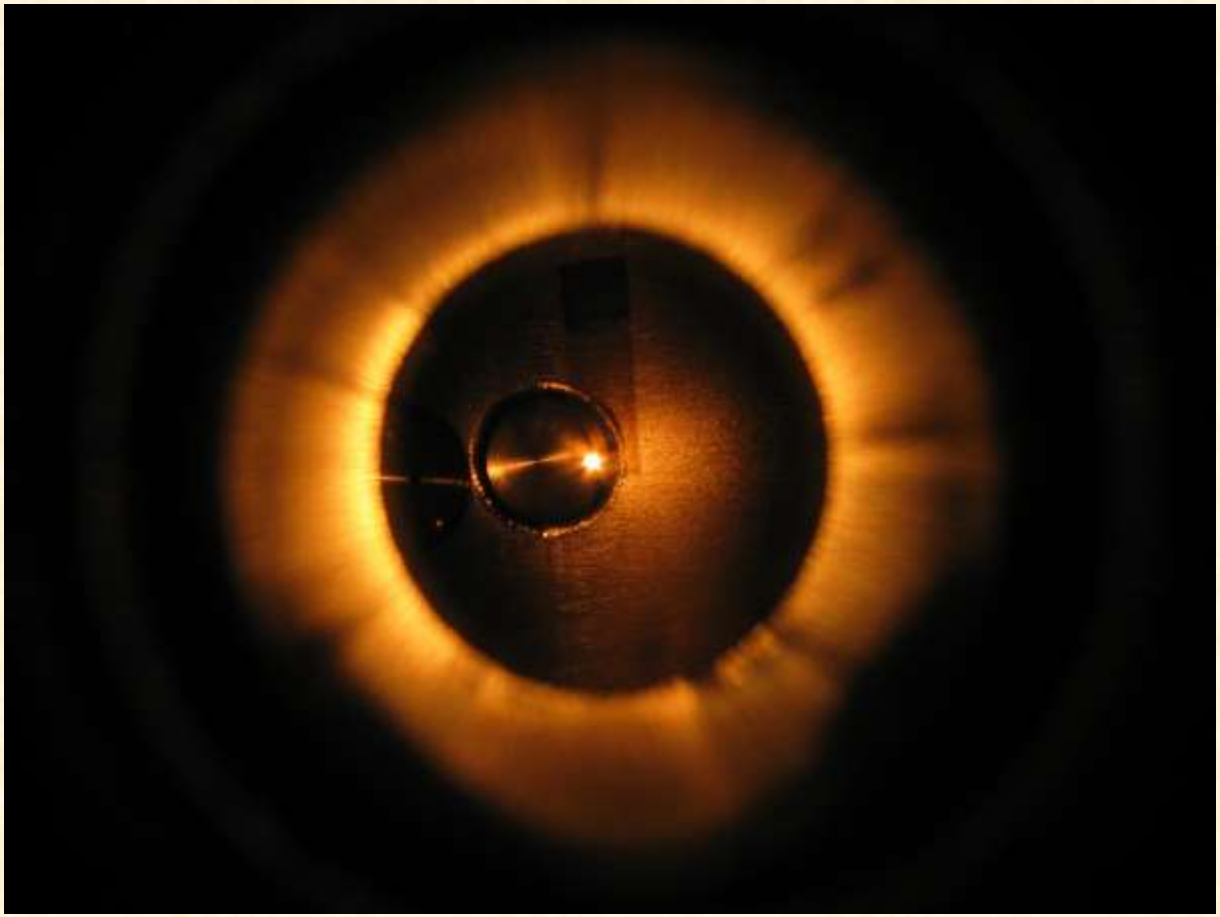
30 keV Electron Beam Test Stand Schematic



Electron Beam Foil Test Stand Ready for Bakeout



Electron Beam on Diamond Foil

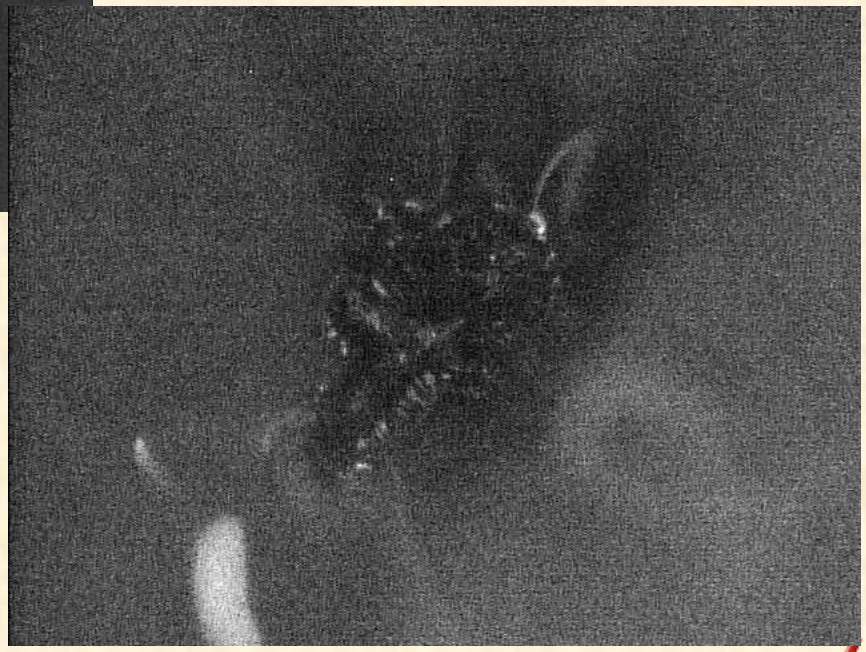


- Snapshot camera without zoom

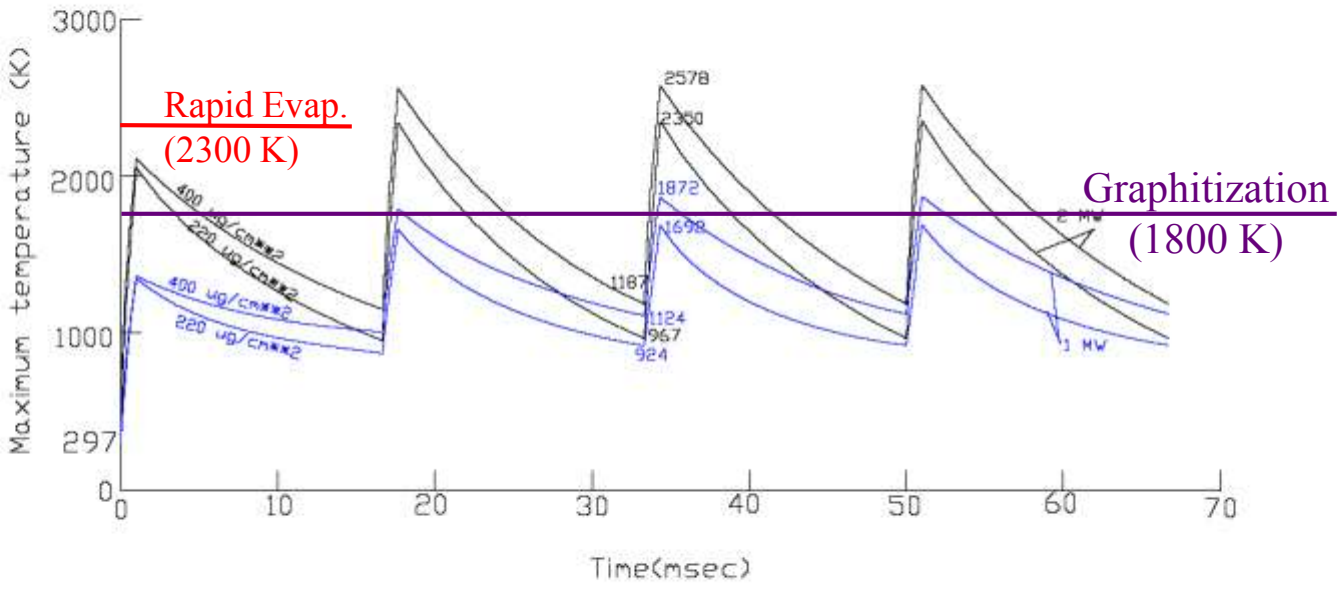
Zoom CCD Camera for Foil Photography

<50 mm Back Port II.png>

<12 X Zoom @ window.png>



CALCULATED FOIL TEMPERATURE



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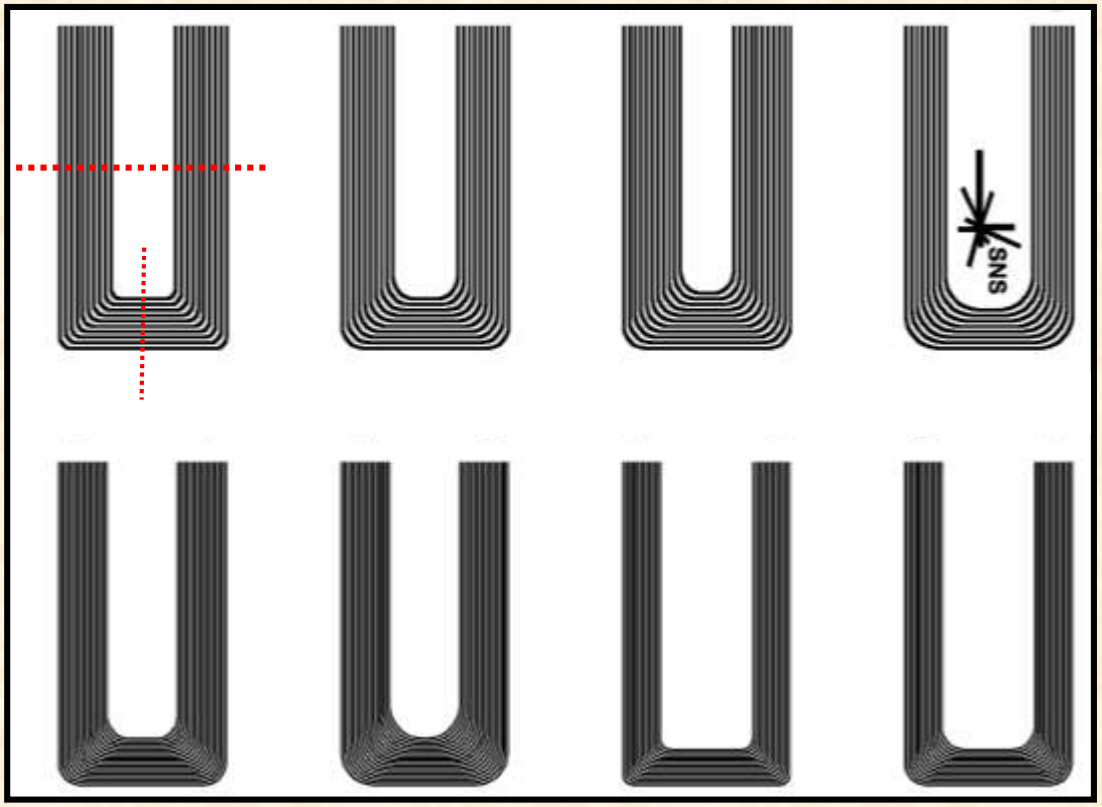
New Directions

- New corrugation patterns.
- Growth of Hybrid Boron Carbon (HBC) foils.

Initial Foil Corrugation Pattern



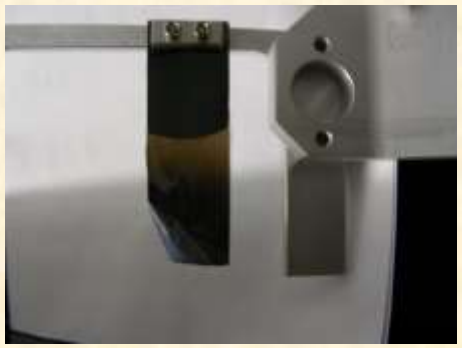
Variables:

- Pitch (25, 50, 100 L/in)
- Radius (1, 2, 3 mm)
- Coverage (40, 60%)

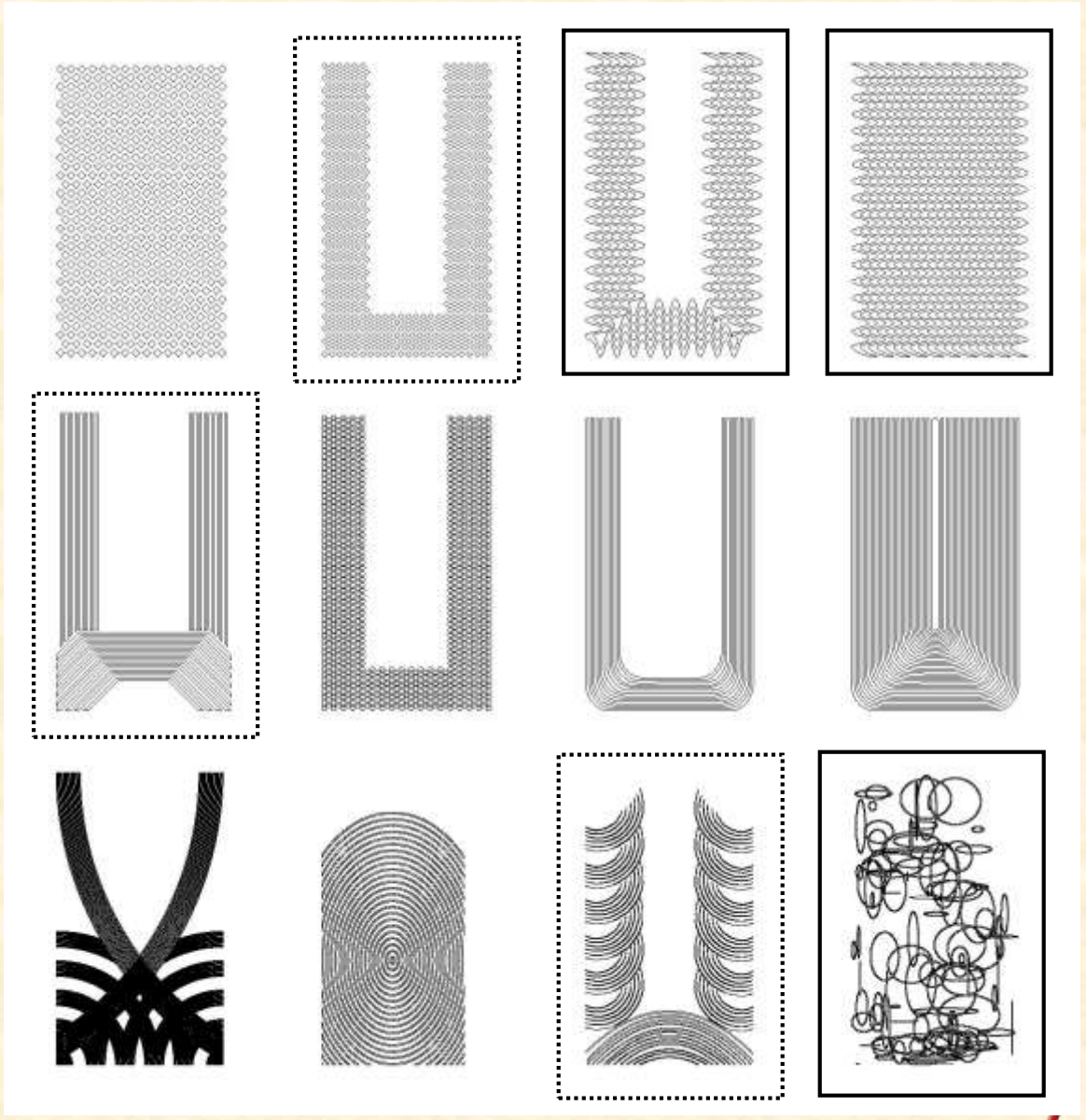
New Lithography Mask Patterns

= Flat @ RT

= Not bad



#601

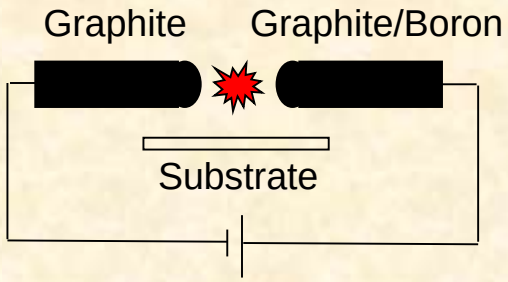


Hybrid Boron Carbon (HBC) Foils

- Isao Sugai has reported HBC foils with excellent life times for proton beams.
  - 20-25% Boron
  - 256 hr lifetimes vs 62 hr for nano-diamond

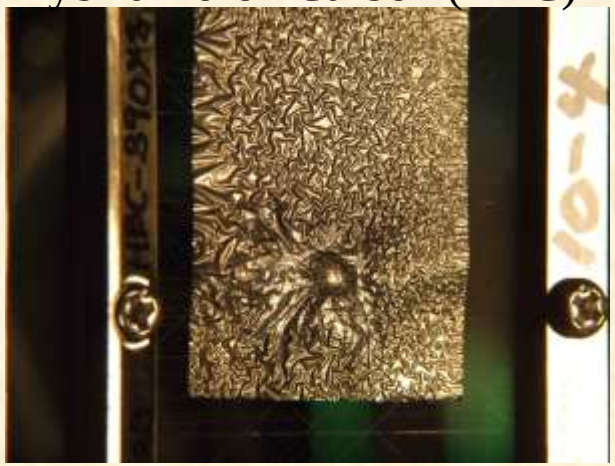
- Limitations: Thickness < 400 μg/cm^2
  Pinholes
  Carbon fiber mounting

- We have begun to prepare similar foils using our PA-CVD growth reactor.



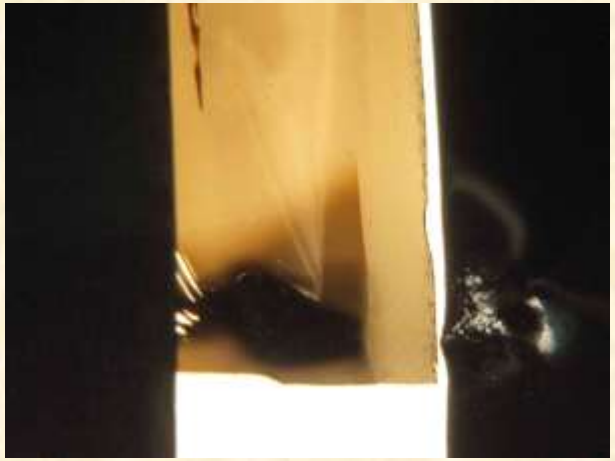
KEK Foil Comparison: HBC and Nano-diamond

Hybrid Boron Carbon (HBC)



- Single HBC foil (417 μm/cm^2) with SiC fibers
- 650 keV dc H^- beam (3.5 mmϕ)
- 90 μA; T = 1970 K
- 256 hr
- 30% thickness reduction

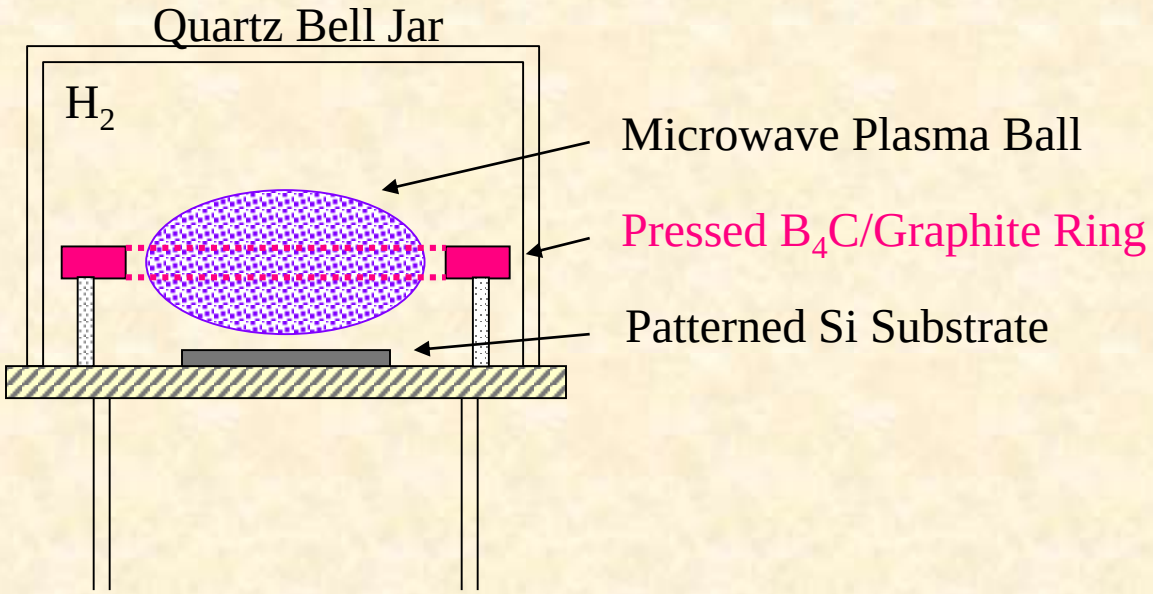
SNS nanocrystalline diamond



- SNS nanocrystalline foil #527 (433 μg/cm^2) without fibers
- 130 μA; T = 1950K
- 21 hr
- 6.5% thickness reduction
- "Inside curling"

(I. Sugai, ICFA5; Nashville, August 08)

Planned Growth of HBC-like foils



- Utilizes the same growth reactor as for diamond foils
- Si substrate to retain patterning and foil "handle" after chemical etching
- Plasma erosion should create boron and carbon in the vapor phase
- Foil composition varied by pressed ring composition
- Material properties may differ from Japanese foils

SNS Foil Development Program

Summary

- Corrugated, nano-diamond stripper foils have performed well at SNS and PSR.

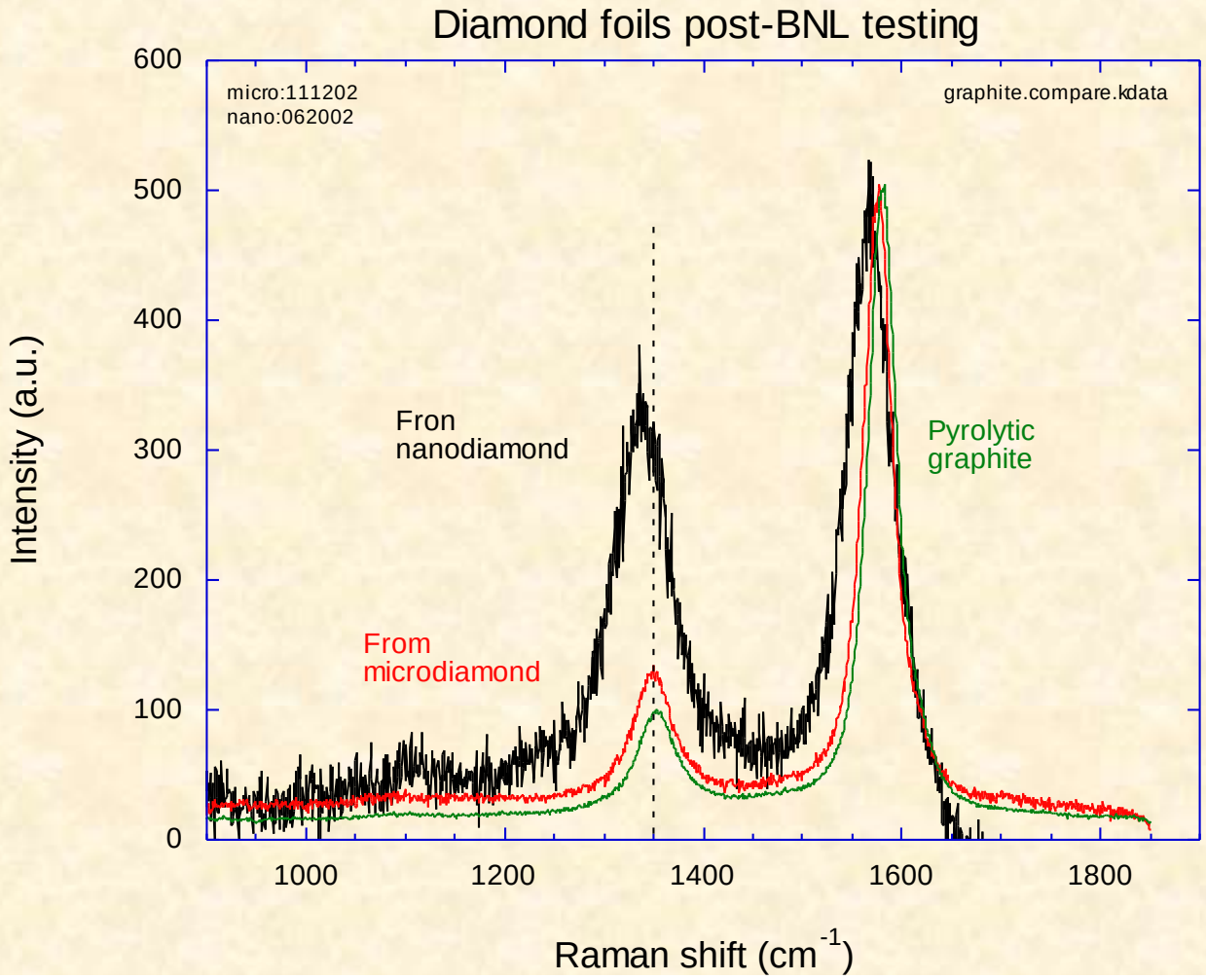
- Improved techniques for growth and characterization have been developed.
  - Nano-seeding for nucleation
  - Alpha ranging for thickness determination

- For an upgraded SNS, different materials may be needed.

- An e-beam test stand has been assembled to increase throughput for foil lifetime testing for a variety of materials.
  - Doped diamond, HBC, Carbon nanotubes

- Growth of another material has begun - HBC.

Thank You !


Diamond foils post-BNL testing
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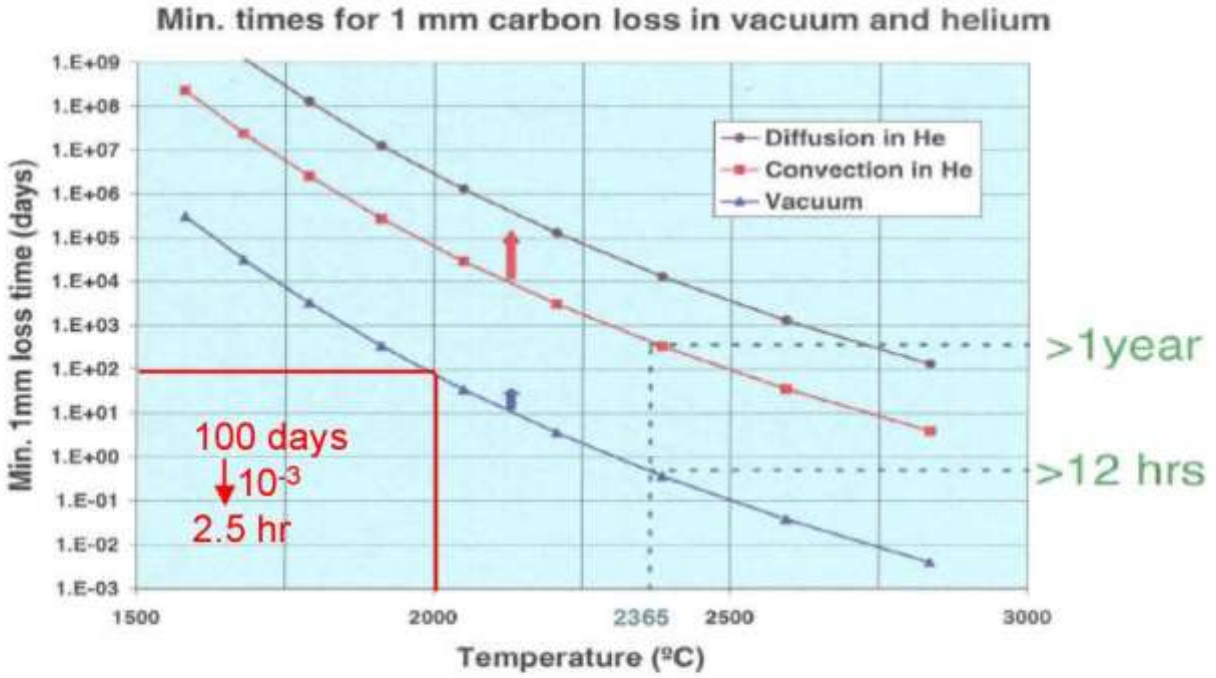
nano:062002
graphite.compare.kdata
Fron
nanodiamond
Pyrolytic
graphite
From
microdiamond
Intensity (a.u.)
Raman shift (cm-1)
600
500
400
300
200
100
0
1000
1200
1400
1600
1800

Graphite Evaporation



P. Thieberger, BNL, 2000