Abstract # 819 Program # B5-2-13

# Wear Resistant Coatings Via Directed Vapor Deposition

Susie Eustis, and Derek Hass
Directed Vapor Technologies International (DVTI)
Charlottesville, VA

susie.eustis@directedvapor.com

Directed Vapor Technologies International, Inc.

# Wear / Erosion Resistant Coatings

**Coatings commonly used to improve wear performance:**

- Increase lifetime (10-20 Times)
- Increase tolerance to applied pressures(Loads)
- Higher productivity
- Enhanced performance
- Decrease coefficient of friction (COF)


**Future enhancements aim to tailor the properties of the wear coating to the use environment and substrate properties**

- Promote adhesion
- Limit fatigue debit

**May also need to add multifunctional requirements:**

- Corrosion
- Oxidation
- Thermal Protection
- Smart Properties

**Wide range of applications:**

- Cutting tools
- Bearings
- Gears

# Goal:Develop Advanced Wear Resistant Coatings

**Approach:** ***Specifically Design Coating Compositions to Enable Both Wear Performance and Properties to Match Substrate Mechanical Properties***

- **Flexible material systems – Nanocomposites**
  - Achieved with **Two or More Immiscible Materials** that Phase Separate During Processing
  - Precisely Control the Elements and their Relative Volume Fractions
  - Results in Nano-composites (ultra-fine grains)

- **Advanced Processing Techniques Required – Directed Vapor Deposition**
  - Multi-Source Evaporation – Composition Control
  - NLOS Coating – Complex Component Coating
  - High Rate Deposition

- **Design Criteria: Mechanical Parameters of Resulting Coating - H/E Ratio**
  - **High Ratio** of $H^3/E^2$
  - Coating ideally **Match Elastic Properties of Substrate**

T.L. Oberle, *J. Met.*, 3 (1951) 438.
A. Leyland and A. Matthews, *Surf. Coat. Technol.177-178* (2004) 317.

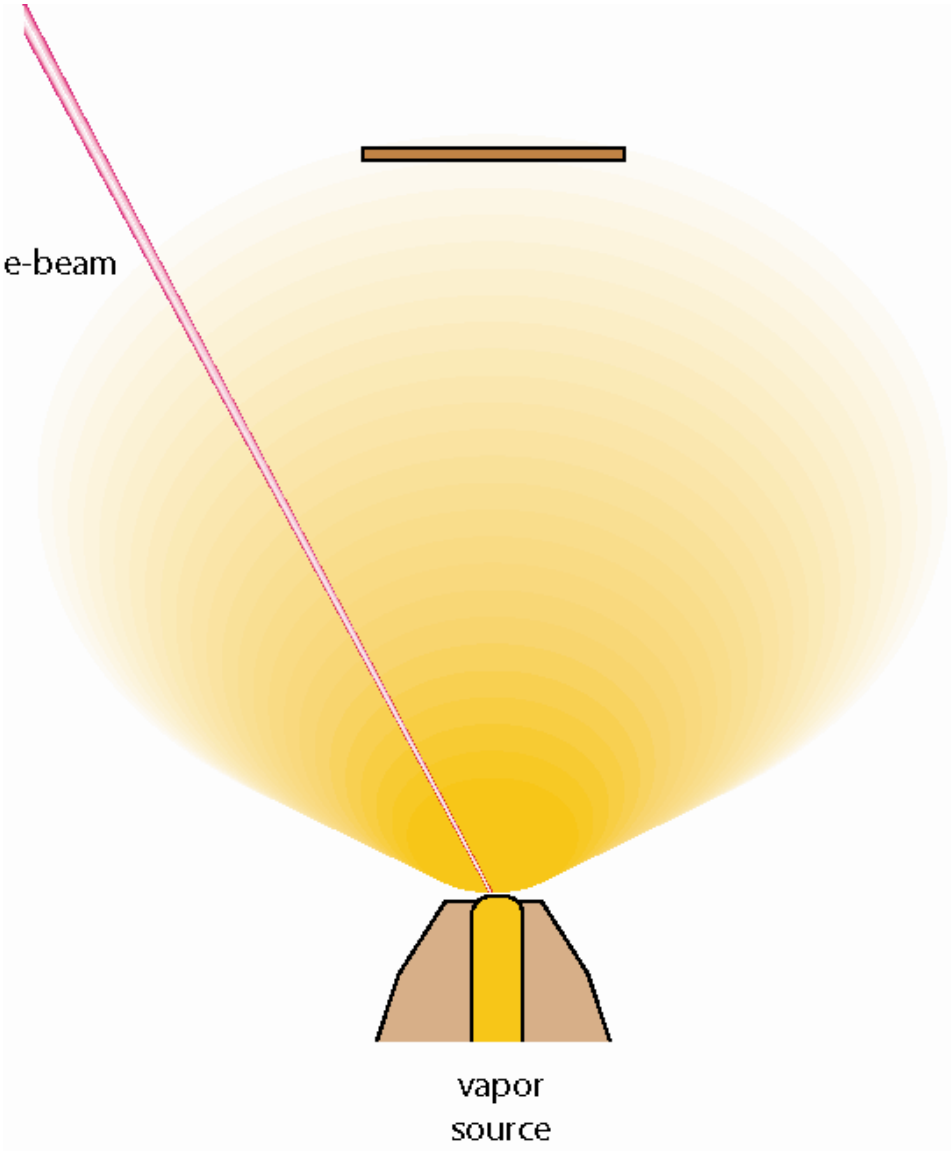
# *Outline*

- Nanocomposite Processing Approach - **Directed Vapor Deposition (DVD)**

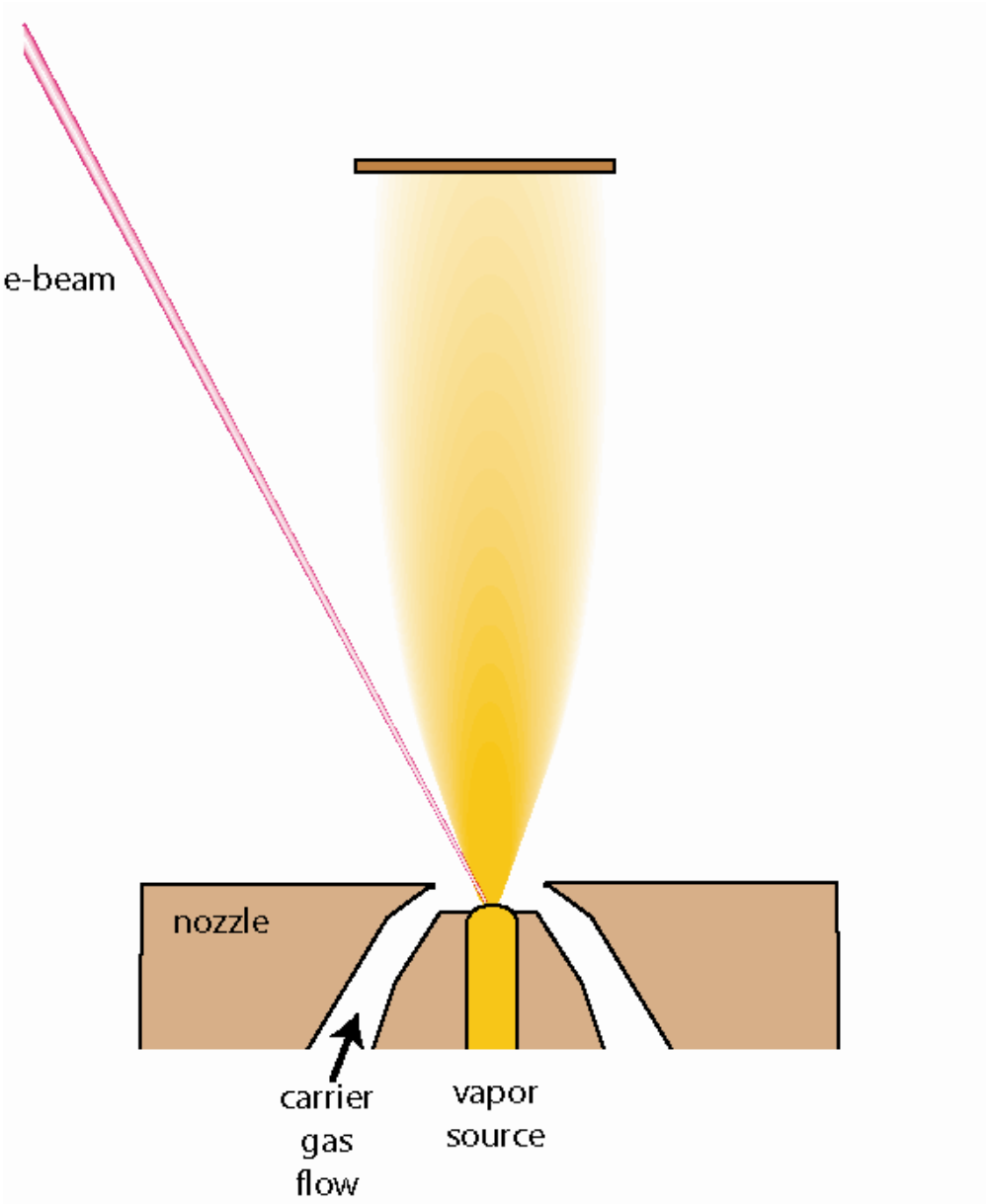
- Using DVD for **Combinatorial Screening** to Identify Chemistries of Interest

- **Wear Rates and Mechanical Properties** of Protective Coatings Deposited by DVD

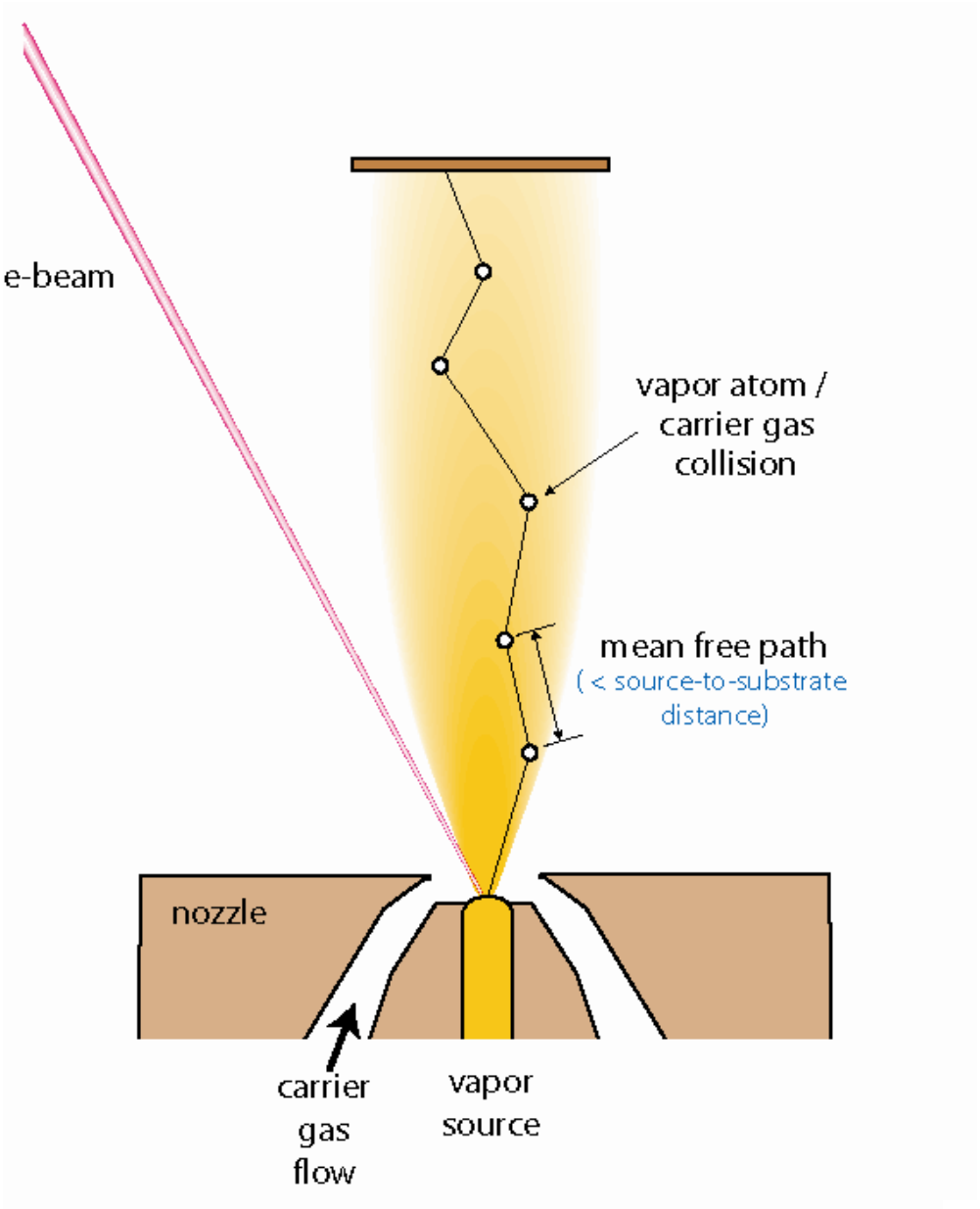
# Directed Vapor Deposition



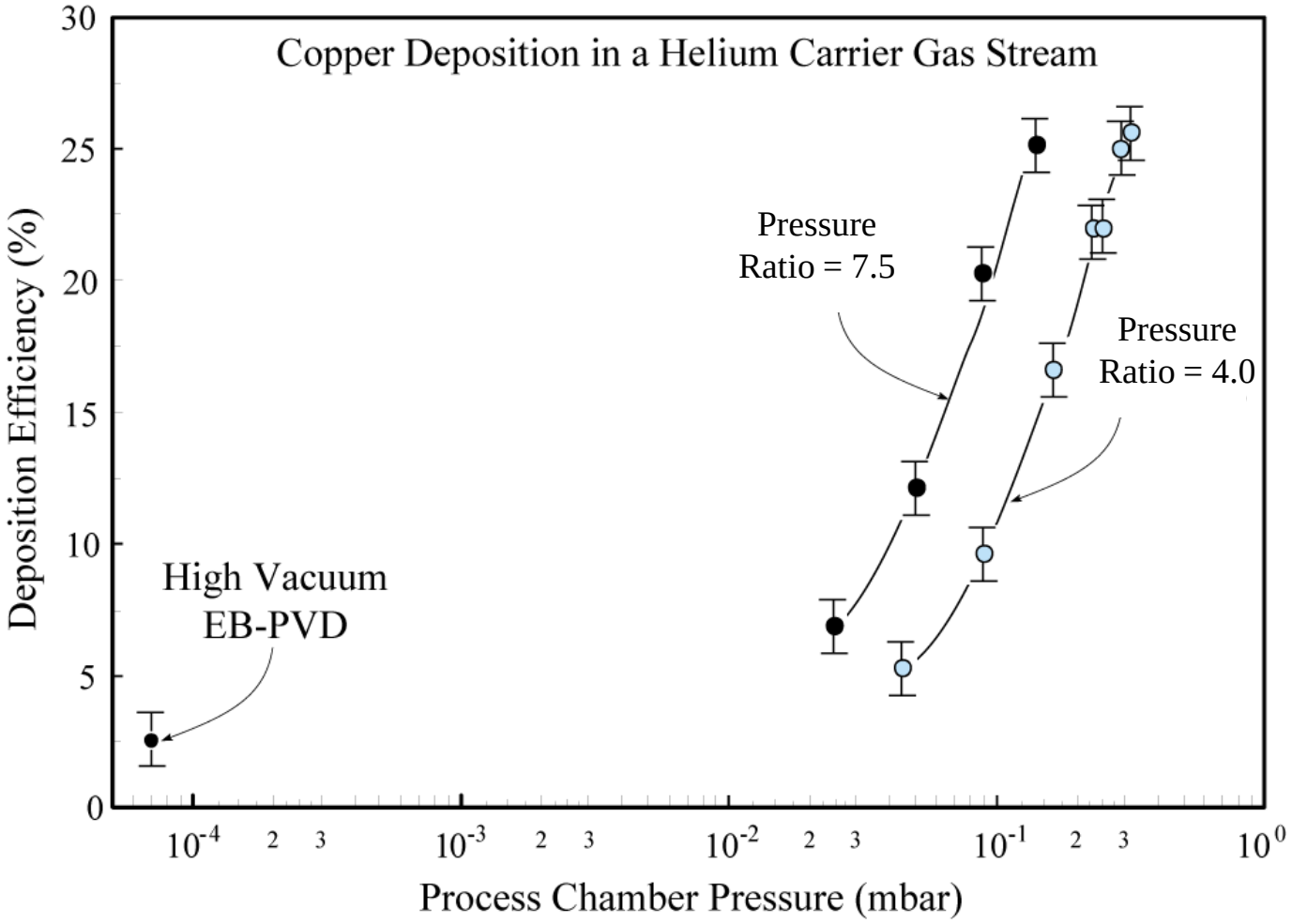
# Directed Vapor Deposition



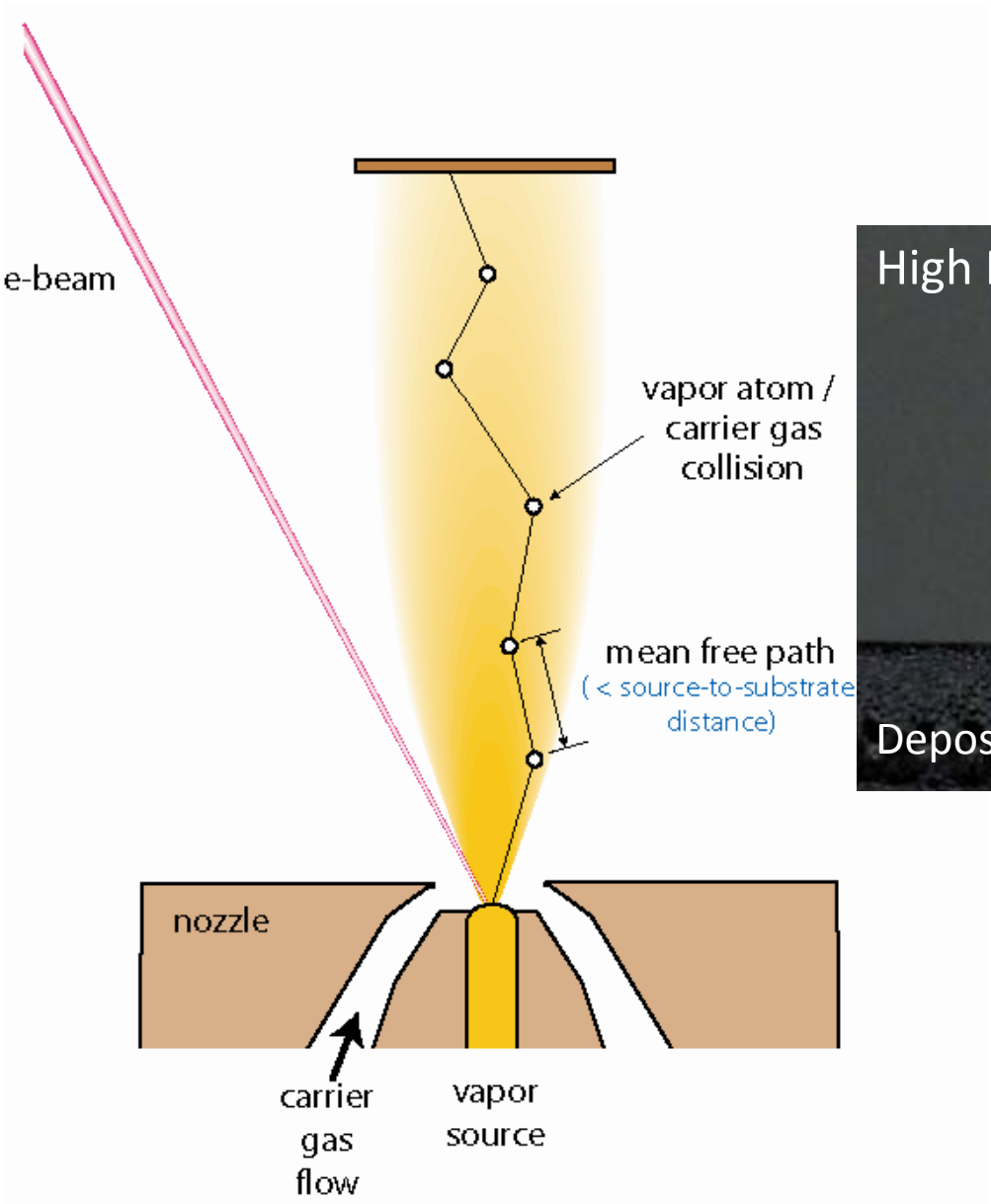
# Directed Vapor Deposition

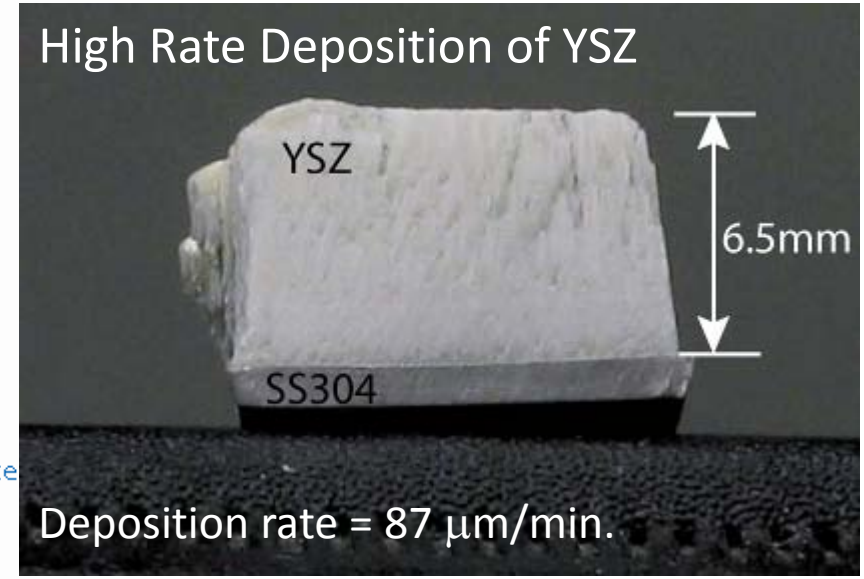



# Directed Vapor Deposition

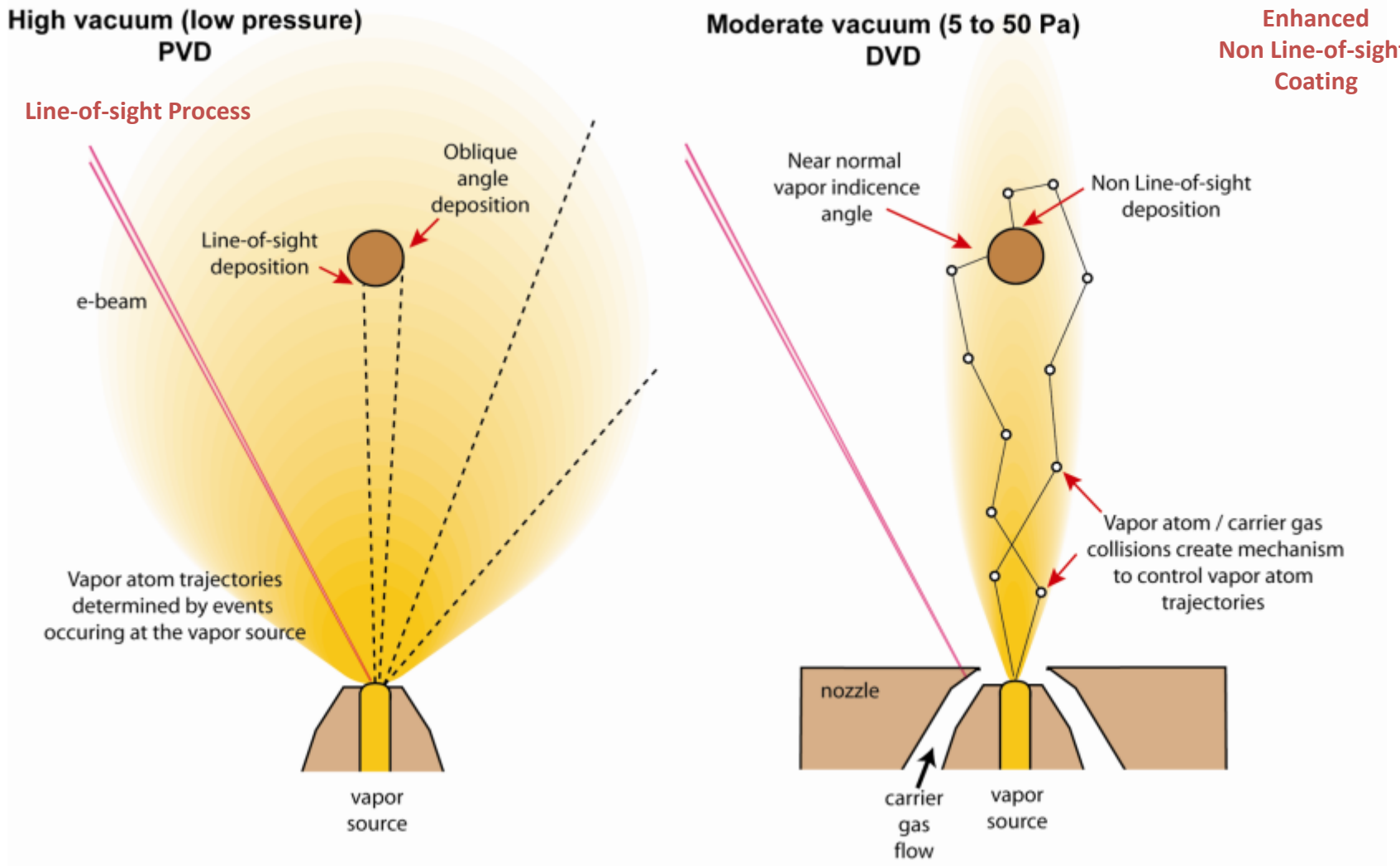


# Directed Vapor Deposition

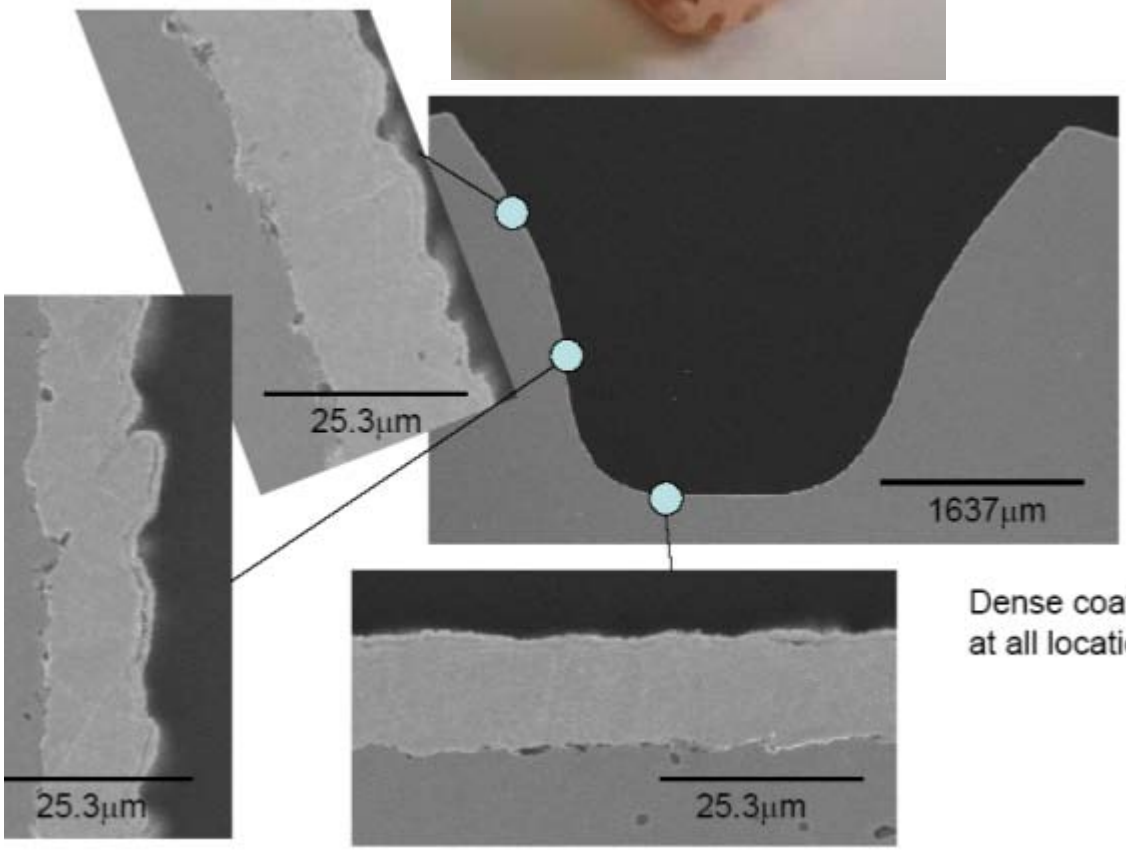


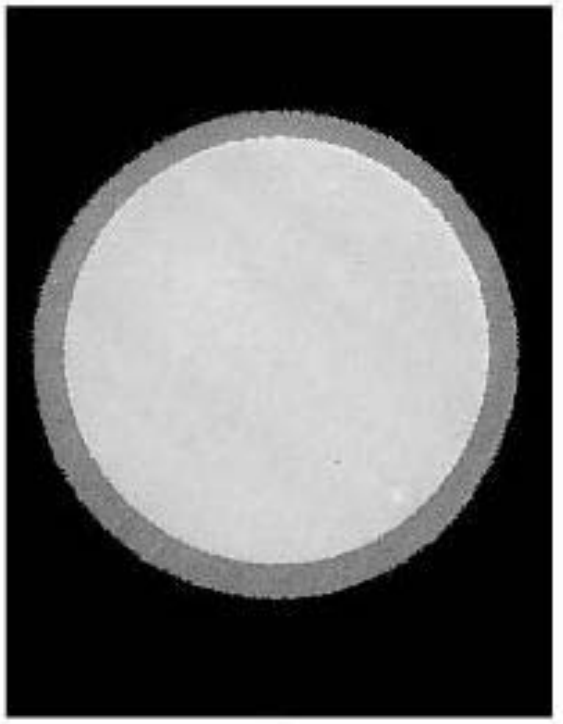
# Directed Vapor Deposition



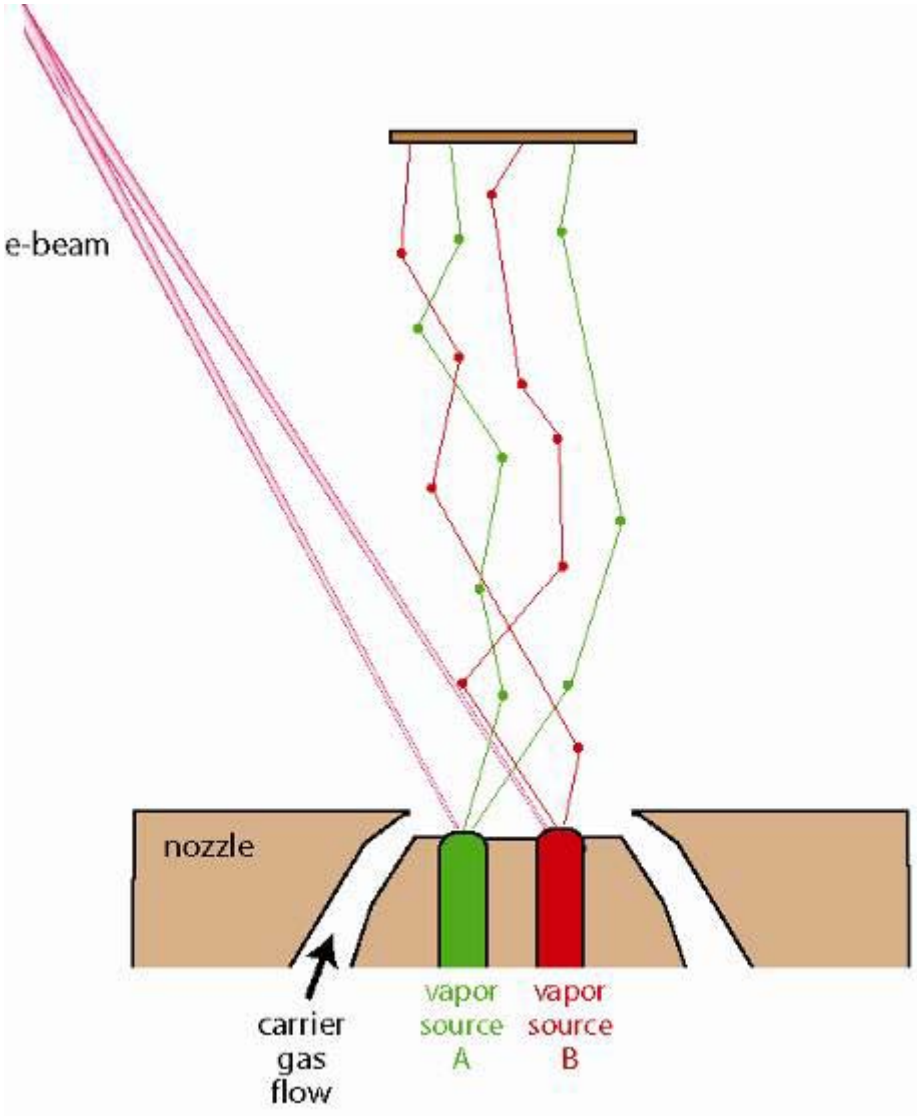
# Uniformity of Non-Line of Sight Coatings

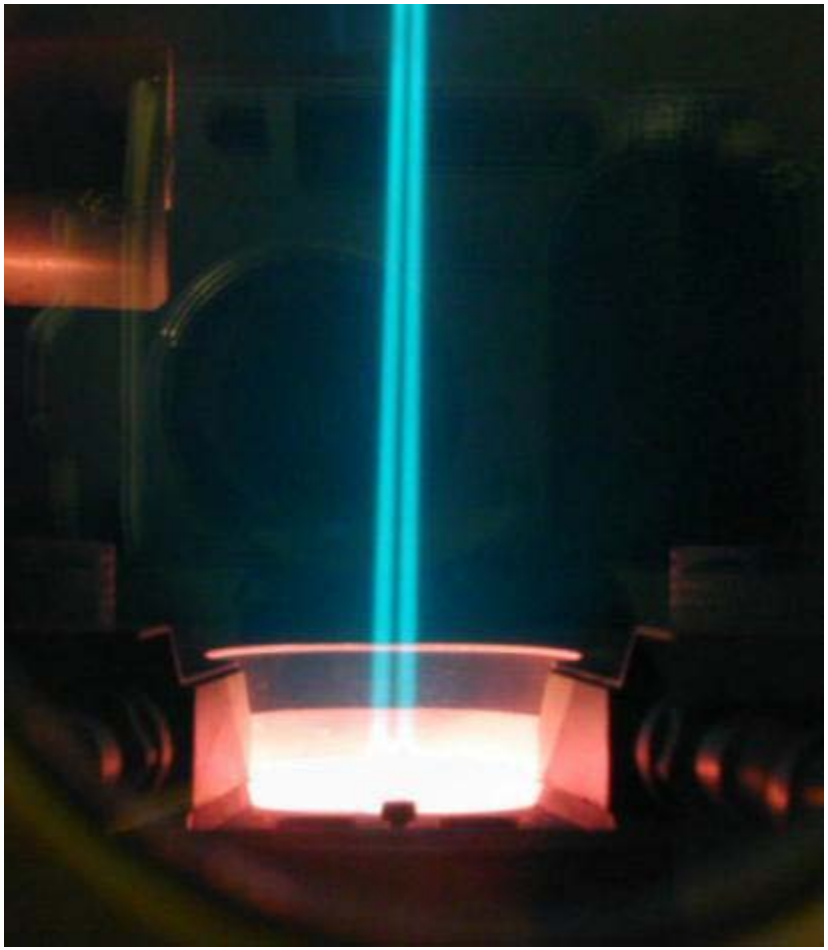




Dense coatings
at all locations



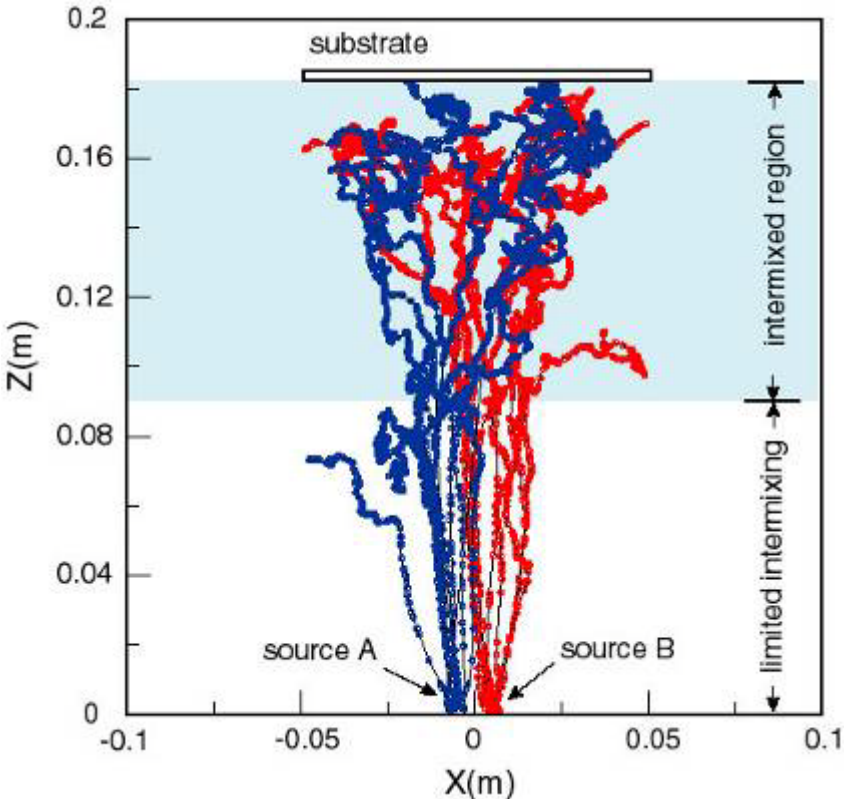
# Compositional Control



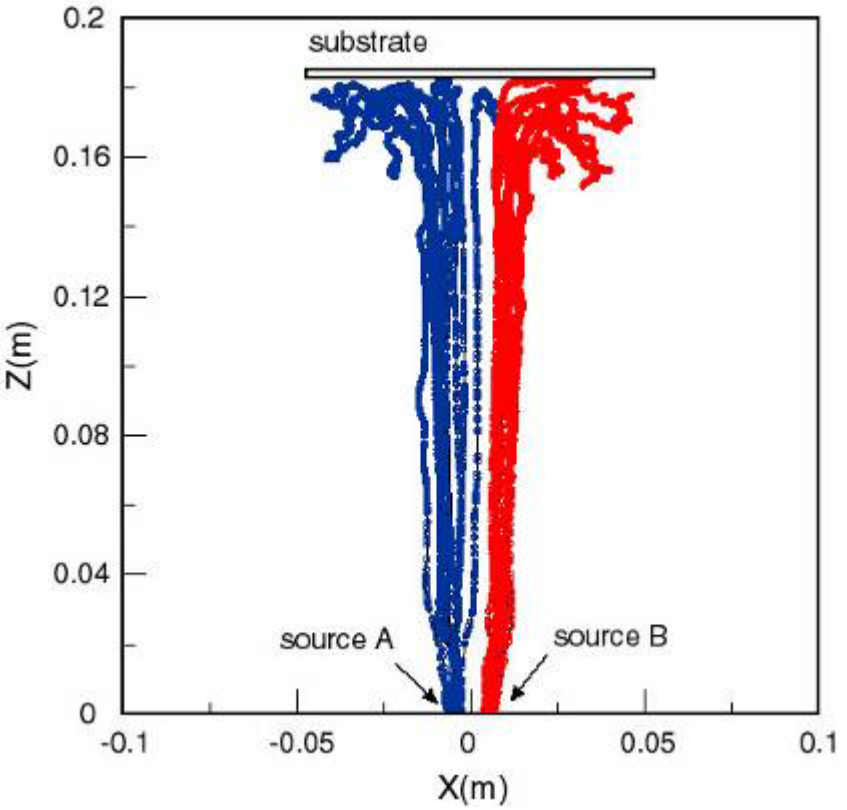



# Atom Tracking Simulations

**low pressure / low velocity**



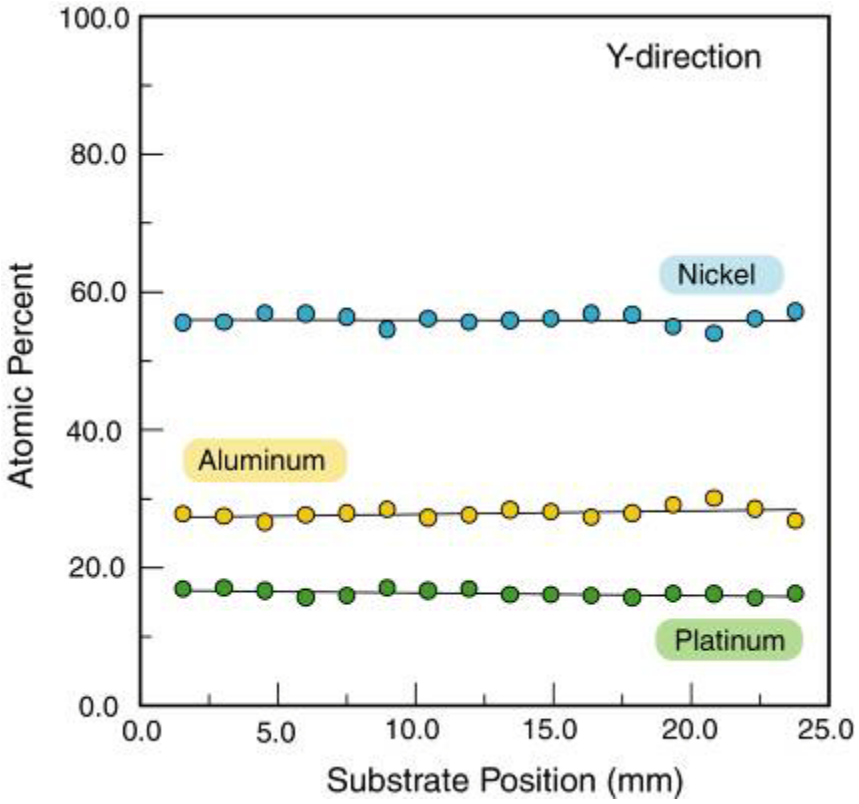

**high pressure / high velocity**



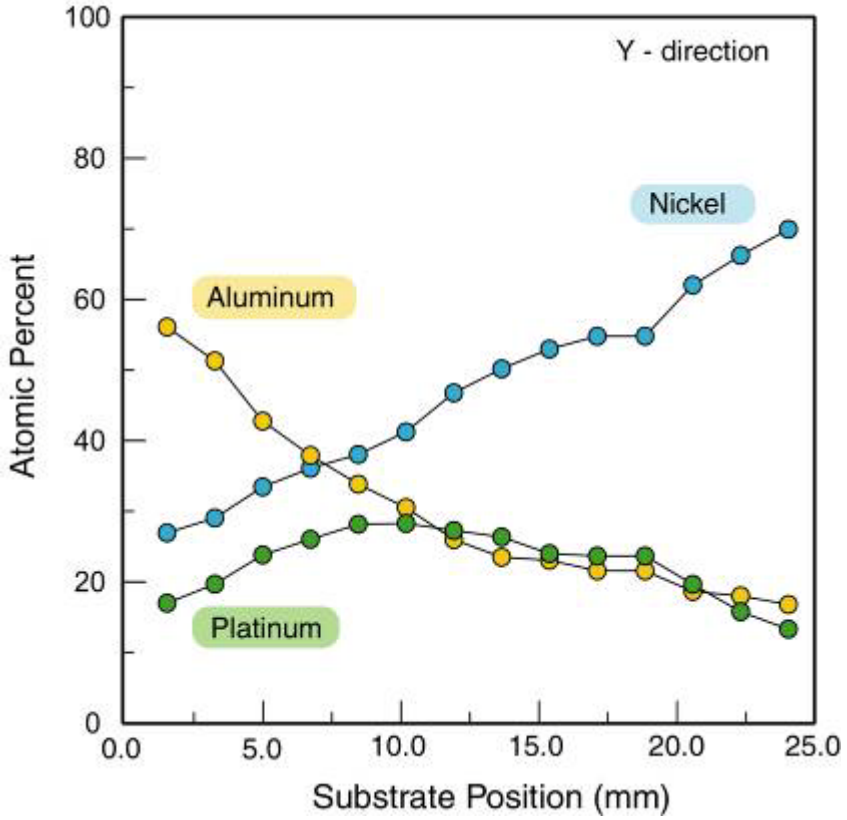

Collaborator: James Groves, UVA

# Compositional Uniformity

Moderate Chamber Pressure (0.10 Torr)



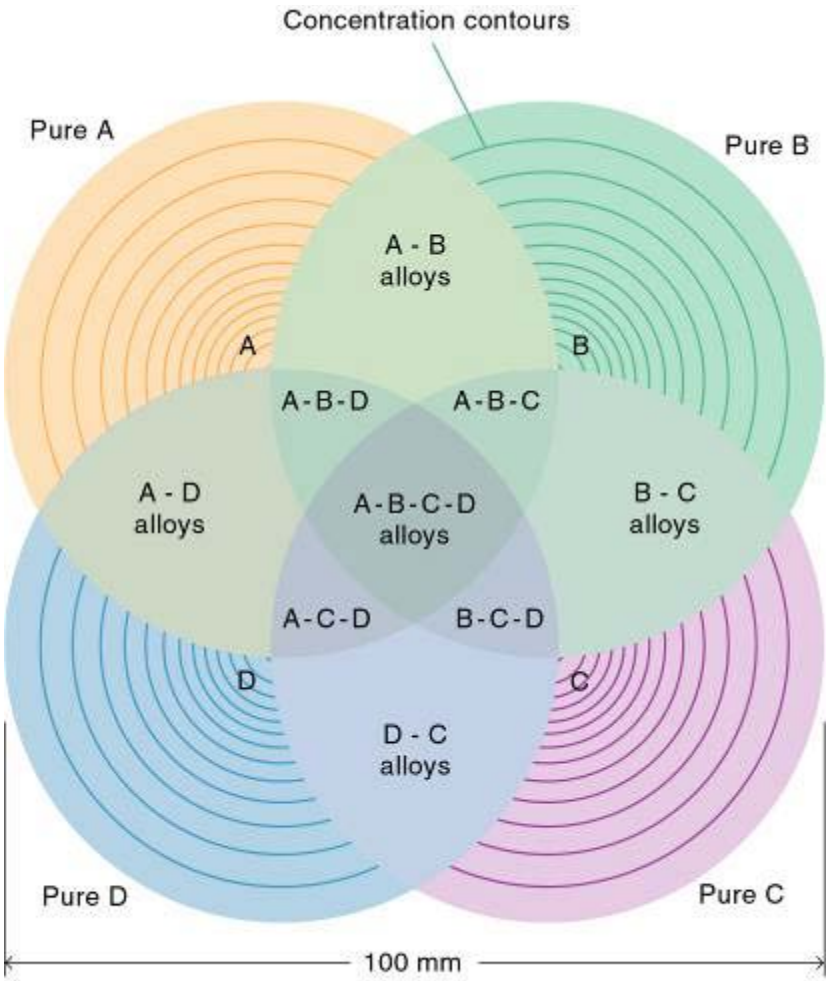

High Chamber Pressure (0.44 Torr)




Sub. Temp.= 1050°C

# Compositional Uniformity

# Combinatorial Synthesis

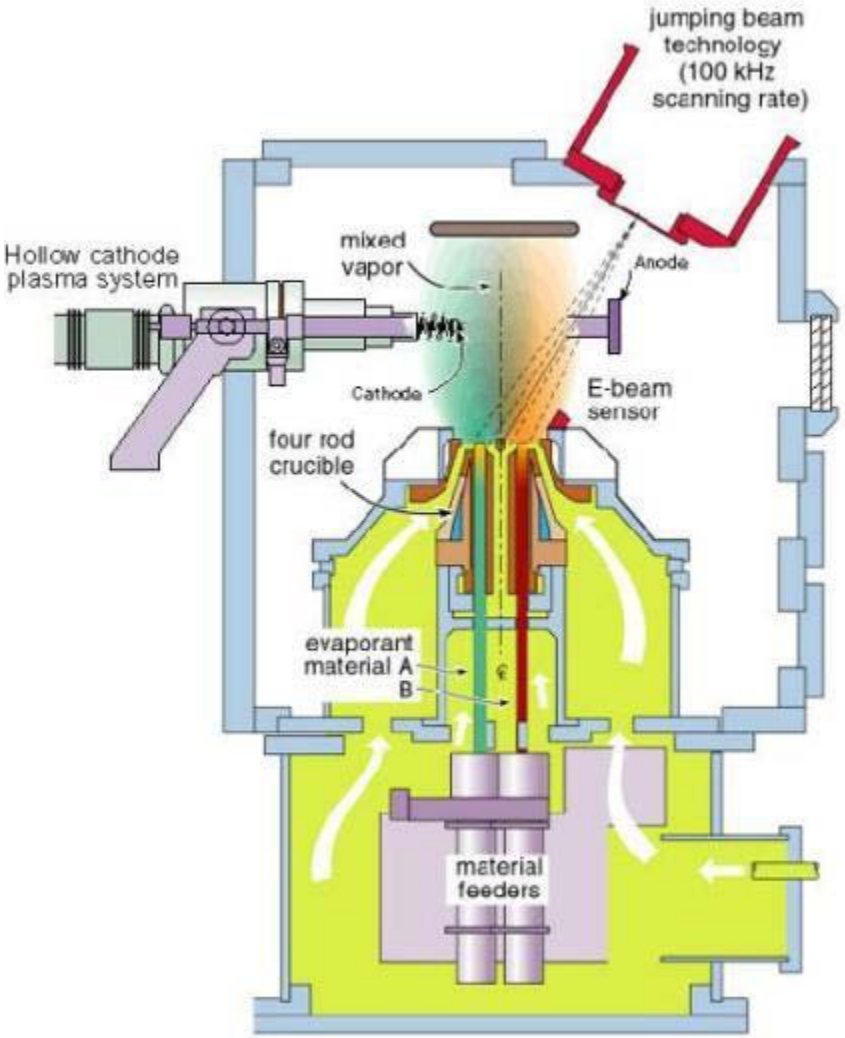



- Up to 4 different source materials can be evaporated at the same time
- Gas flow conditions are tuned to have limited mixing during deposition
- Different areas of substrates will give different composition

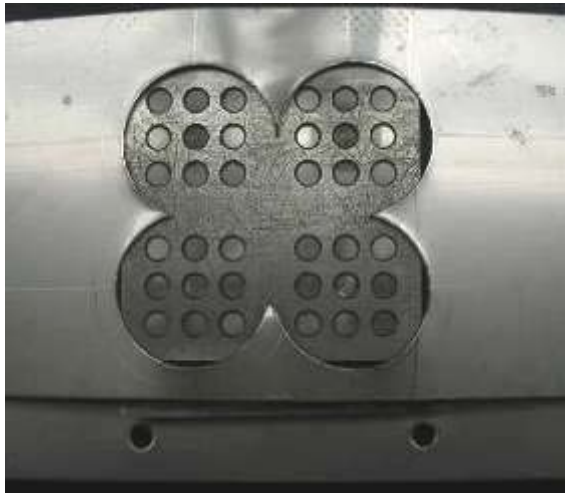
High density / high velocity jets lead to concentration gradients along the substrate

# Combinatorial Synthesis

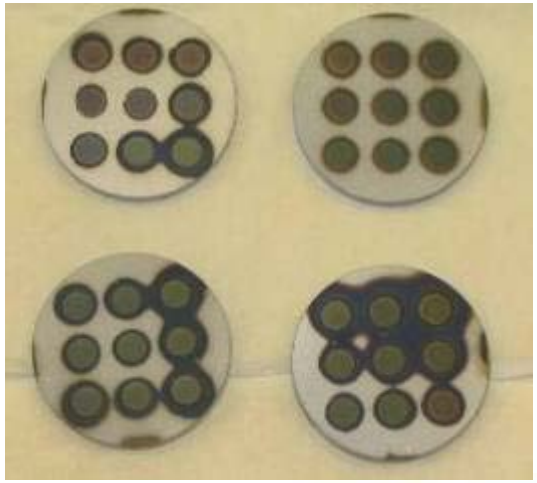
Wear Resistant Coatings




Masking approach



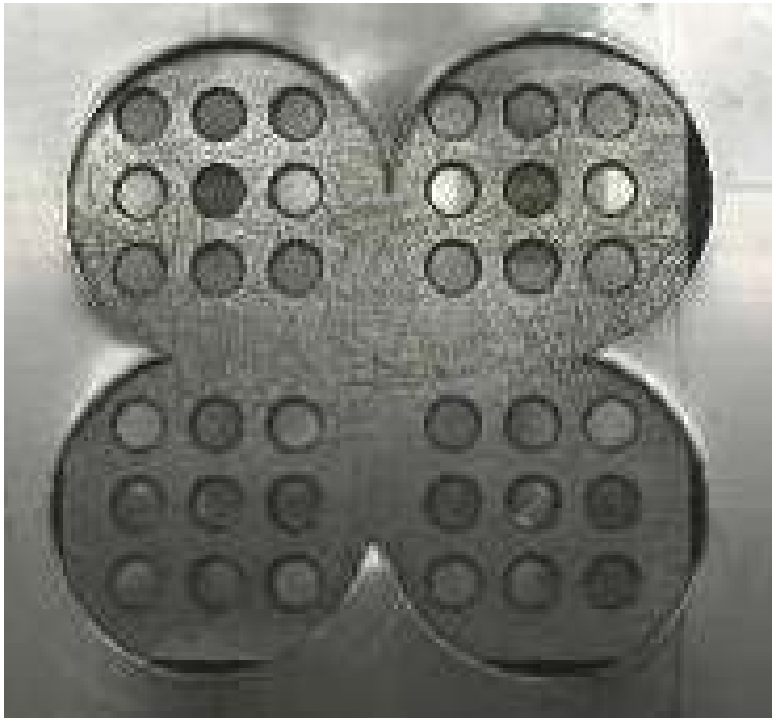
Individual pixels

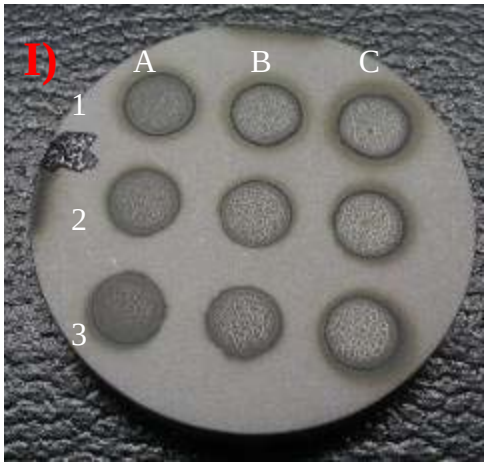


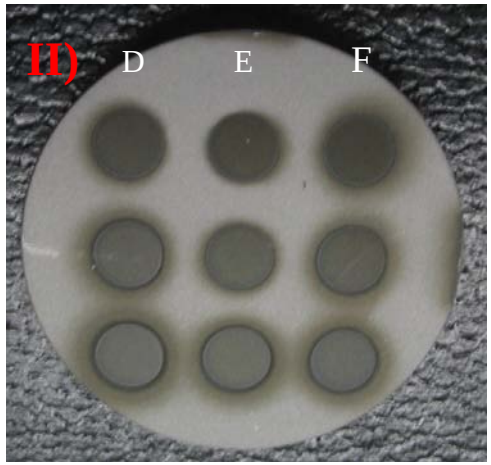
20 slm gas flow rate, 33 Pa chamber pressure

# Combinatorial Approach

Lateral composition gradients resulting in location specific compositions



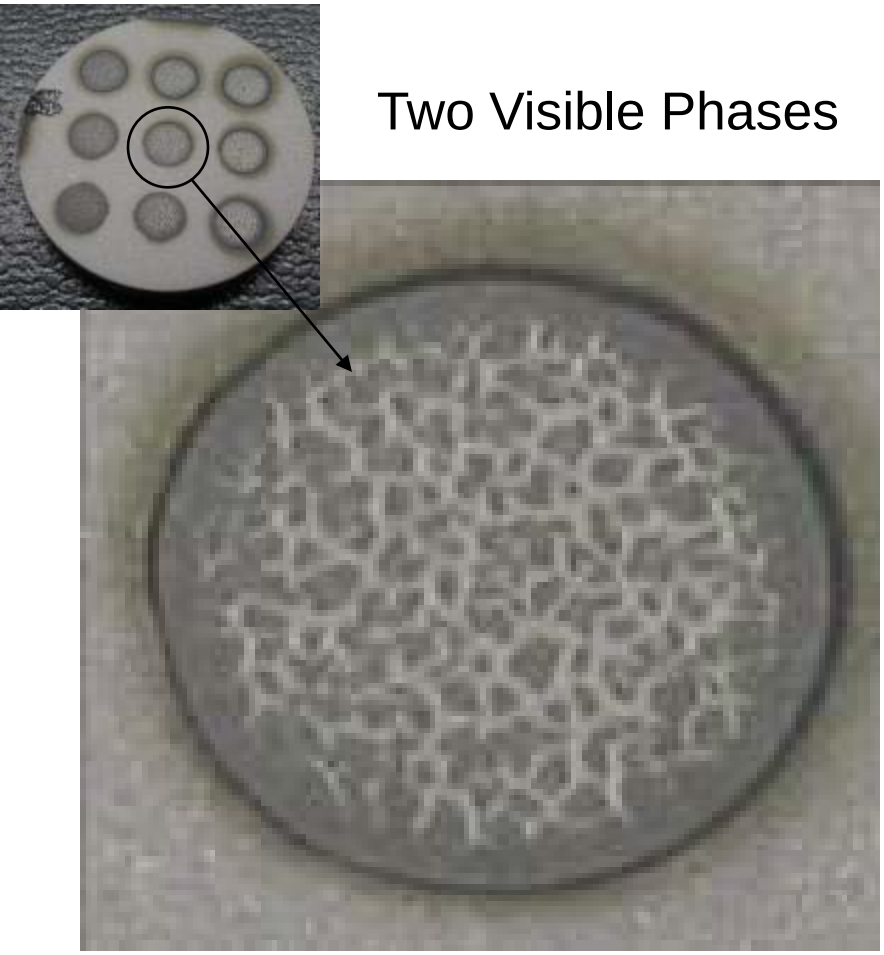


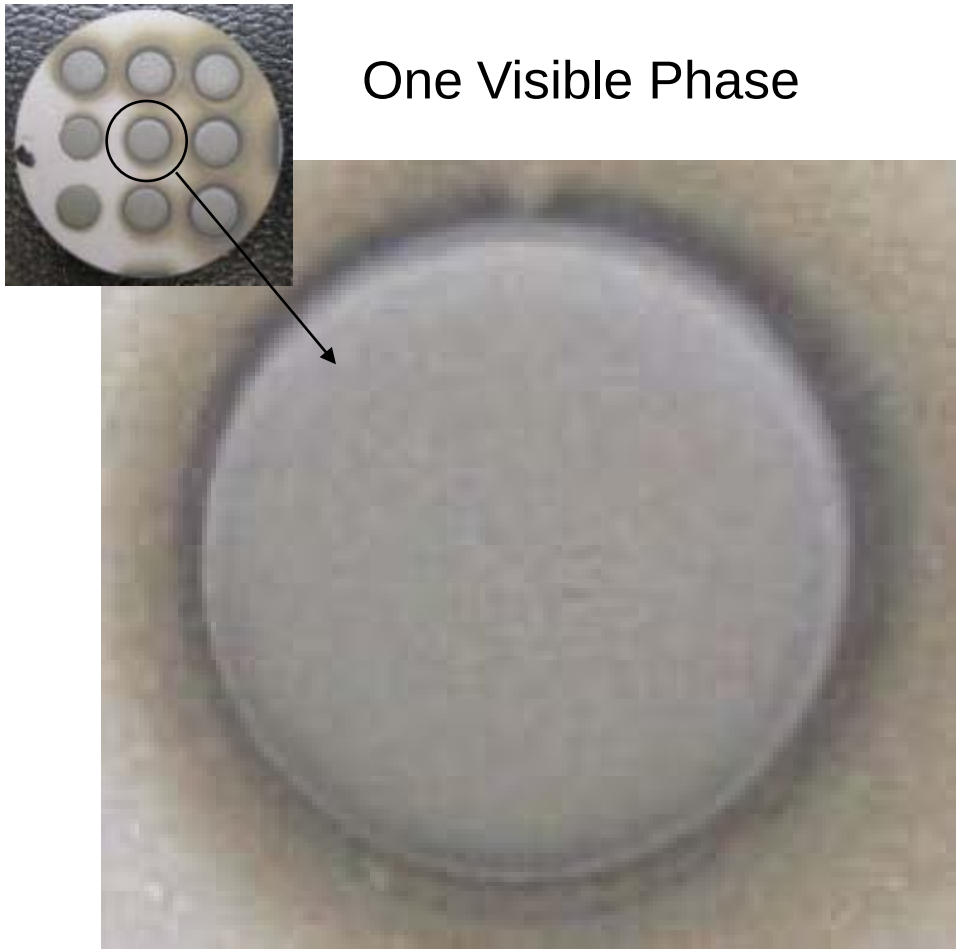





# Nanocomposites for Wear

Two phased aluminum alloys having nano-sized grains have been developed as potential replacement of hard chrome coating on landing gear



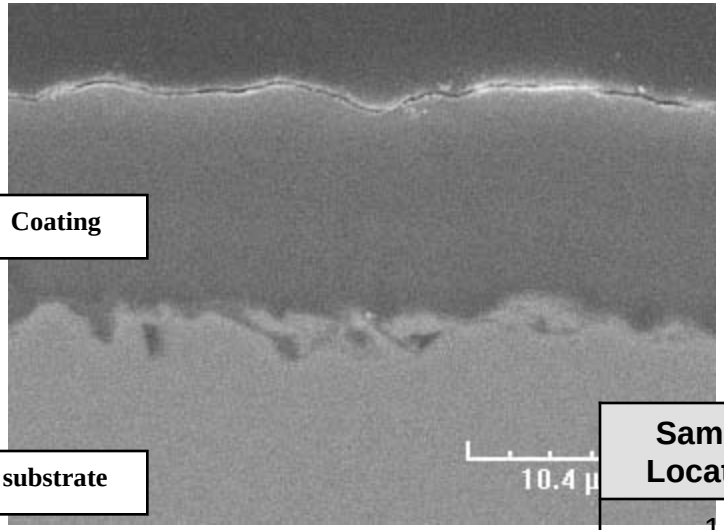

Appearance depends on position on substrate

# Hardness and Wear Testing


- Visual Inspection Lead to Selection of Pixels of Interest
- Mechanical Properties of Selected Pixels were Tested
- Compositions of pixels of interest measured using EDS and WDS
- Desired Compositions Were Deposited on Coupons for Mechanical Testing

# Wear Resistant Coatings (Nanocomposites)

## Wear Coating (coupon application)




Hardness / Modulus Testing

>3X Cr

>40X Cr

| Sample Location | Hardness (GPa) | Hardness (Vickers) | Elastic Modulus (GPa) | $H^3/E^2$ |
|---|---|---|---|---|
| 1 | 33.3 | 3087 | 189 | 1.03 |
| 2 | 35.2 | 3178 | 210 | 0.98 |
| 3 | 30.0 | 2586 | 171 | 0.92 |
| 4 | 35.4 | 3000 | 193 | 1.19 |
| 5 | 26.3 | 2319 | 136 | 0.98 |

Pin-on-disc testing

| | Sample Area of Wear Track [ microns$^2$ ] | Sample Wear Rate [ $10^{-4}$ mm$^3$/Nm ] |
|---|---|---|
| **DVTI - LG031** | 523 ± 58 | 2.74 |
| **DVTI - LG029** | 304 ± 66 | 1.59 |
| **Hard Chrome** | 1 558 ± 218 | 8.16 |

→ 3 to 5x reduction in wear rate over Cr

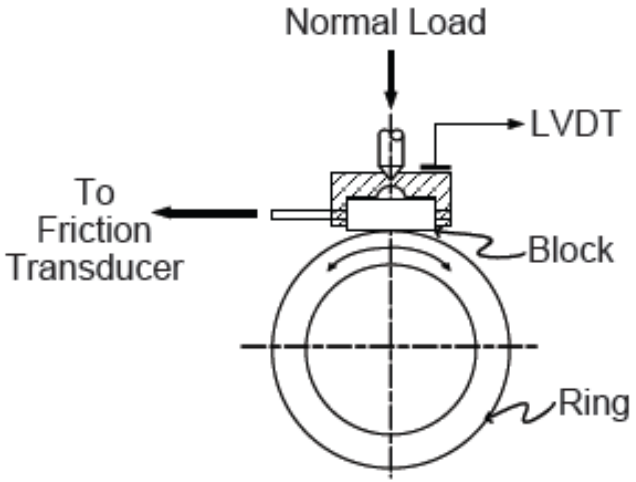
# Tribological Testing

## Light Weight Wear Coatings for Chrome Replacement on Aircraft Landing Gear

Metal-on-metal test Based on loads from a C-5 gudgeon pin

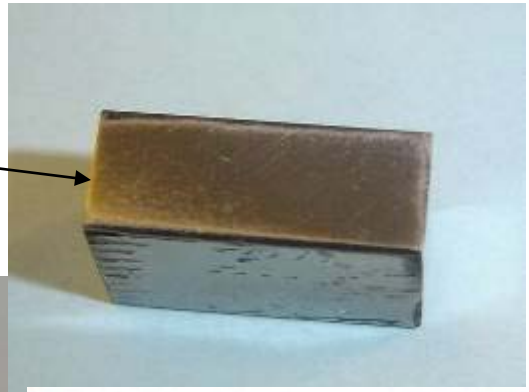
Configuration: block-on-ring 10-14˚ motion @ 0.75 in/s (load to be determined)

Materials: DVD OD coatings and EHC




Analysis will be optically measured size of the wear zone

Block and ring coated with wear resistant coating

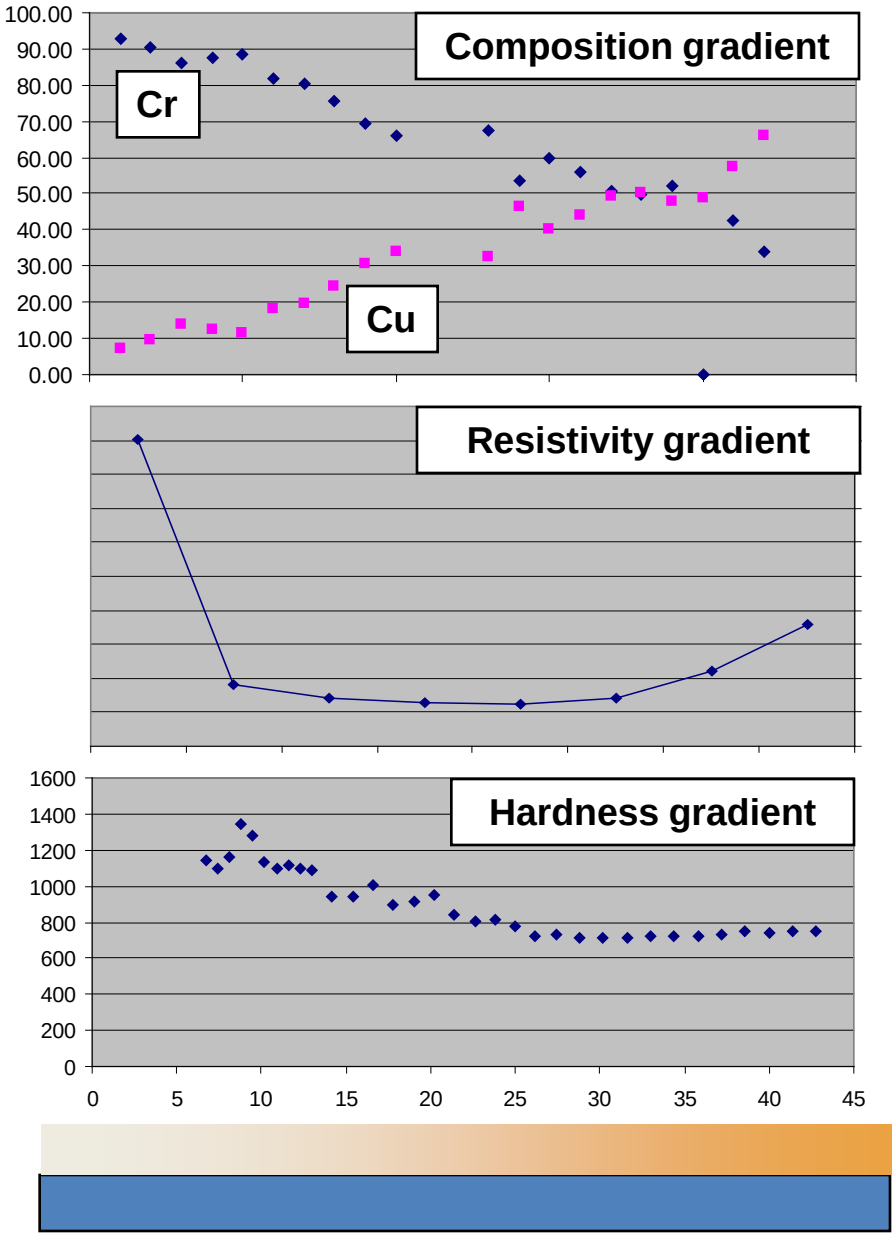


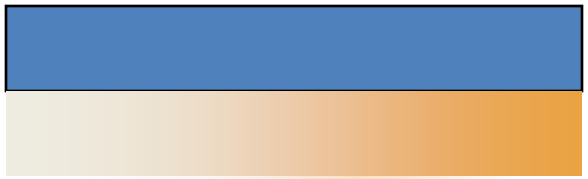

**DVTI-coated block vs. Cd plated ring**

Testing at 30 and 60 lb. load indicates that wear performance is essentially equal to that of hard chrome

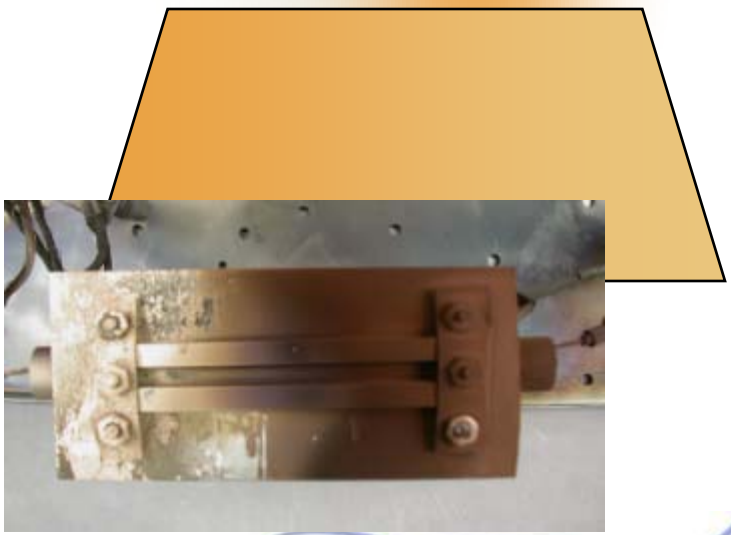
Testing Performed:
Steve Shafer – Battelle
shaffers@battelle.org

# Combinatorial Approach (Cu-Cr-N)



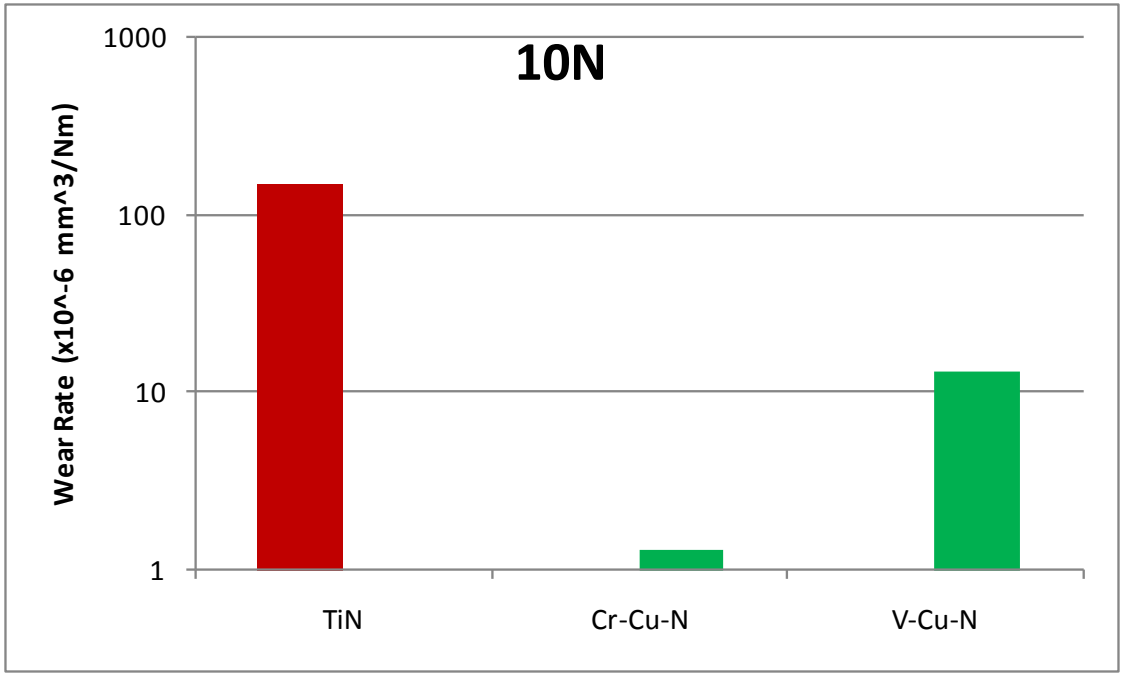



Effect of compositional variation on coating properties studied

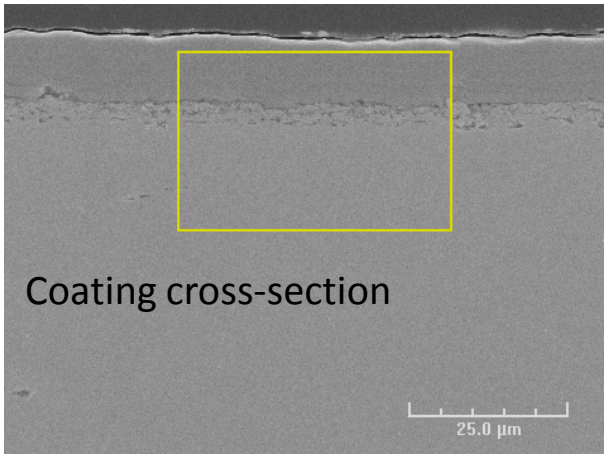


# Wear Resistant Coatings

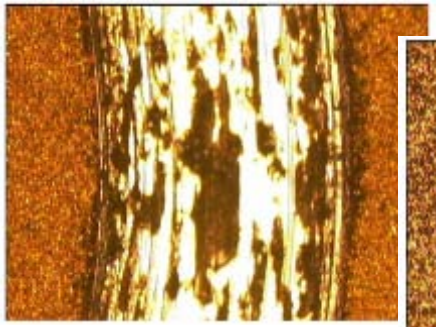
**Best performing pin-on-disc samples**



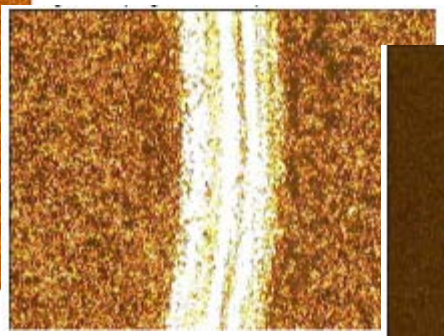

DVD deposited wear coating



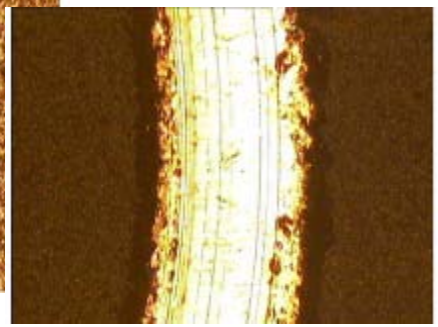

**TiN (reference)**



**DVTI Cr-Cu-N**

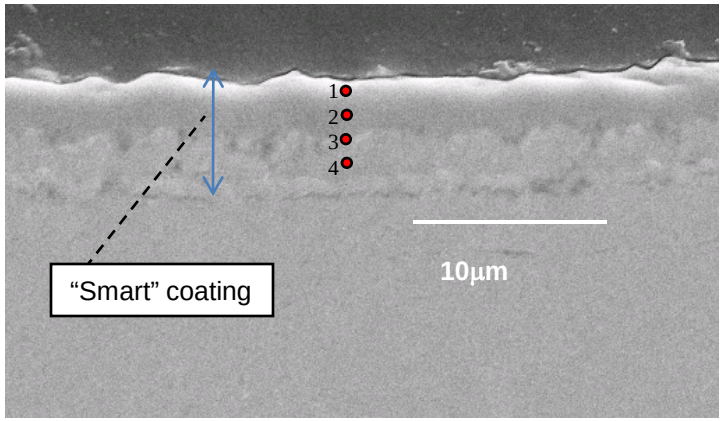


**DVTI V-Cu-N**



10N

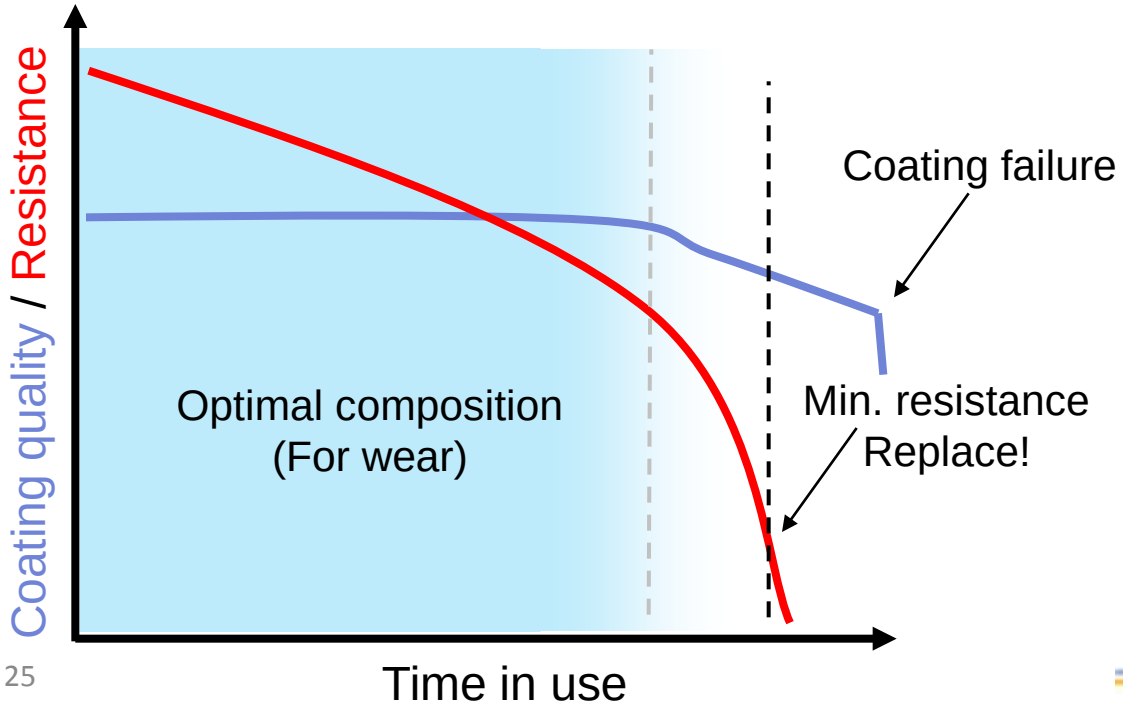
# Functional Gradient - Smart Wear Coatings



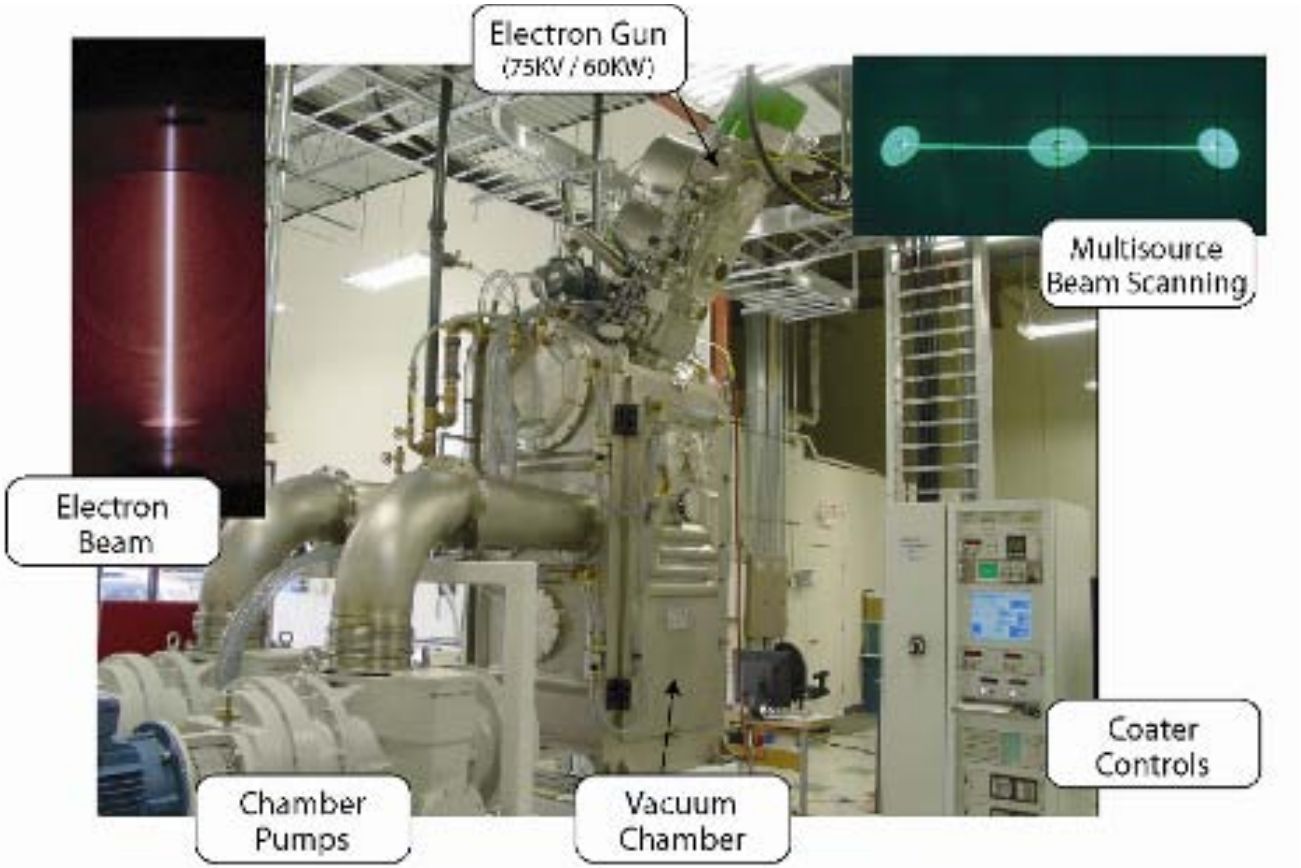

*SEM micrograph showing the microstructure of a V-Cu-N coating having a through thickness compositional gradient*

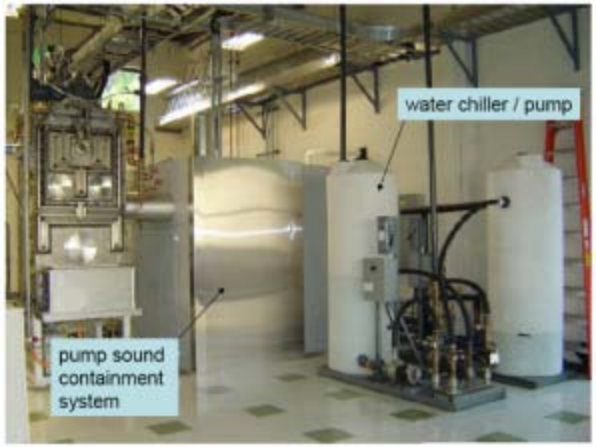
| Coating Location | Coating Composition (EDS) |
|---|---|
| 1 | 96V - 4Cu +N* |
| 2 | 96V - 4Cu +N |
| 3 | 51V- 49Cu +N |
| 4 | 8V-92Cu + N |

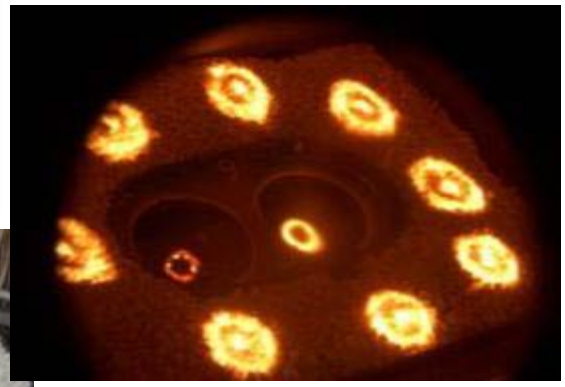
*EDS measured composition at different locations of the coating cross-section*



# Production Scale DVD Coater



# *Thanks To:*

Directed Vapor Technologies International, Inc.

The Directed Vapor Technologies International Team

U.S. AIR FORCE

Funding

**All of you!**