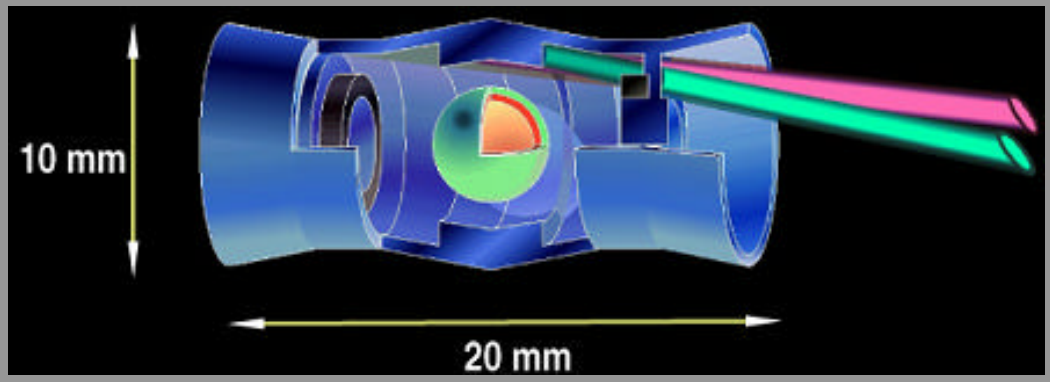
Fabrication of Functionally-Graded Inertial Fusion Energy (IFE) Targets



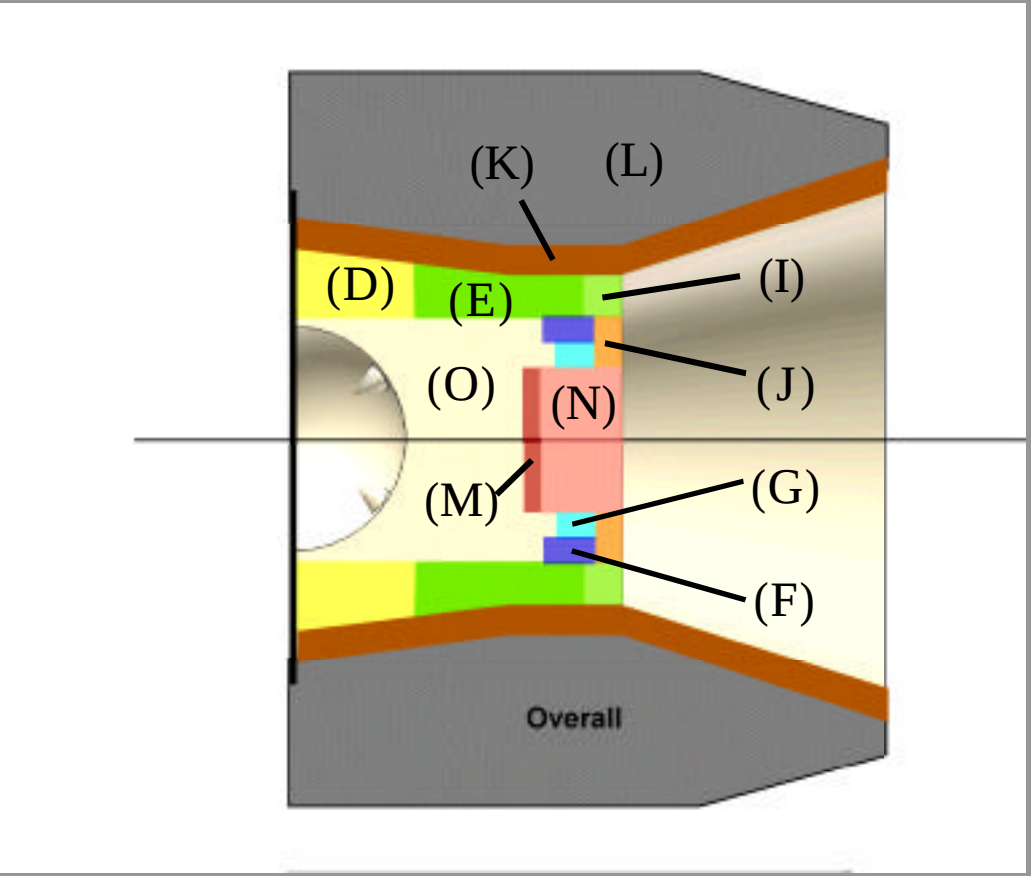
Target Fabrication Facility, Materials Science & Technology Division Los Alamos National Lab, jmaxwell@lanl.gov, ph: 505-665-4289

General Atomics, San Diego, CA

HIF Target Design

HIF Distributed Radiator Target (Densities in g/cm³)

- **(D) Au (.032)**
- **(E) CD2Au0.03 (0.011)**
- **(F) Fe (0.064)**
- **(G) Fe (0.083)**
- **(I) AuGd (0.10)**
- **(J) AuGD (0.26)**
- **(K) AuGd (0.099)**
- **(L) AuGd (13.5)**
- **(M) Al (0.055)**
- **(N) AuGd (0.099, 1.0, 0.5)**
- **(O) D2 (0.001)**



- **Callahan & Tabak, Nuc. Fus. V.39 (884)**

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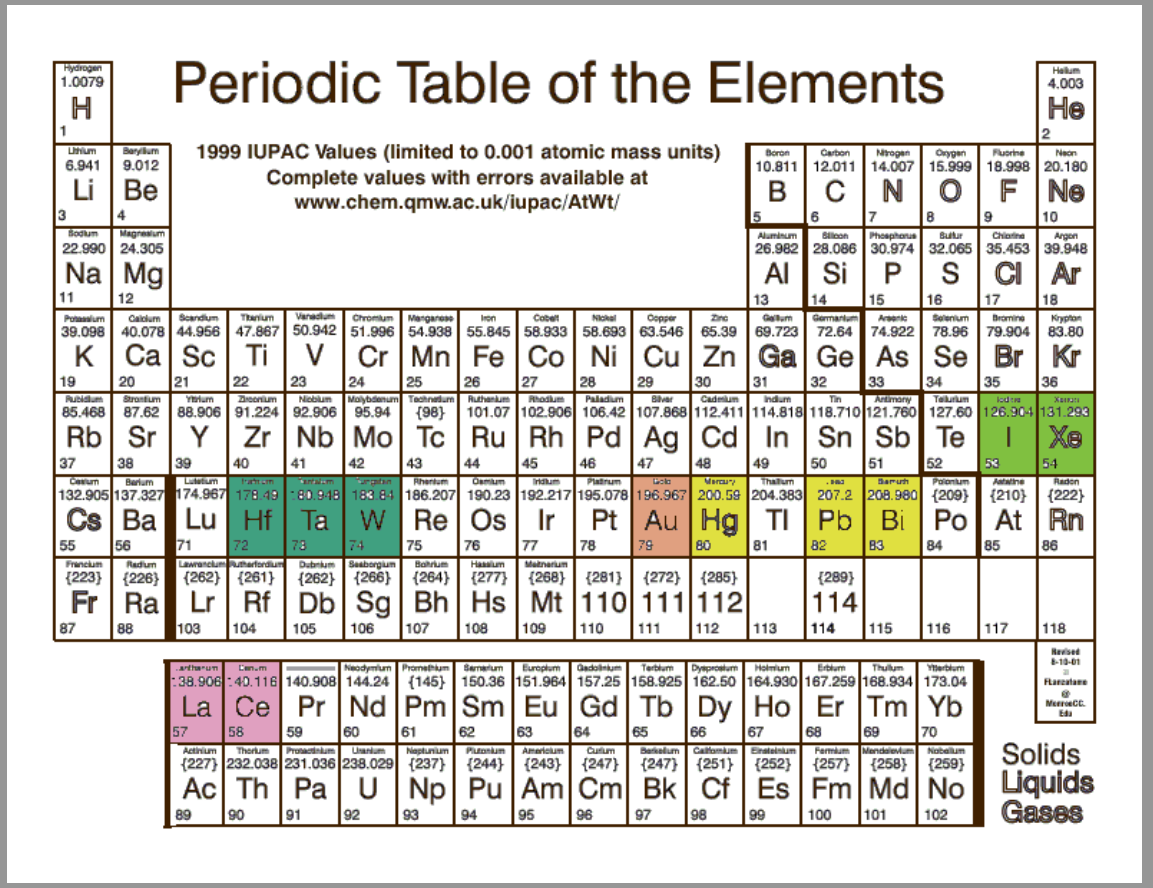
Low-p, High-Z Lattices

- **Material Substitutions**
  - **AuGd→**
    - Alloys A-B
  - **High-Z (A)→**
    - La, Ta, Hf, W
  - **High-Z (B)→**
    - Hg, Pb, Bi, I



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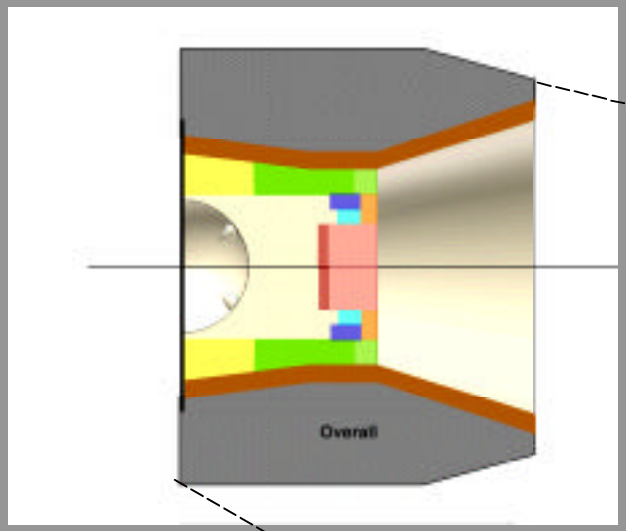
Low-p, High-Z Lattices

Additional Substitutions

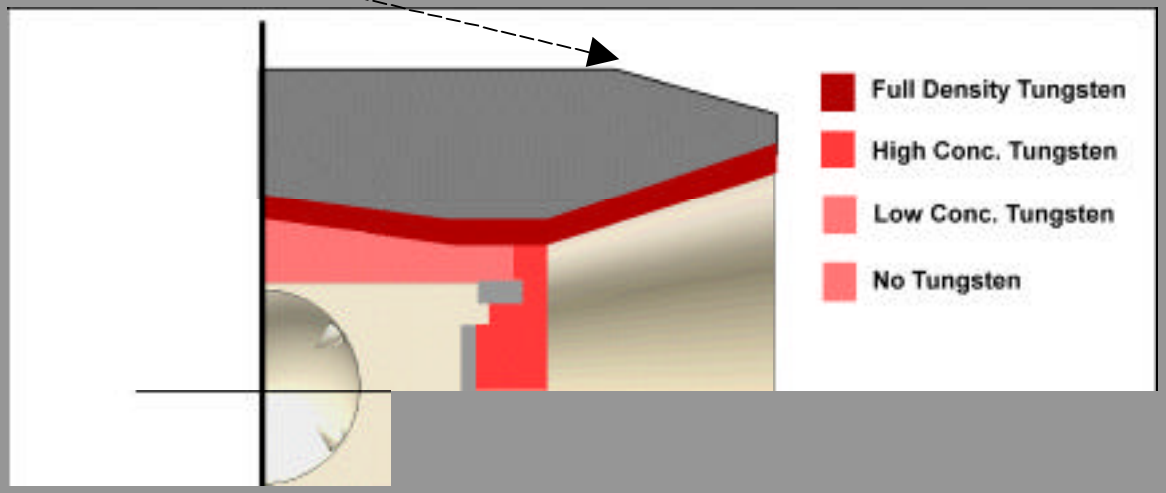
- **CD2Au Foam→**
  - High-Z metals in B lattice
- **Al →Boron Lattice**
- **Fe →High–Z metals in B or Si lattice**
- **CD2 →Boron Lattice**

Simplifies to Three Elements

Low-Density Lattice



- Relative Tungsten Concentration vs. Location within Hohlraum



- Callahan & Tabak, HIF Distributed Radiator Target Nuc. Fus. V.39 (884)

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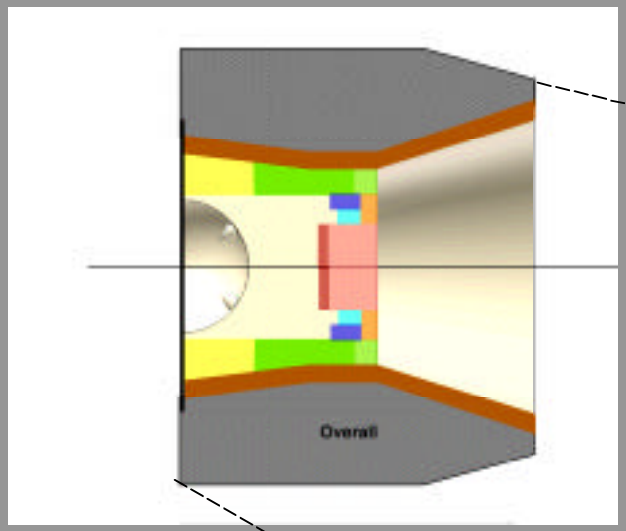
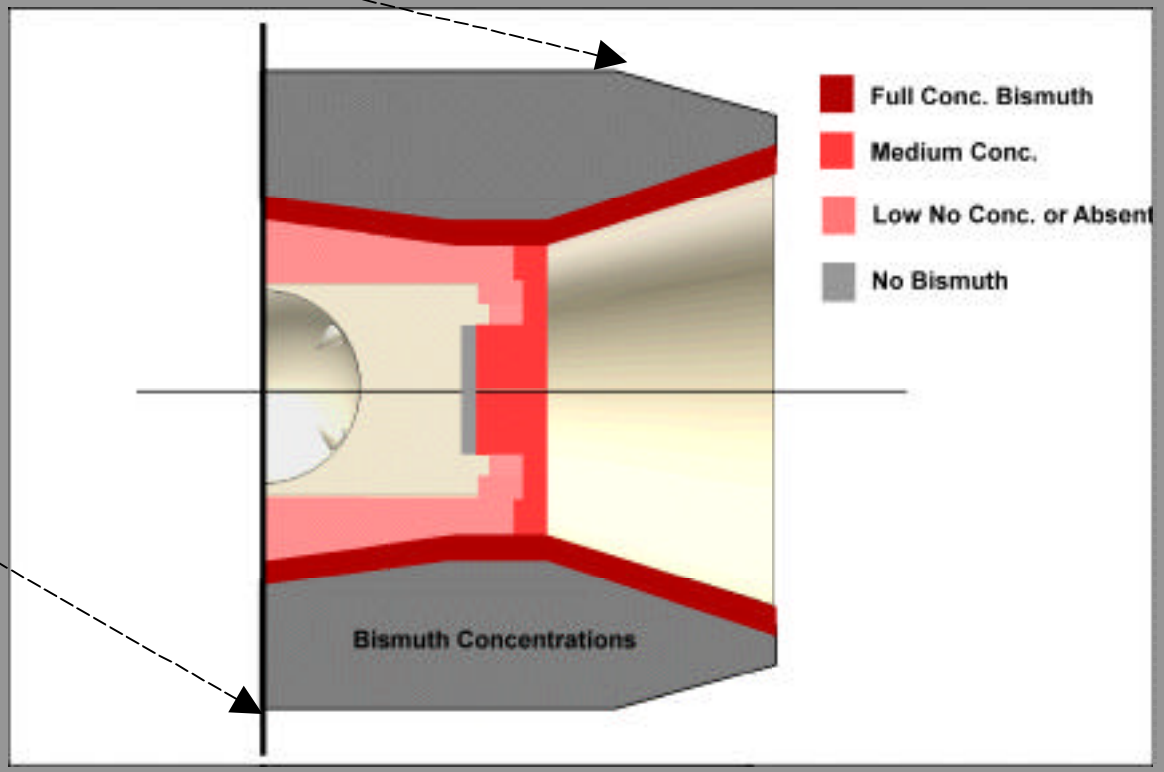
Low-Density Lattice



- **Relative Bismuth Concentration vs. Location within Hohlraum**



- **Callahan & Tabak, HIF Distributed Radiator Target Nuc. Fus. V.39 (884)**

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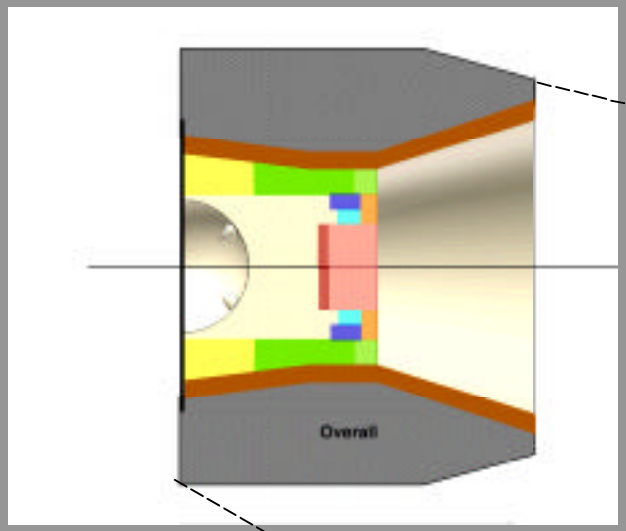
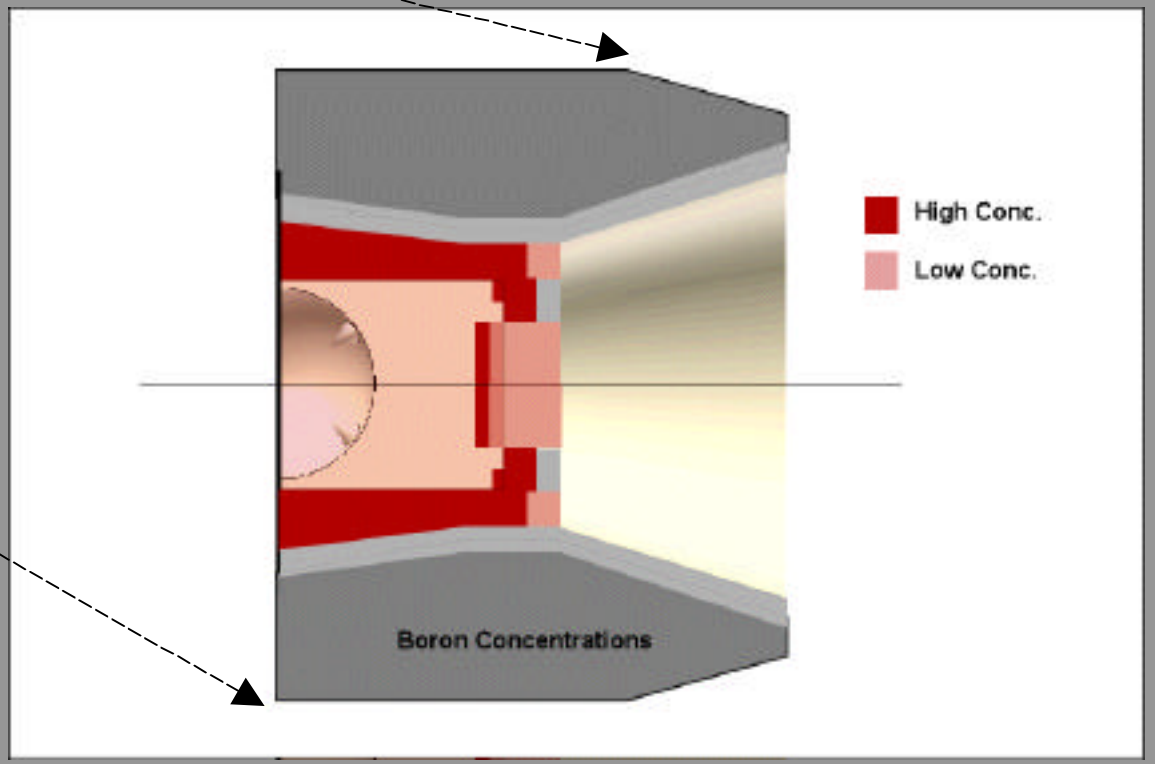
Low-Density Lattice



- **Relative Boron Concentration vs. Location within Hohlraum**



- **Callahan & Tabak, HIF Distributed Radiator Target Nuc. Fus. V.39 (884)**

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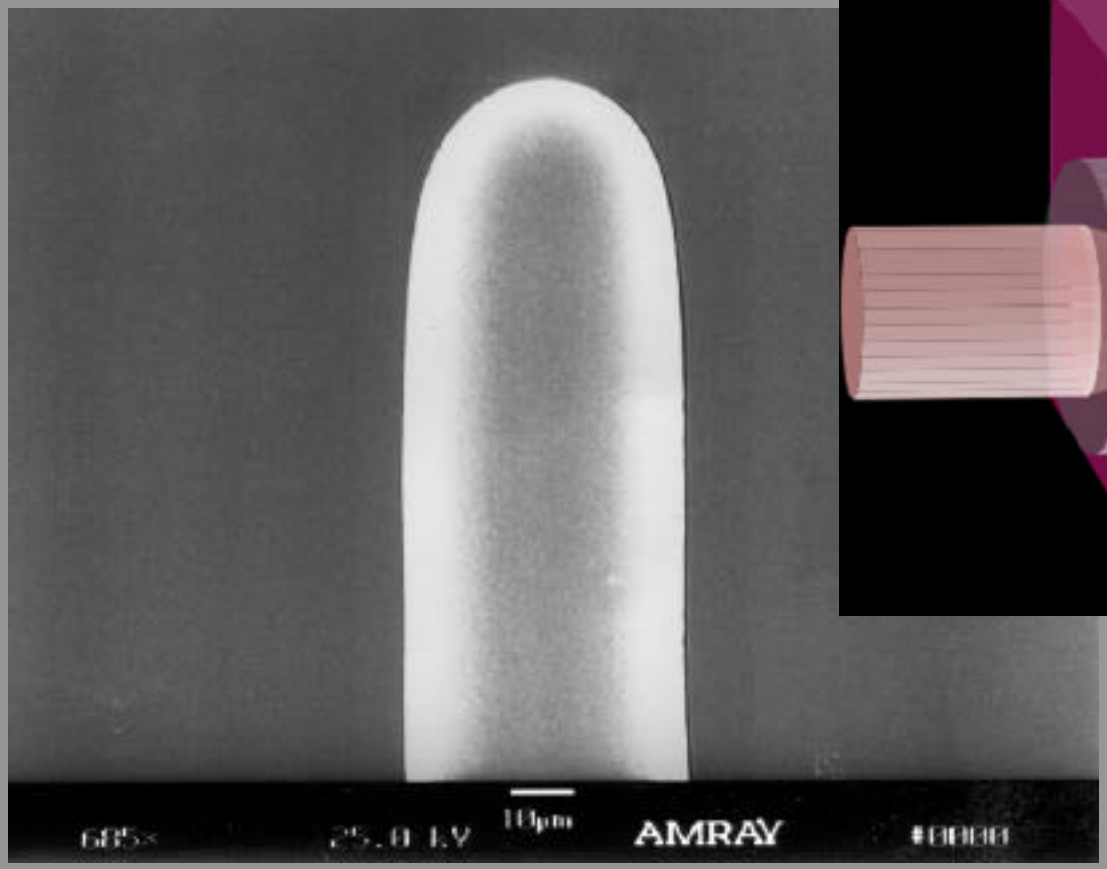
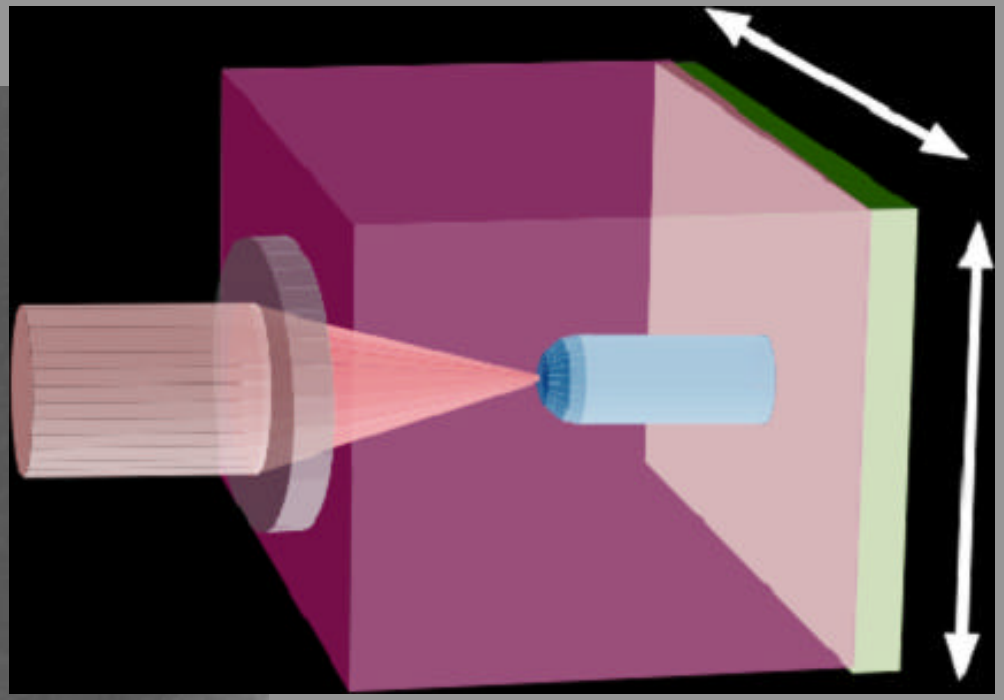
What is LCVD?





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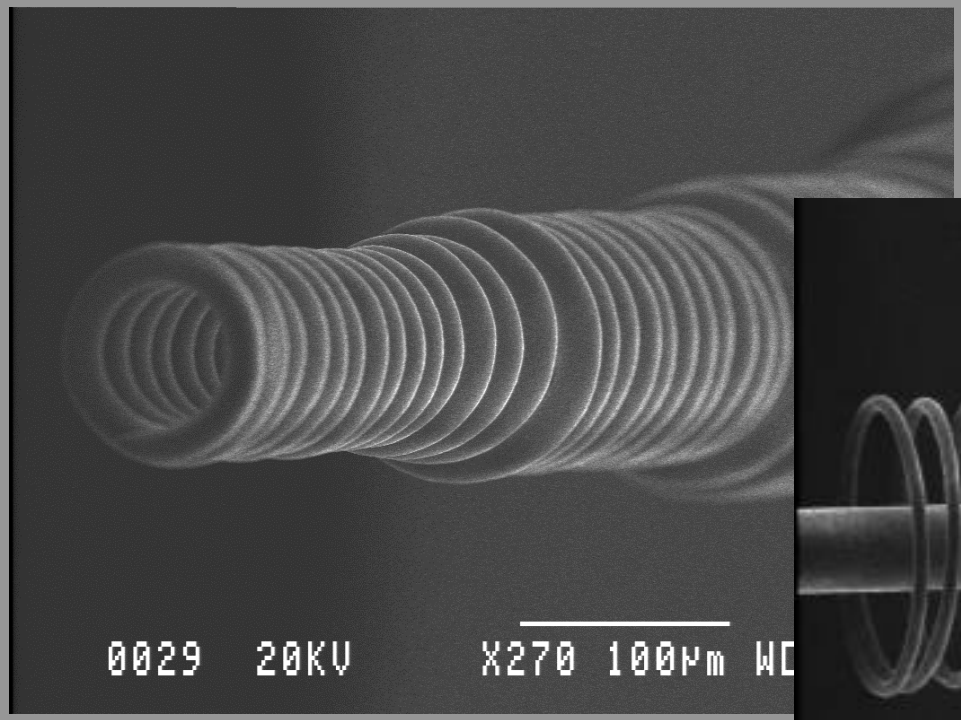
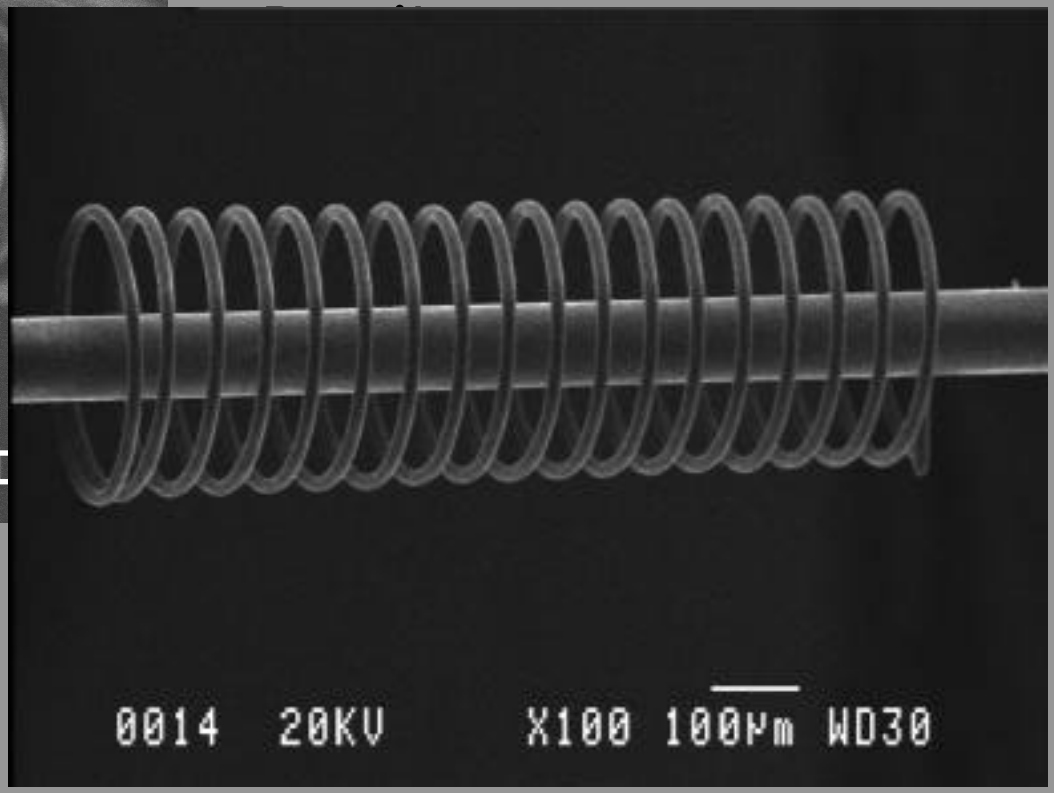
Engineered Materials



- **Variable Spacing, Variable Fiber Diameter→Variable**



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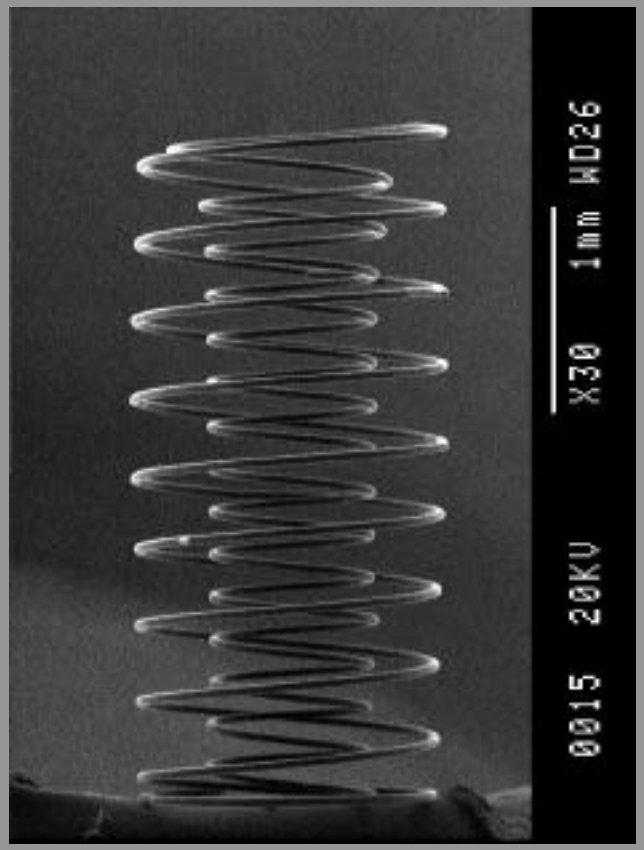

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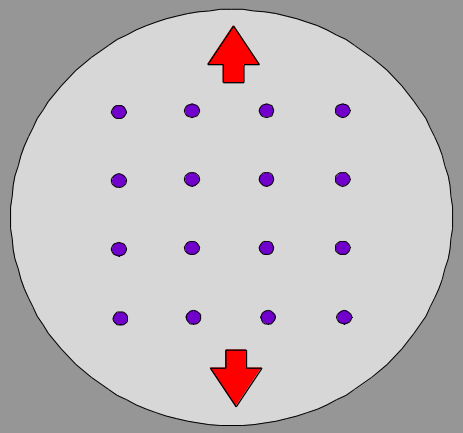
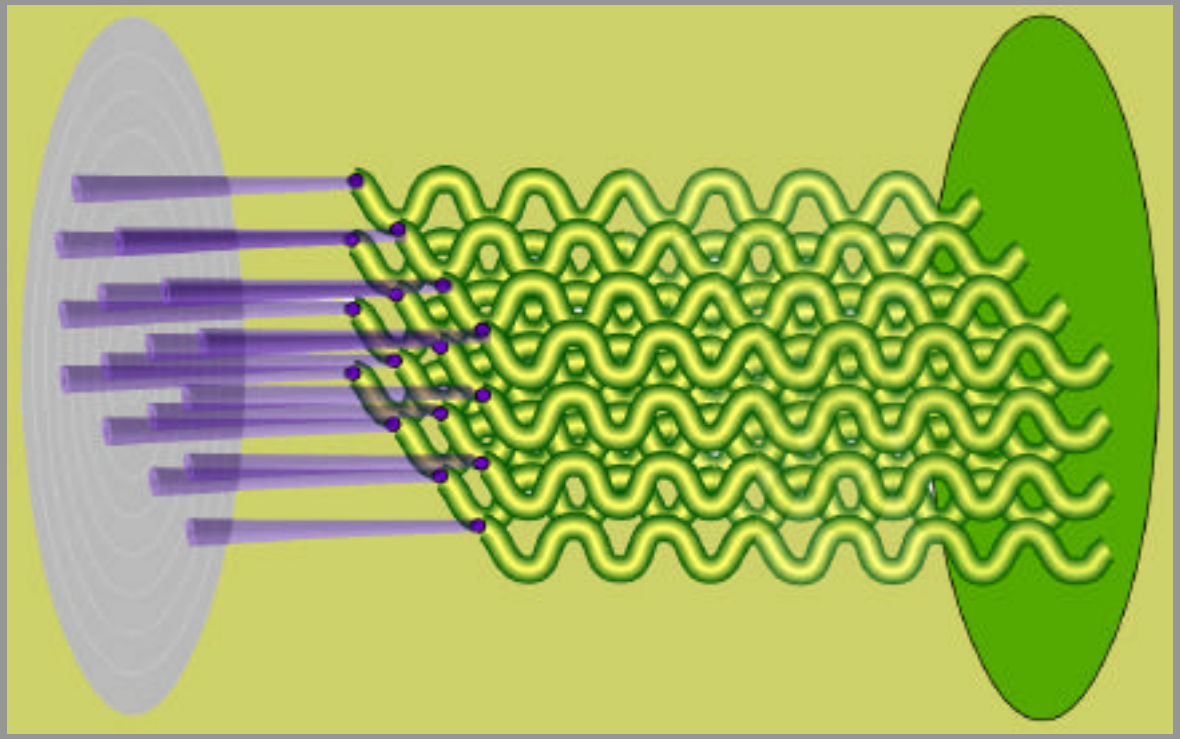
Engineered Lattices

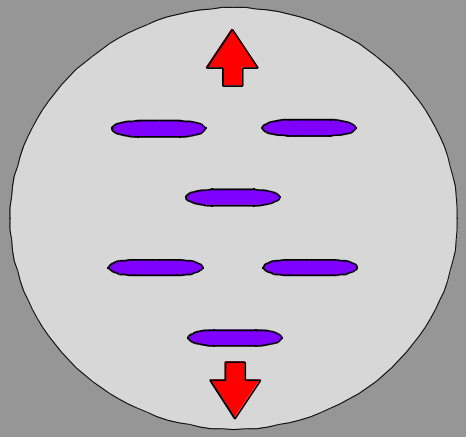
- **Diffractive Optic Spot Array**
  - **2-D Grid of Gaussian Spots**
  - **Source Oscillated During Growth to Form "Snake-like" Fibers**

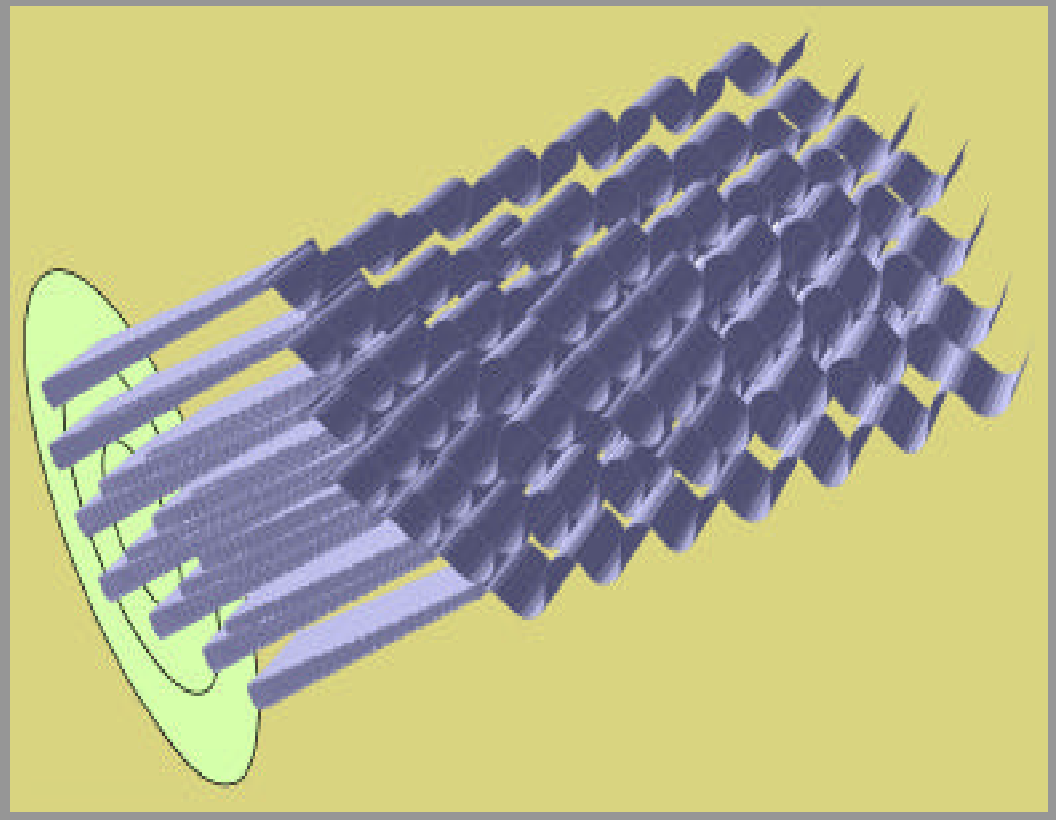




Engineered Lattices

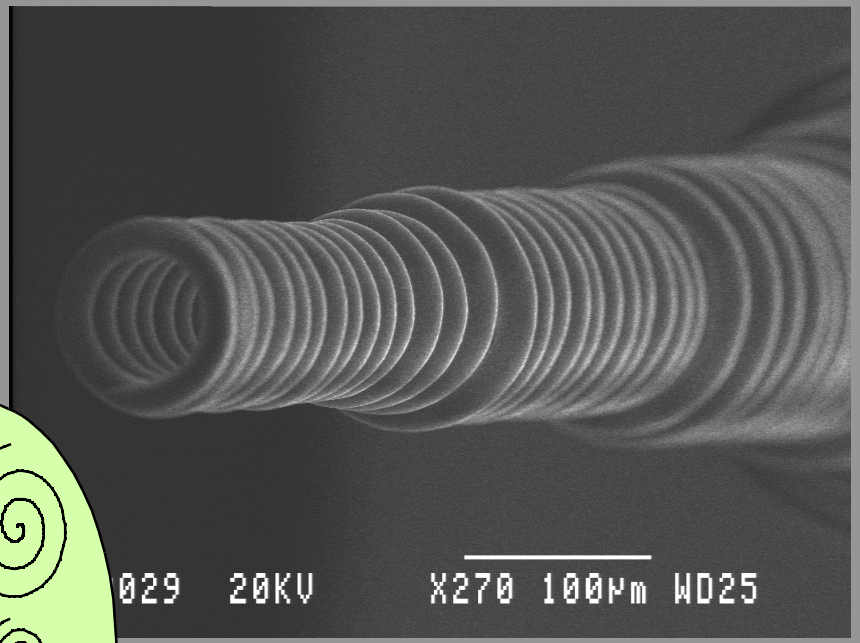
- **Line-Source Diffractive Patterns**
  - 2-D grid of lines
  - Source Oscillated During Growth to Form Ribbon-like Structures

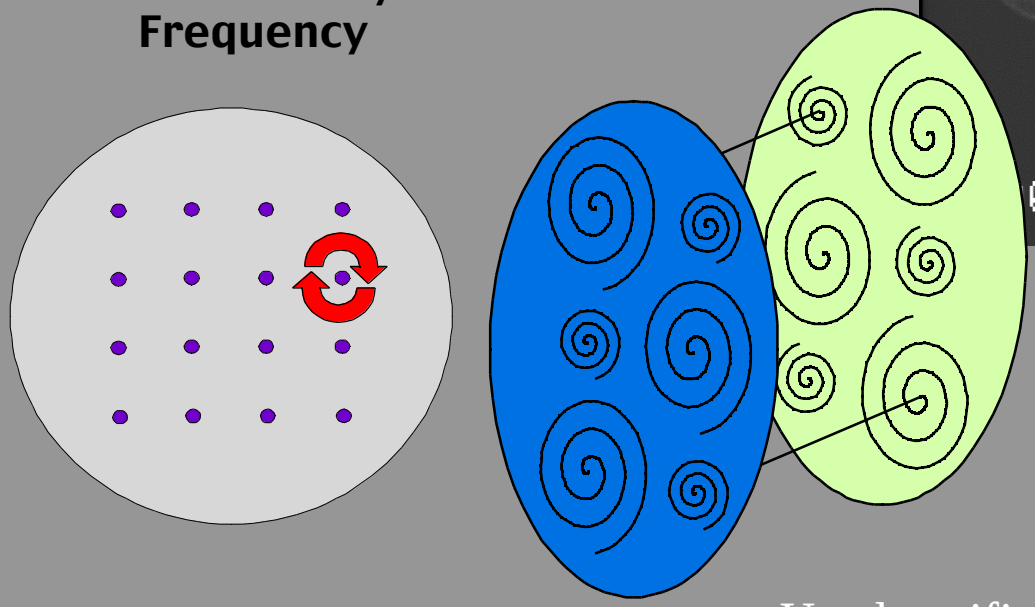




Laser Deposition of Lattices

- **Spiroidal Lattices**
  - 2-D array of Dots
  - Pattern Oscillates Rapidly in 2-D
  - Amplitude (Radius) of Oscillation also varies Sinusoidally at Lower Frequency





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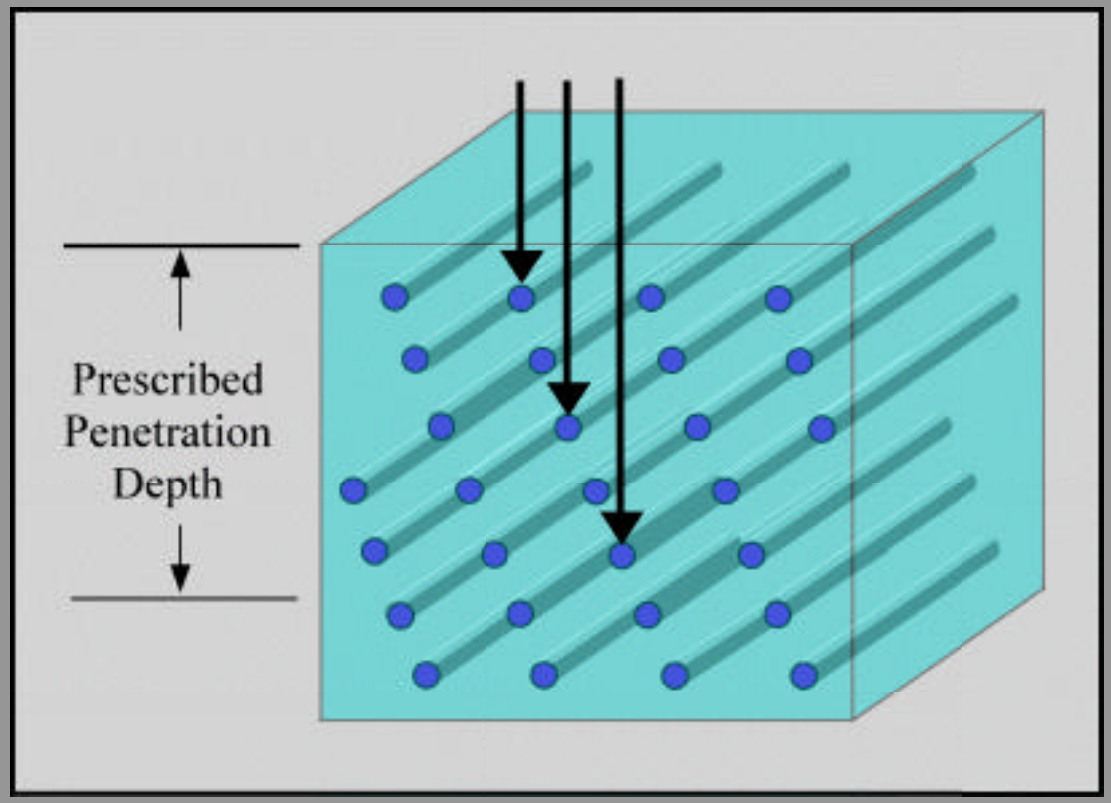
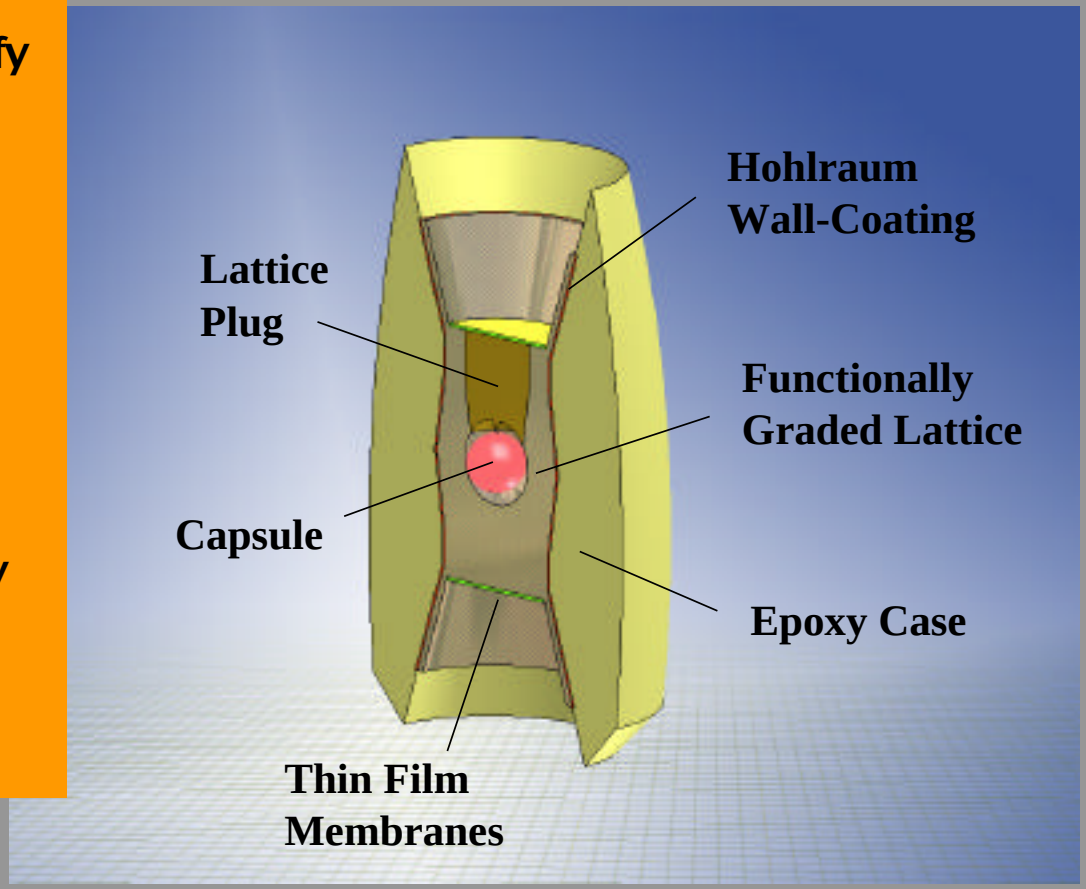
Engineered Lattices

- **Hohlraum Low-Density "Foams"**
- **Create Materials that Exhibit:**
  - **Variable Ion Penetration Depth**
  - **Variable (Low) Density**
  - **Variable, High-Z Doping**
  - **Variable X-ray Absorption**
  - **Handling-Shock Resistant, Mechanically Elastic Materials**
  - **Variable Geometries**



HIF Target Design

- **Final Assembly**
  - Uses Functionally-graded Engineered Foams to Simplify Fabrication
- **Design for Manufacture:**
  - Builds from Inside Out
  - Avoids Precision Machining Steps
  - Avoids Assembly Steps
  - Avoids "Split" Hohlraum Assemblies
  - Auto-aligned Final Assembly Step for Capsule Insertion
  - Fewest Process Steps
  - Uses Low-cost Materials & Processes



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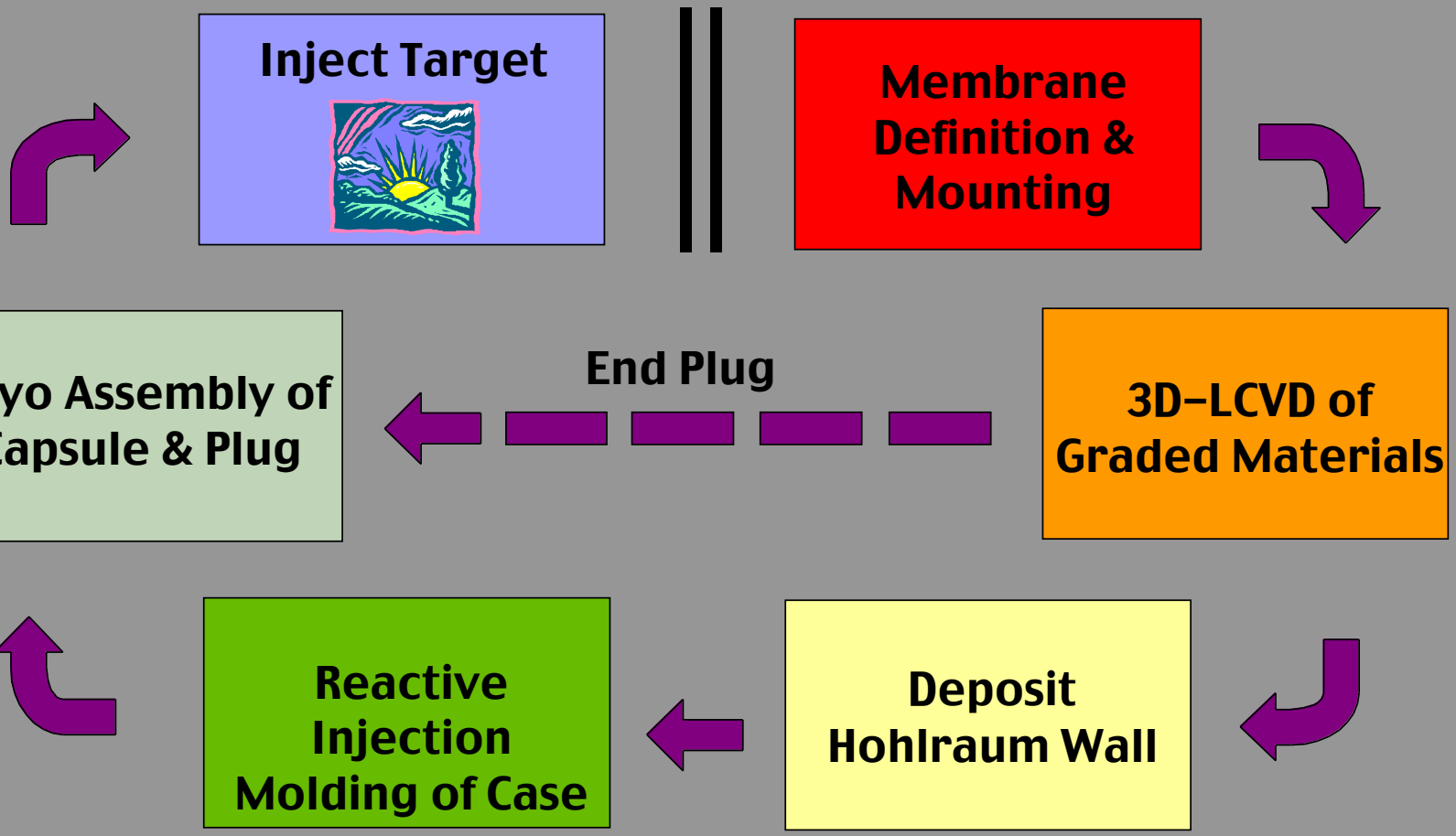
Process Sequence



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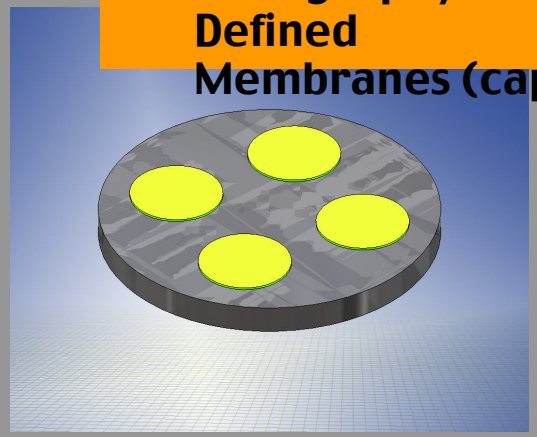
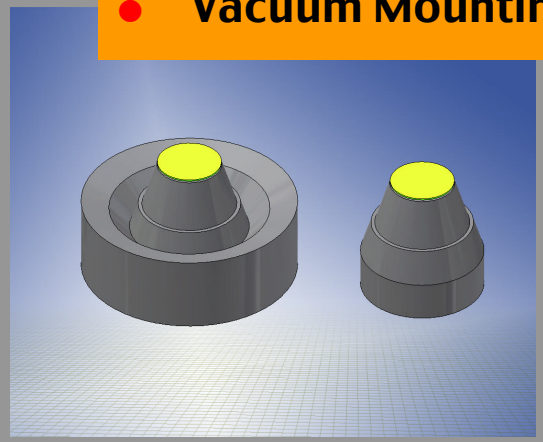
Fabrication Sequence

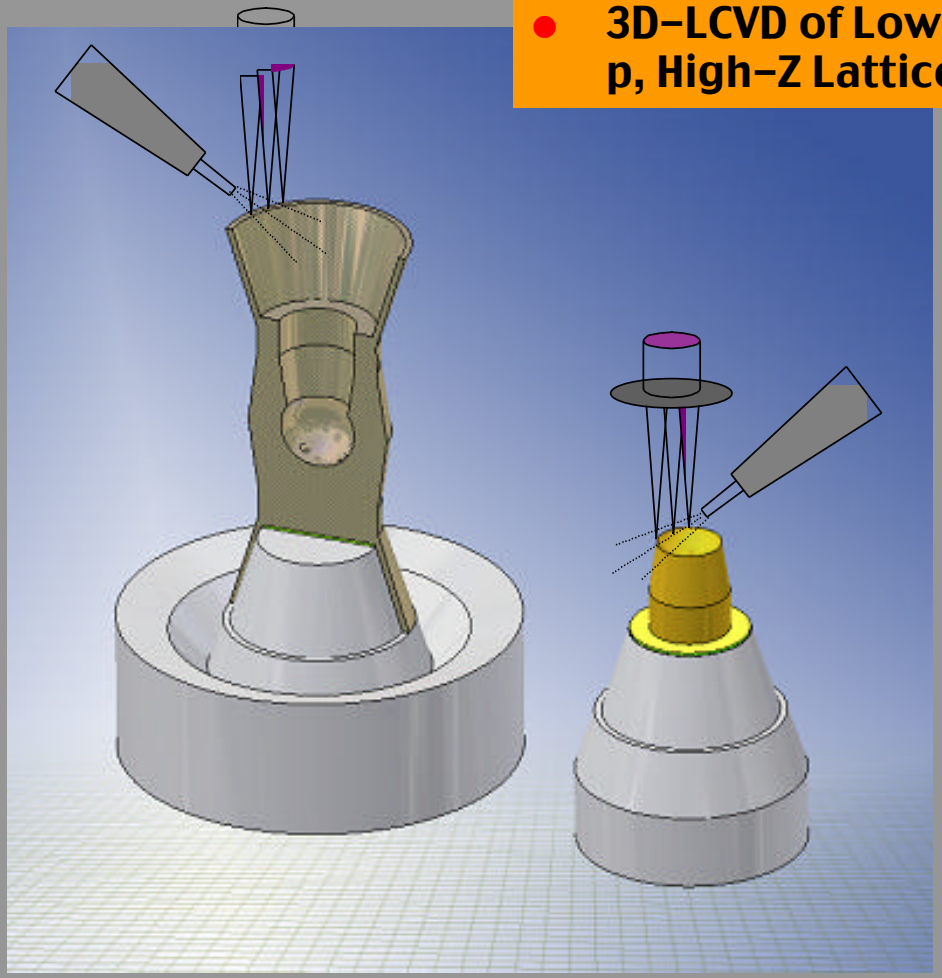
- **Lithography–Defined Membranes (caps)**



- **Vacuum Mounting**



- **3D–LCVD of Low–p, High–Z Lattices**



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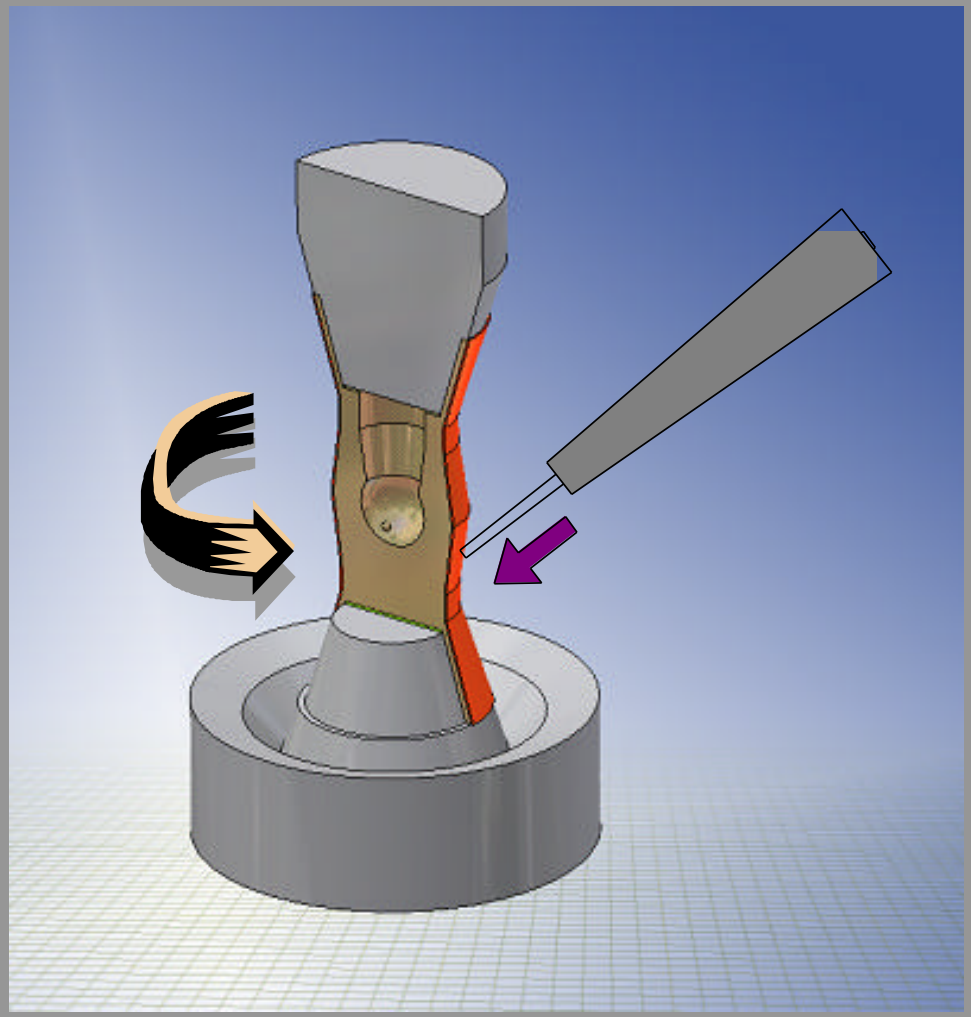
Fabrication Sequence



- **Coat Hohlraum Wall**
  - **Closes Exterior of Lattice**
  - **Builds thick Overlayer for Support & Containment**
- **Relevant Processes**
  - **Plasma Spray**
  - **Flame Spray**
  - **DW LCVD**

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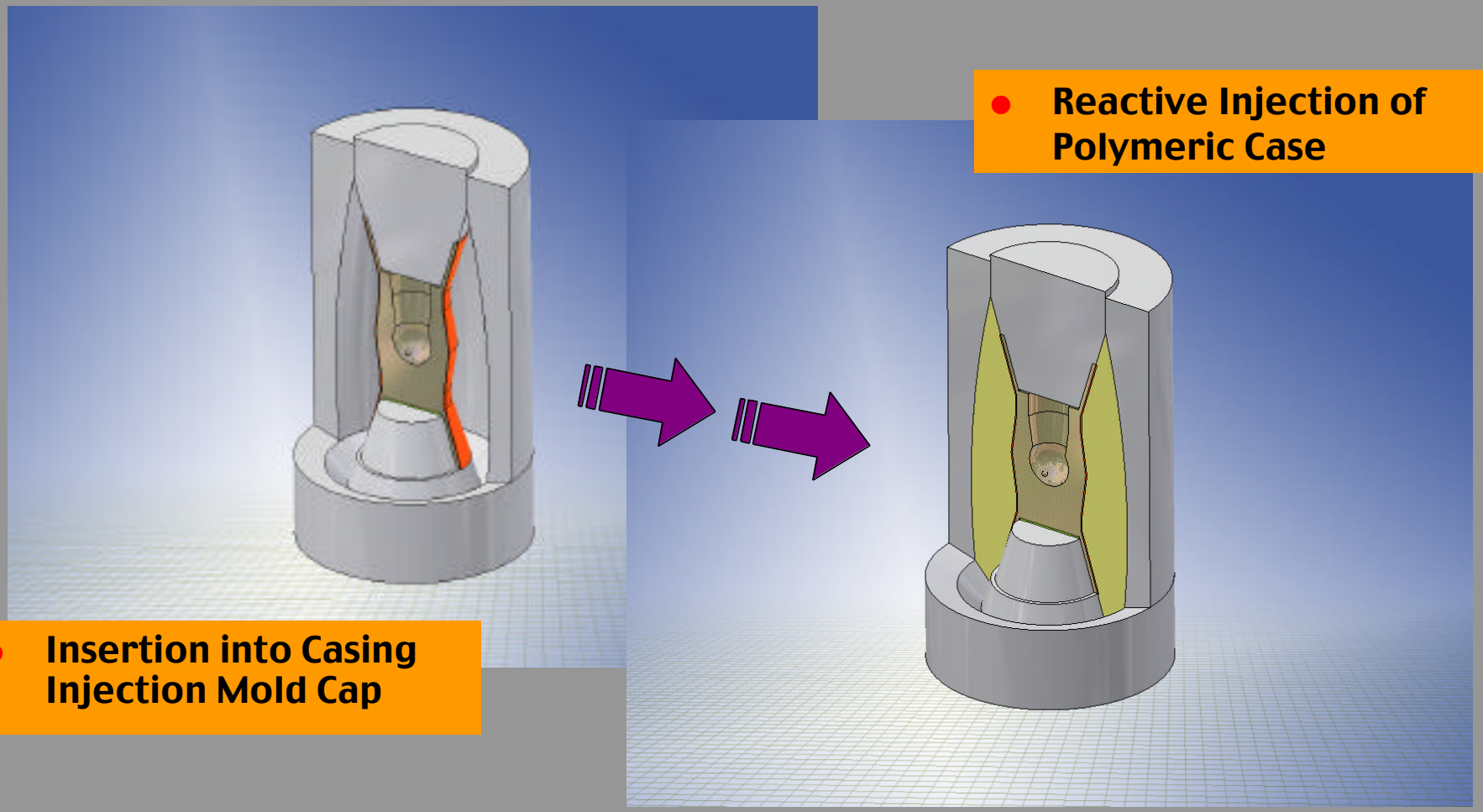
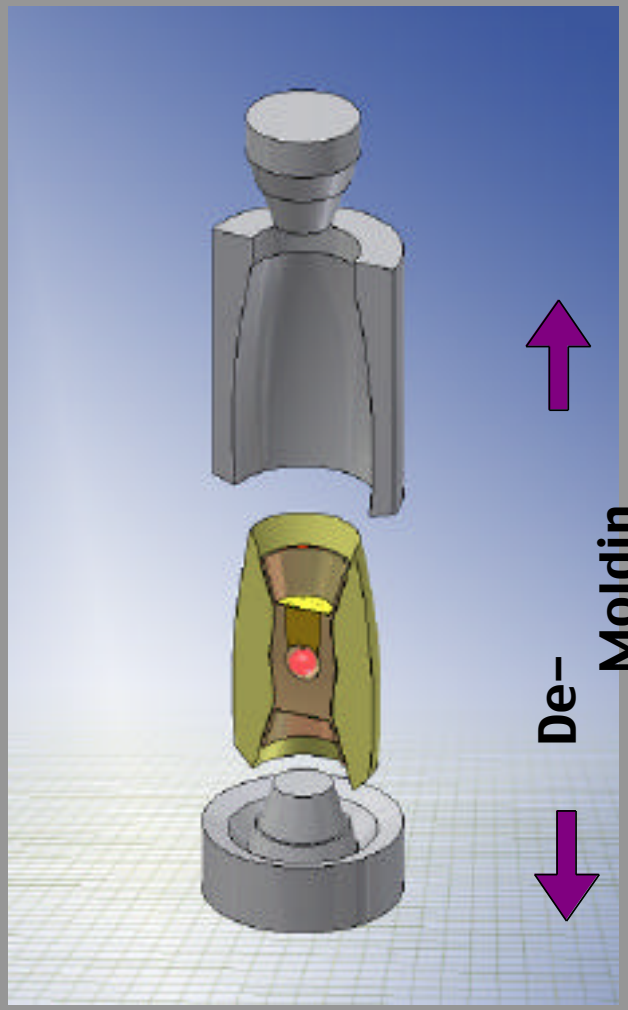
Fabrication Sequence

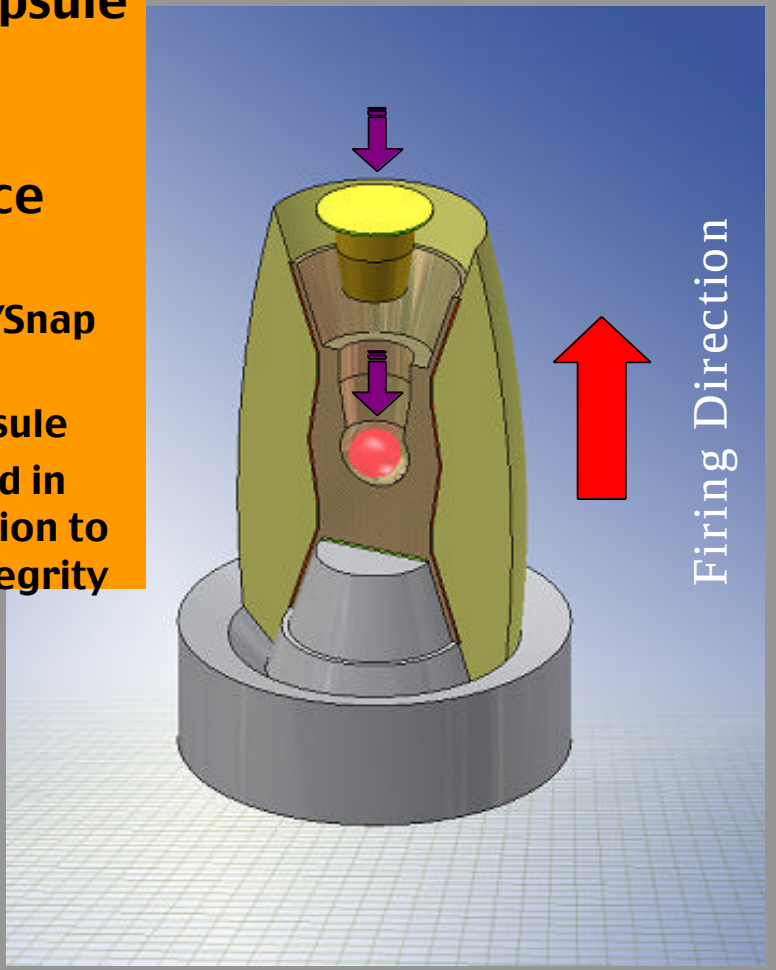


- **Insertion into Casing Injection Mold Cap**
- **Reactive Injection of Polymeric Case**

Fabrication Sequence

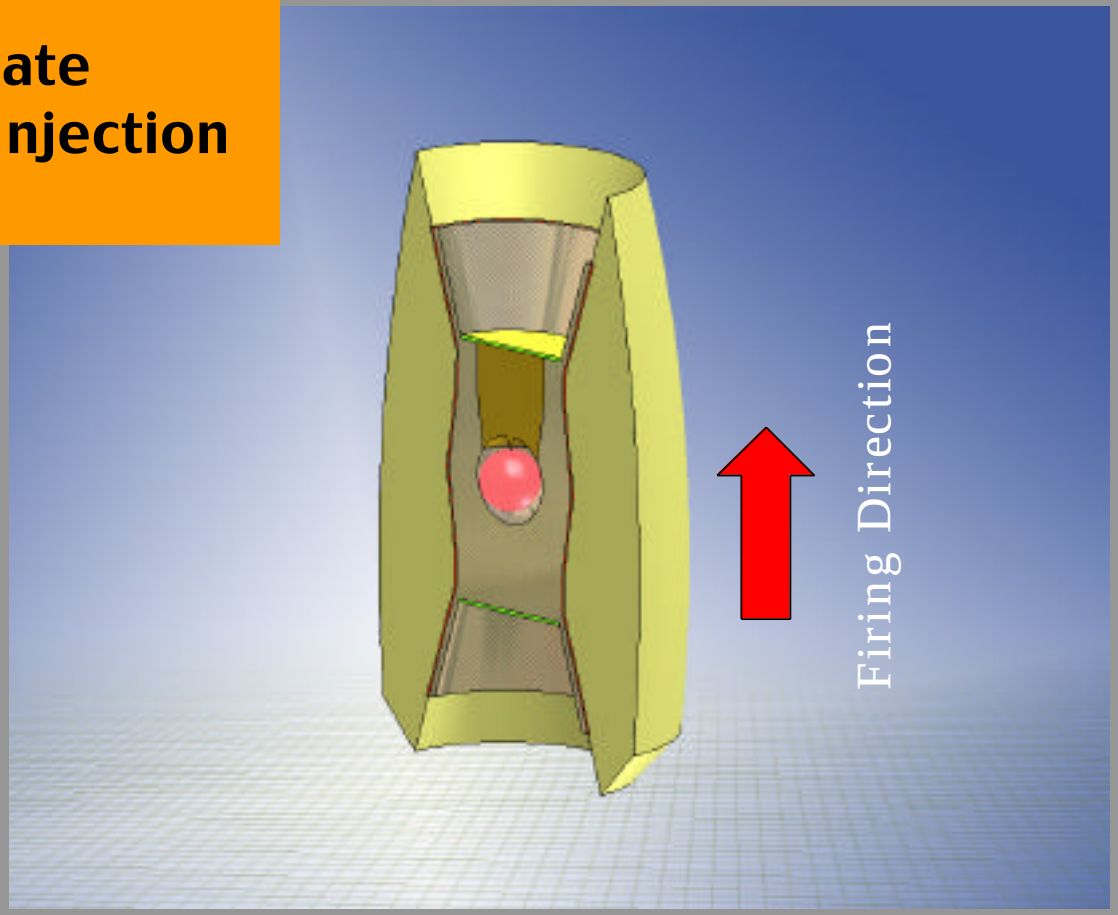


- Cryogenic Capsule Placement
- Insertion of "Foam" Lattice Cap
  - Auto-aligns/Snap Fit
  - Secures Capsule
  - Plug Oriented in Firing Direction to Maintain Integrity



Fabrication Sequence

- **Immediate Target Injection**



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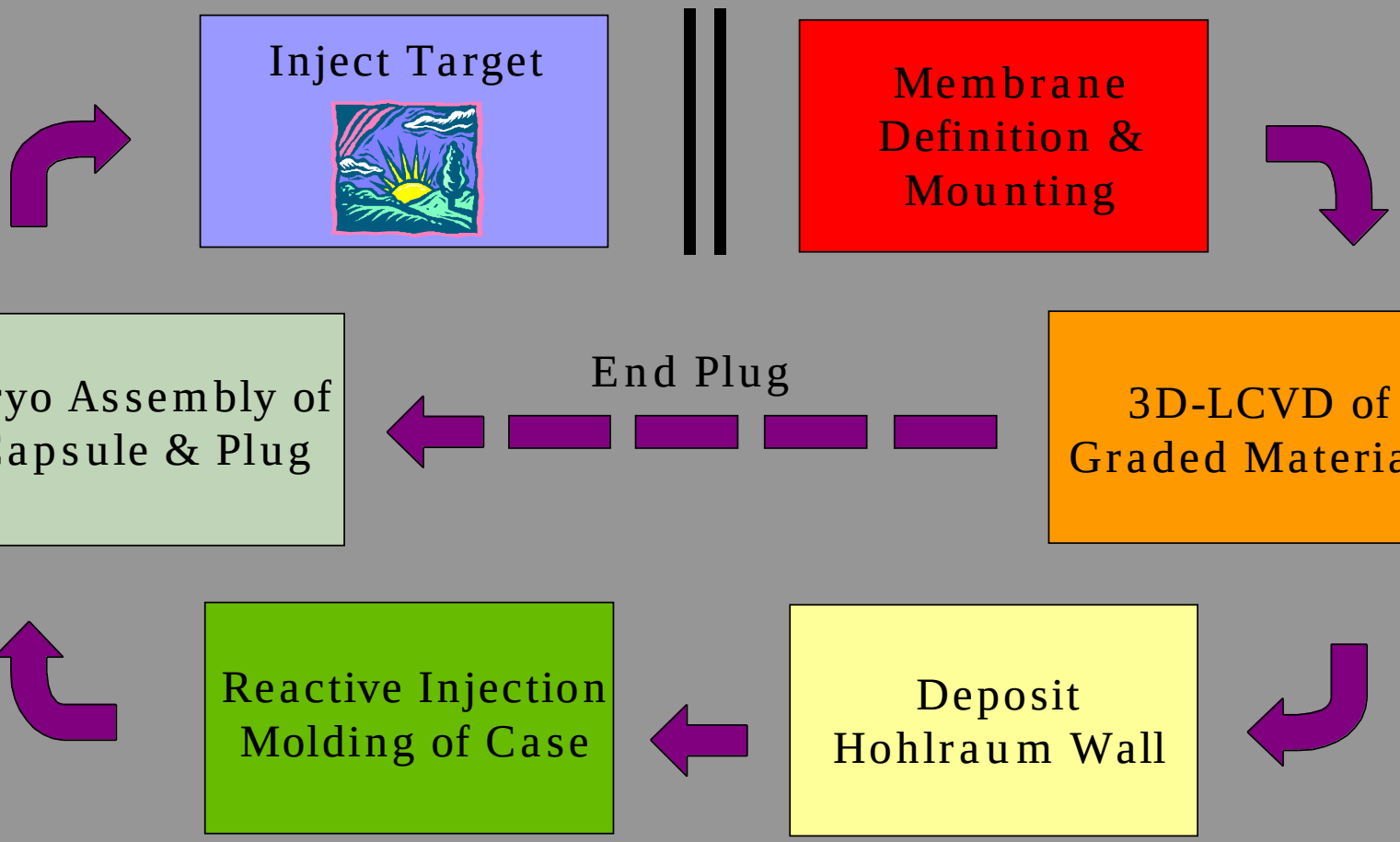
Process Sequence



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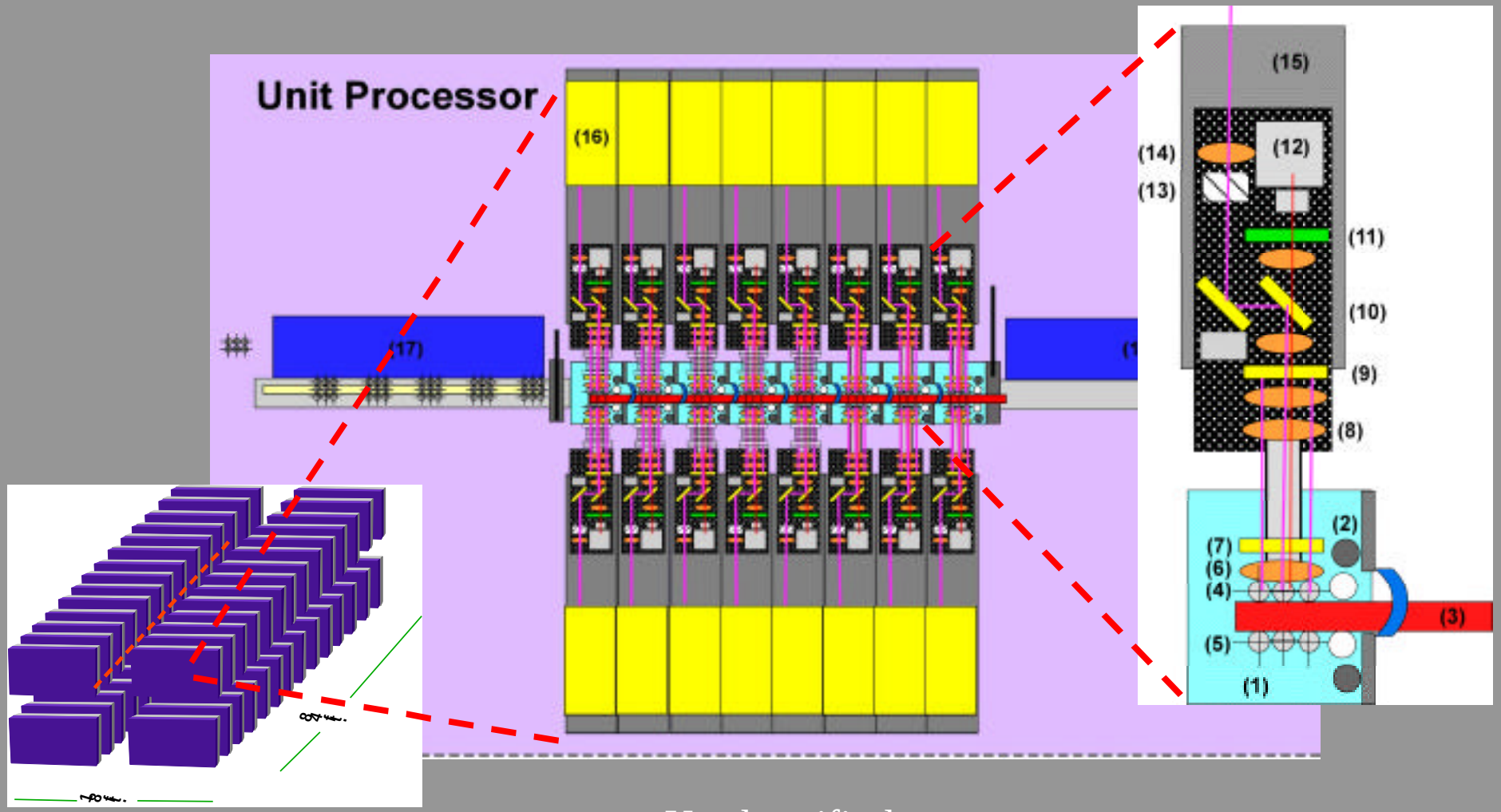
Manufacturing Plant



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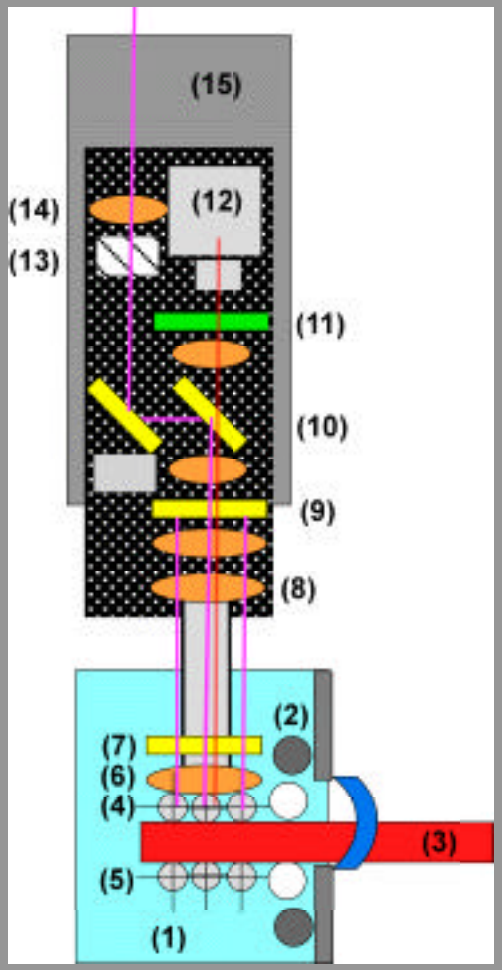
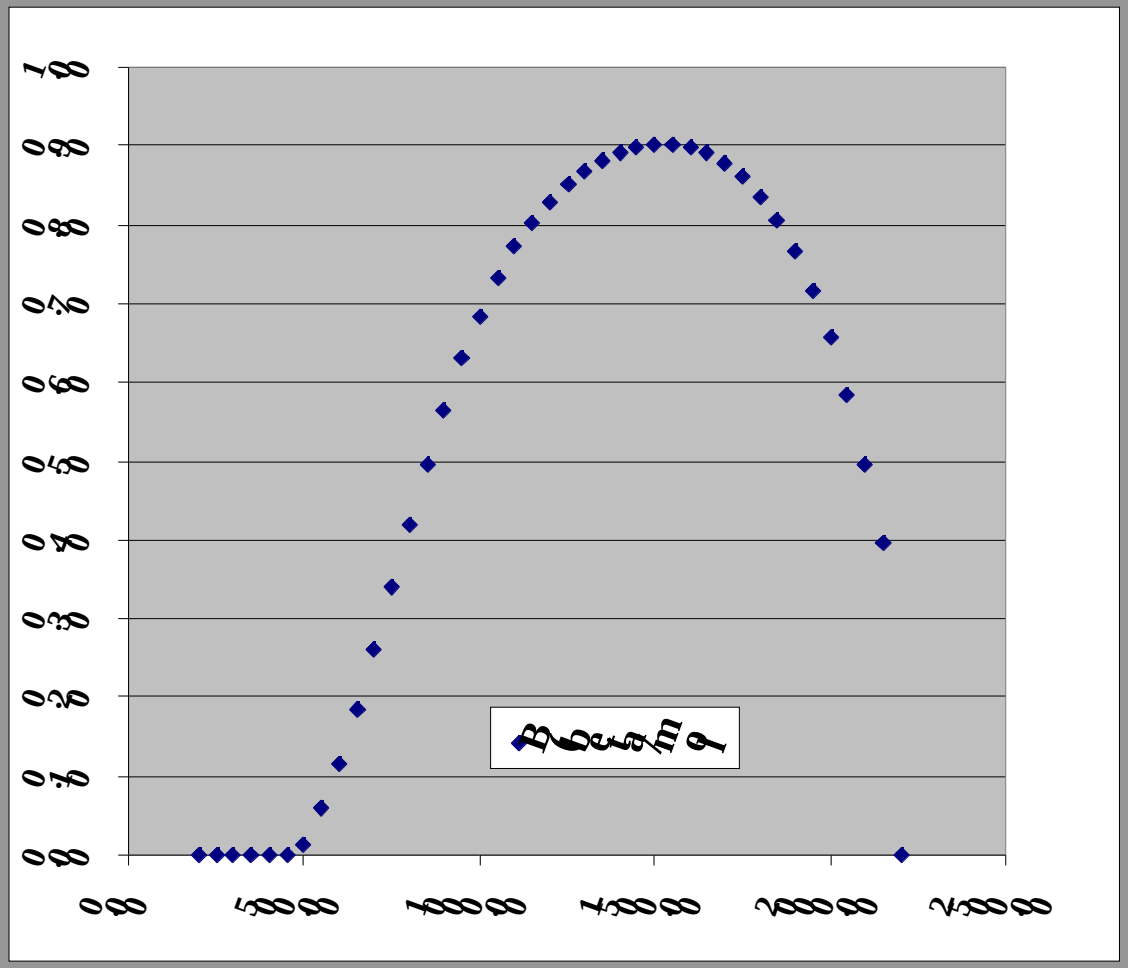
Manufacturing Plant



- **Important System Conponents**
  - Pressure Vessel Compartment
  - Gas Inlet/Outlet
  - Sample Mandrel
  - Samples (3 in Parallel)
  - Archived Samples (9 on mandrel)
  - Focusing Optics
  - Diffractive Optic
  - Beam Expander
  - Beam Splitter
  - Steering Optics
  - Narrow-band Filters
  - Power Meter
  - Pockels Cell
  - Beam Polarizer
  - Precision Stages
  - Gaussian Beam Output 3kW
  - Load Lock and Transfer Systems

Precursors for Boron Lattice



- **Boron Deposition**
  - Halides: BCl3, BBr3, BI3
  - Hydrides: B2H6, etc.

$2BBr_3 + 3H_2 \rightarrow 2B_{(s)} + 6HBr$

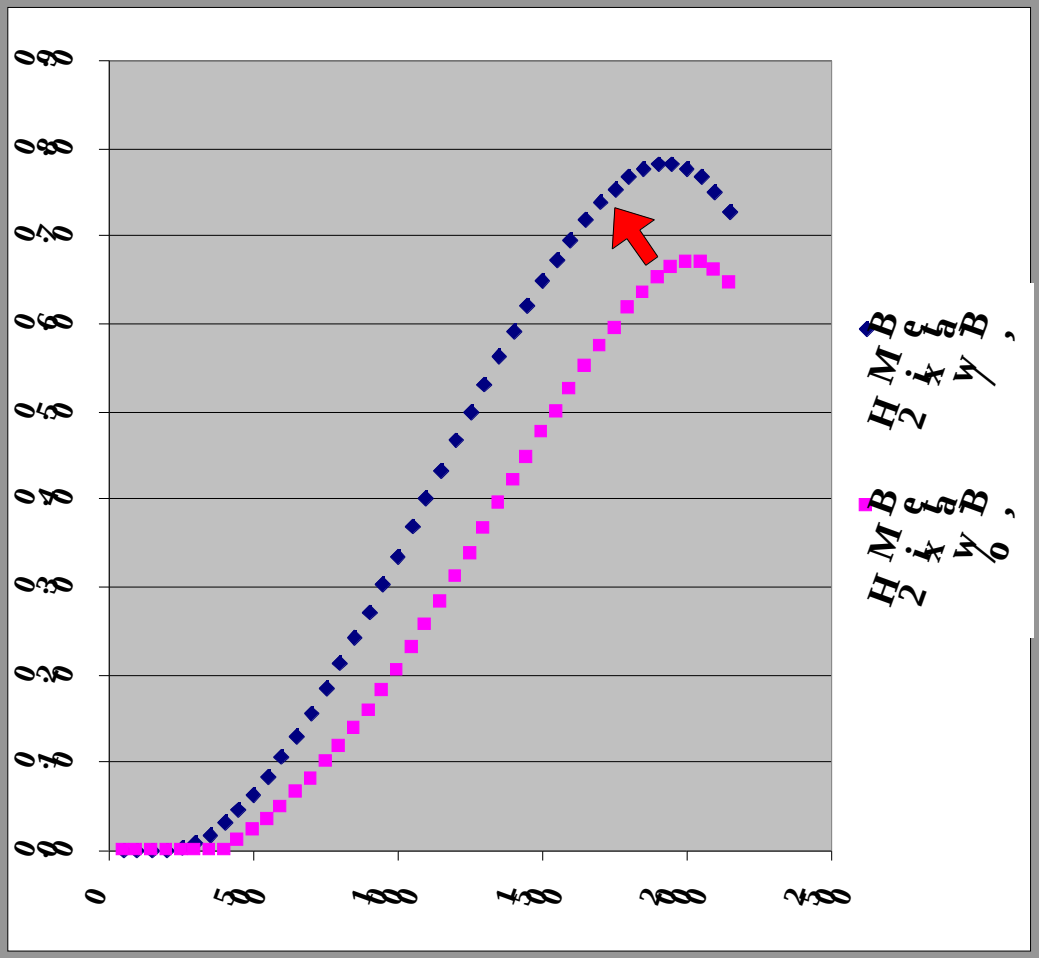
$2BI_3 + 3H_2 \rightarrow 2B_{(s)} + 6HI$

$B_2H_6 \rightarrow 2B_{(s)} + 3H_2$

Thermodynamics of Boron

- **Simultaneous Use:**
  - Boron Tribromide
  - Hydrogen Iodide
  - Optional Hydrogen
- **1 Atm Pressure**

$$2BBr_3 + 6HI + (H_2) \rightarrow 2B_{(s)} + 6HBr + 6I$$

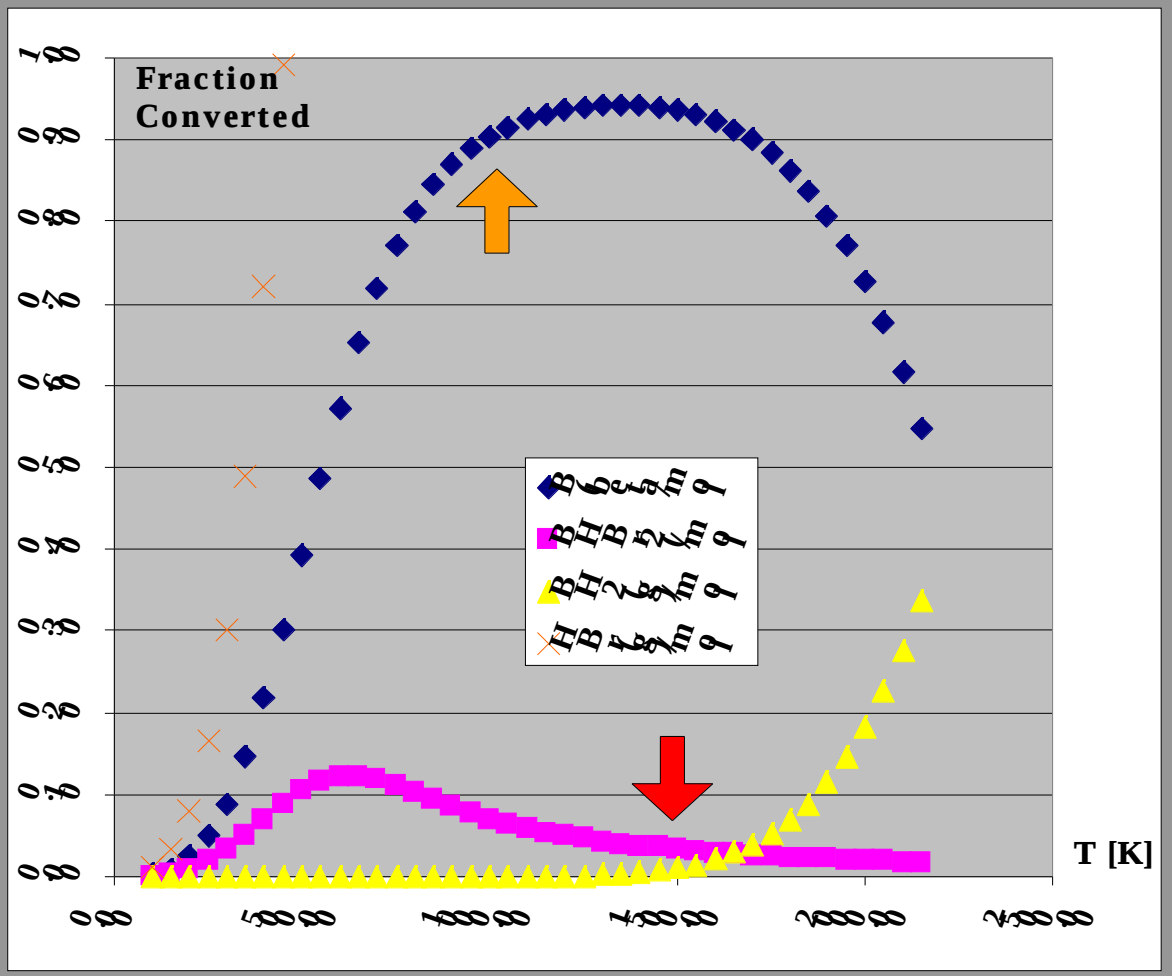


Unclassified

Thermodynamics of Boron

- By–Products from:
  - Boron TriBromide
  - Hydrogen
- 10 Atm Pressure

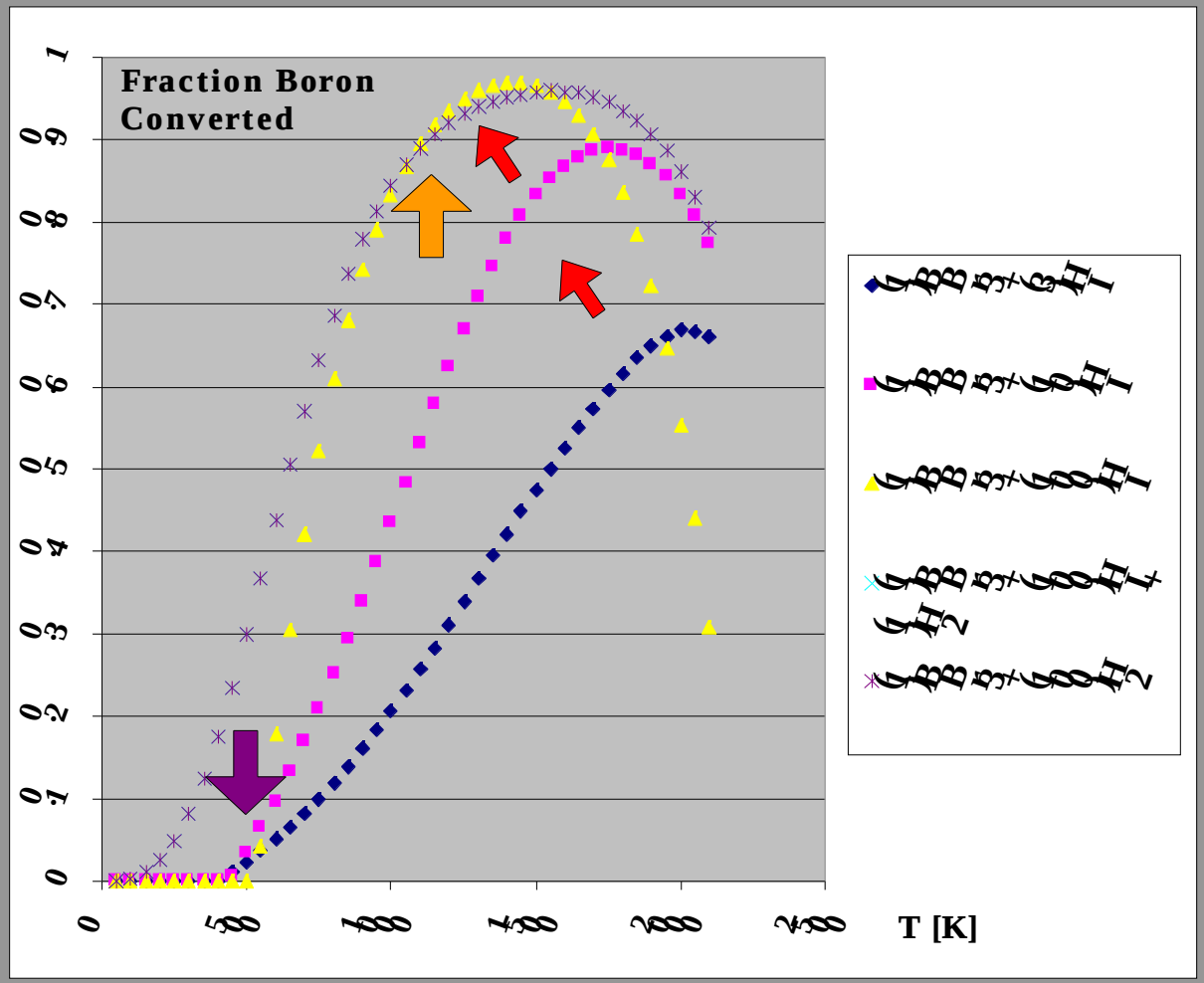
$$2BBr_3 + 3H2 \rightarrow 4B_{(s)} + 6HBr$$



Thermodynamics of Boron

- **Simultaneous Use:**
  - Boron Tribromide
  - Hydrogen
  - Hydrogen Iodide

$$4BBr_3 + 3H2 + 6HI \rightarrow 4B_{(s)} + 12HBr + 6I$$



Precursors for HfB2

- **Boron Deposition**
  - Halides: BCl3, BBr3, BI3
  - Hydrides: B
- **HfB2 Doping**
  - Halides: HfCl4, HfBr4, HfI4
  - Temp. >300 C
  - Hydrides: non-volatile
  - Organometallics: tetrakis-Diethylamido Hafnium: Hf[N(CH2CH3)2]4
- **Combination Precursors**
  - Hf(BH4)4 (Boron-rich Deposits)...New

Candidate Reactions

$$2BBr_3+HfCl_4+5H_2 \rightarrow HfB_{2(s)}+4HCl+6HBr$$

$$2BCl_3+HfCl_4+5H_2 \rightarrow HfB_{2(s)}+10HCl_4$$

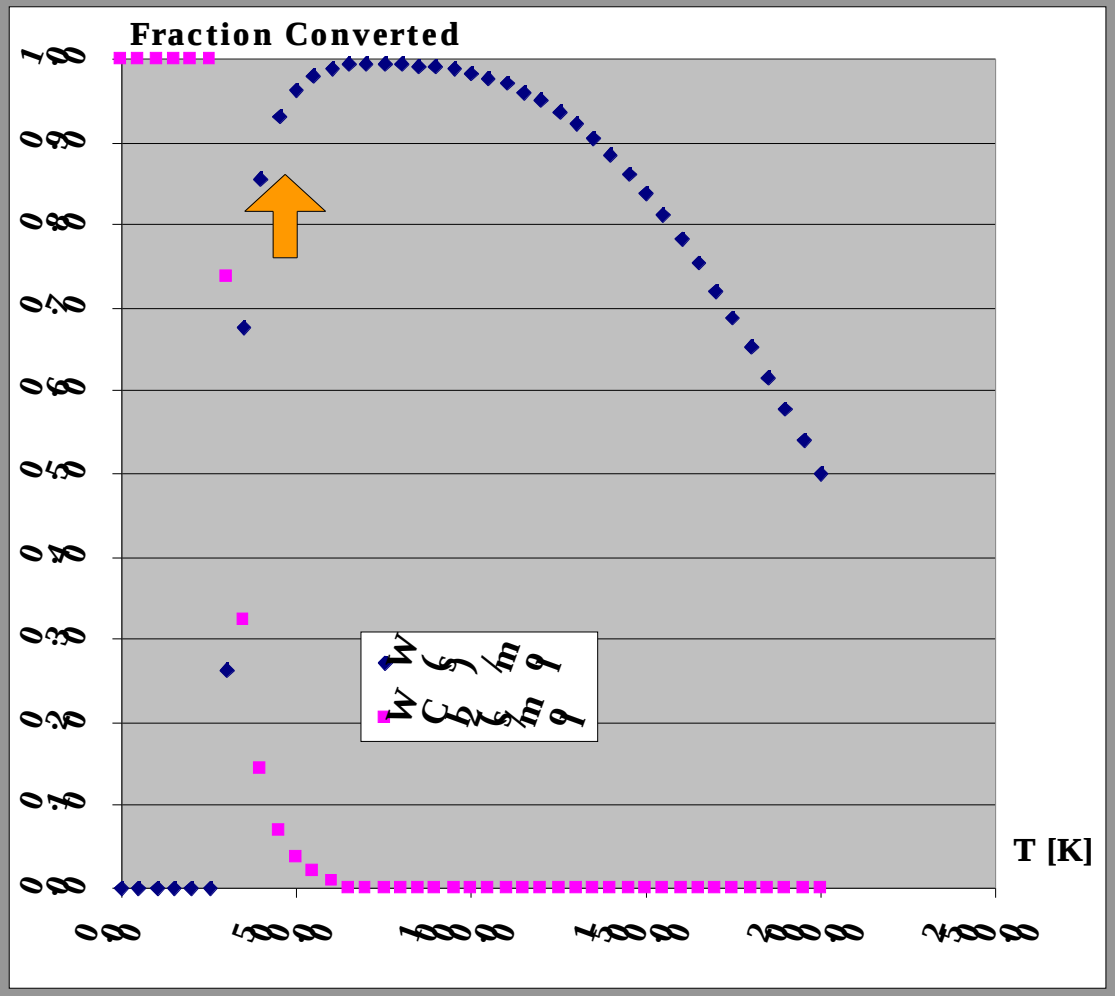
$$B_2H_6+HfCl_4 \rightarrow HfB_{2(s)}+4HCl+2H_2$$

Thermodynamics: Tungsten

- **Simultaneous Use:**
  - Tungsten Hexachloride
  - Hydrogen

WCl6 + 3H2 → W(s) + 6HCl

- **Tungsten Hexafluoride begins decomposing at about 200–250C**



Summary of Progress

Current

- Assembled LCVD System
- Performed Thermodyanic Calculations, selecting Optimal Precursors for High-Z Alloys
- Worked with Target Designers to Simplify Hohlraum Materials→ Alloys/Intermetallics of 3 Elements
- Developed Alternate Fabrication Processes
- Narrowed Options to a Simple Process

Future

- Kinetic Experiments with High-Z Precursors
- Pulsed Deposition
- High-Temperature Chamber(s)
- Parallel Growth