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

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Unclassified
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)
Material Substitutions

- **Alloys A-B**
  - High-Z (A) → La, Ta, Hf, W
  - High-Z (B) → Hg, Pb, Bi, I
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)
Low-Density Lattice

- Relative Bismuth Concentration vs. Location within Hohlraum

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

- Relative Boron Concentration vs. Location within Hohlraum

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

Unclassified
Engineered Materials

- Variable Spacing, Variable Fiber Diameter → Variable Density
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
• Spiroidal Lattices
  2-D array of Dots
  Pattern Oscillates Rapidly in 2-D
  Amplitude (Radius) of Oscillation also varies Sinusoidally at Lower Frequency
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
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
Fabrication Sequence

- Lithography-Defined Membranes (caps)
- Vacuum Mounting
- 3D-LCVD of Low-\(p\), High-\(Z\) Lattices
Fabrication Sequence

- Coat Hohlraum Wall
  Closes Exterior of Lattice
  Builds thick Overlayer for Support & Containment

- Relevant Processes
  Plasma Spray
  Flame Spray
  DW LCVD
Fabrication Sequence

- Reactive Injection of Polymeric Case
- Insertion into Casing Injection Mold Cap
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
Inject Target

Membrane Definition & Mounting

Cryo Assembly of Capsule & Plug

End Plug

3D-LCVD of Graded Materials

Reactive Injection Molding of Case

Deposit Hohlraum Wall
Manufacturing Plant

- Important System Components
  - 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.

\[
2\text{BCl}_3 + 3\text{H}_2 \rightarrow 2\text{B}(s) + 6\text{HCl}
\]

\[
2\text{BBr}_3 + 3\text{H}_2 \rightarrow 2\text{B}(s) + 6\text{HBr}
\]

\[
2\text{BI}_3 + 3\text{H}_2 \rightarrow 2\text{B}(s) + 6\text{HI}
\]

\[
\text{B}_2\text{H}_6 \rightarrow 2\text{B}(s) + 3\text{H}_2
\]
Simultaneous Use:
Boron Tribromide
Hydrogen Iodide
Optional Hydrogen

1 Atm Pressure

$2\text{BBr}_3 + 6\text{HI} + (\text{H}_2) \rightarrow 2\text{B}_{(s)} + 6\text{HBr} + 6\text{I}$
By–Products from:
Boron TriBromide
Hydrogen
10 Atm Pressure

\[ 2BBr_3 + 3H_2 \rightarrow 4B(s) + 6HBr \]
Simultaneous Use:
Boron Tribromide
Hydrogen
Hydrogen Iodide

\[ 4 \text{BBr}_3 + 3 \text{H}_2 + 6 \text{HI} \rightarrow 4 \text{B}_\text{s} + 12 \text{HBr} + 6 \text{I} \]
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

\[
2\text{BBr}_3 + \text{HfCl}_4 + 5\text{H}_2 \rightarrow \text{HfB}_2(s) + 4\text{HCl} + 6\text{HBr}
\]

\[
2\text{BCl}_3 + \text{HfCl}_4 + 5\text{H}_2 \rightarrow \text{HfB}_2(s) + 10\text{HCl}_4
\]

\[
\text{B}_2\text{H}_6 + \text{HfCl}_4 \rightarrow \text{HfB}_2(s) + 4\text{HCl} + 2\text{H}_2
\]
Simultaneous Use:
- Tungsten Hexachloride
- Hydrogen

\[ \text{WCl}_6 + 3\text{H}_2 \rightarrow \text{W}(s) + 6\text{HCl} \]

- Tungsten Hexafluoride begins decomposing at about 200–250°C
Assembled LCVD System
- Performed Thermodynamic 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

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

Unclassified