

Development of SiC Large Tapered Crystal Growth

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Project Duration: FY09 to FY11

DOE Vehicle Technologies Program

Advanced Power Electronics and Electric Machines Research

FY11 Kickoff Meeting

Oak Ridge National Laboratory

Oak Ridge, Tennessee

November 16, 2010

The Problem

- Majority of very large potential benefits of wide band gap semiconductor power electronics have NOT been realized due in large part to high cost and high defect density of commercial wafers.
- Despite 20 years of development, present SiC wafer growth approach is yet to deliver majority of SiC's inherent performance and cost benefits to power systems.
- Commercial SiC power devices are significantly de-rated in order to function reliably due to the adverse effects of SiC crystal dislocation defects (thousands per cm^2) in the SiC wafer.



Project Overview

Research Focus Area: Power Electronics

→ Temperature Tolerant Devices

Objective

- Demonstrate initial feasibility of totally new “Large Tapered Crystal” (LTC) process for growing vastly improved large-diameter wide-band gap wafers.

Addresses Targets

- The goal of this research is to experimentally investigate and demonstrate feasibility of the key unproven LTC growth processes in SiC.
 - Laser-assisted growth of long SiC fiber seeds.
 - Radial epitaxial growth enlargement of seeds into large SiC boules.

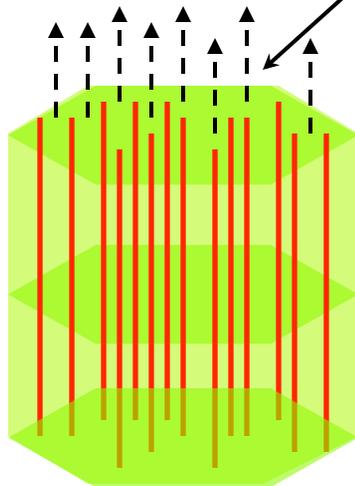
Uniqueness and Impacts

- Open a new technology path to large-diameter SiC and GaN wafers with **1000-fold defect density improvement at 2-4 fold lower cost.**
- Leapfrog improvement in wide band gap power device capability and cost.

Description of Technology (4H-SiC)

Existing SiC Wafer Growth Approach

(Sublimation growth or High Temperature CVD)



C-axis (vertical) growth proceeds from top surface of large-area seed crystal via **thousands of screw dislocations**.

Vertical growth rate would not be commercially viable (i.e., would not be high enough) without high density ($> 100 \text{ cm}^{-2}$) of screw dislocations.

Crystal enlargement is vertical (up c-axis). Negligible lateral enlargement.

Thermal gradient driven growth at $T > 2200 \text{ }^\circ\text{C}$
High thermal stress/strain

Fundamental Flaw: Abundant screw dislocation defects are needed for present SiC wafer growth approach, yet these same defects harm SiC power device yield and performance (cause blocking voltage de-rating, leakage, etc.)

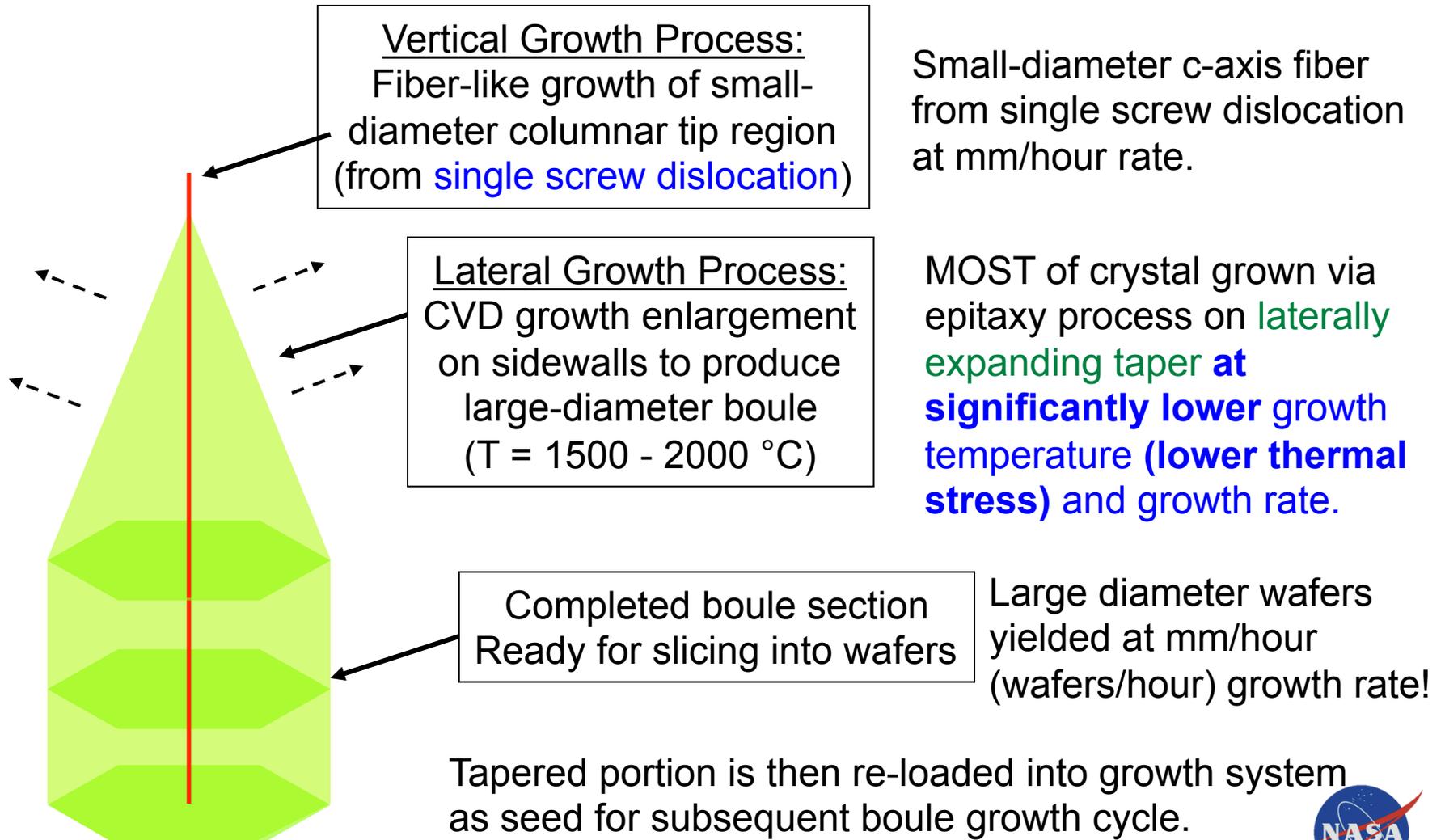
- **High thermal stress also generates dislocations.**



Description of Technology (4H-SiC)

Future: Game Changer - Large Tapered Crystal (LTC) Growth

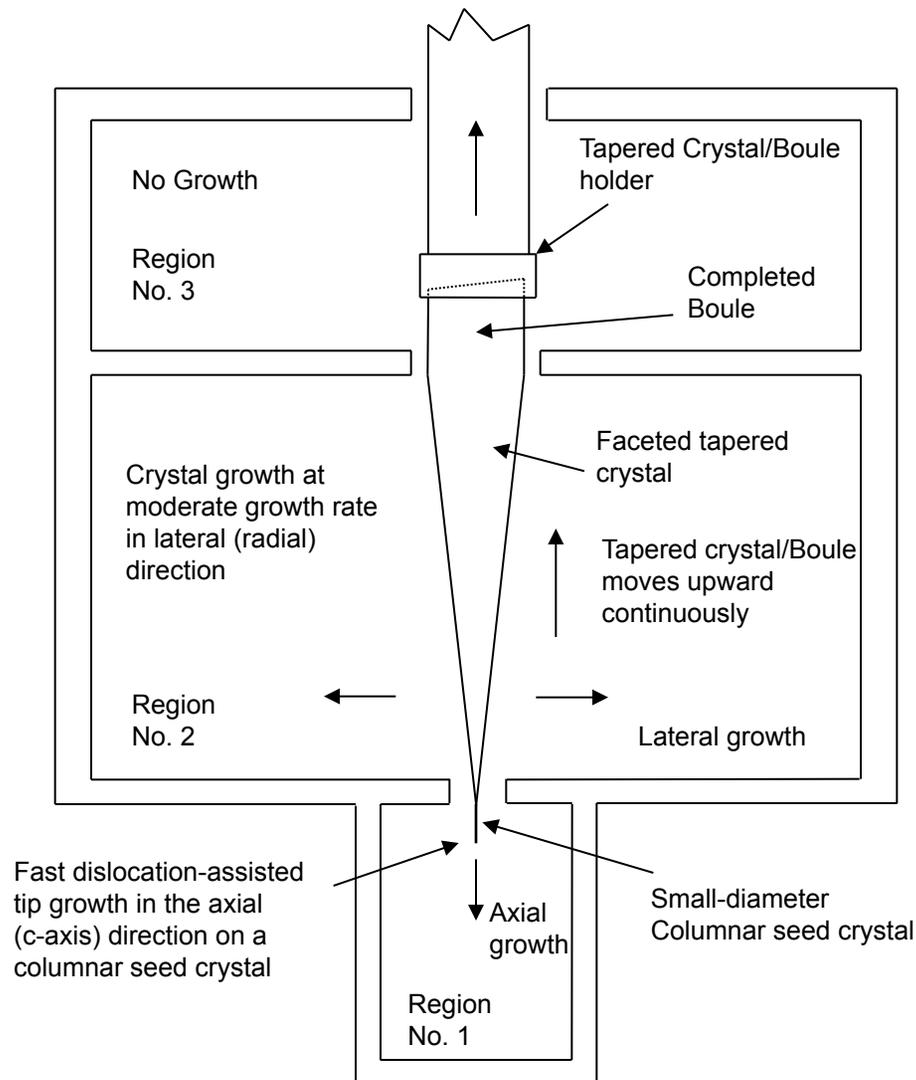
(US Patent 7,449,065 Owned by OAI, Sest, Inc., with NASA Rights)



Description of Technology

Large Tapered Crystal (LTC) Growth Method

Simplified Schematic Cross-Sectional Representation

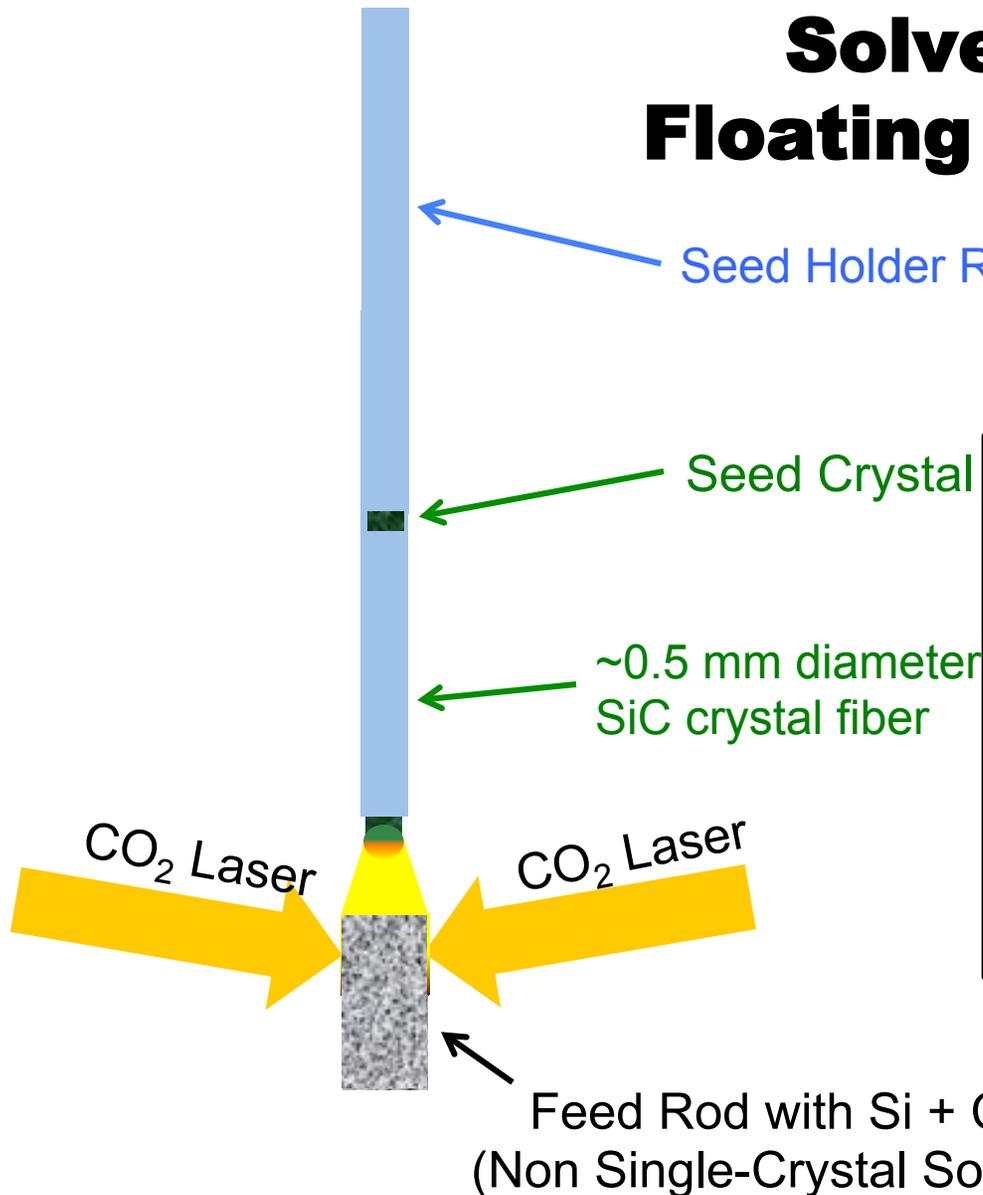


Features (one embodiment):

1. 3-Region growth apparatus for 3 different growth actions.
2. Region 1: Axial (c-axis) growth on a very small diameter columnar portion enables fast growth in the c-axis direction.
3. Region 2: Lateral (m-direction) growth at moderate growth rate on the tapered portion
4. Region 3: No growth after LTC boule reaches desired diameter.
5. Growth rate of boule in c-axis direction equals fast growth rate of columnar seed crystal.
6. Boule contains only one SD along its axis; the remainder of the boule is nominally defect-free

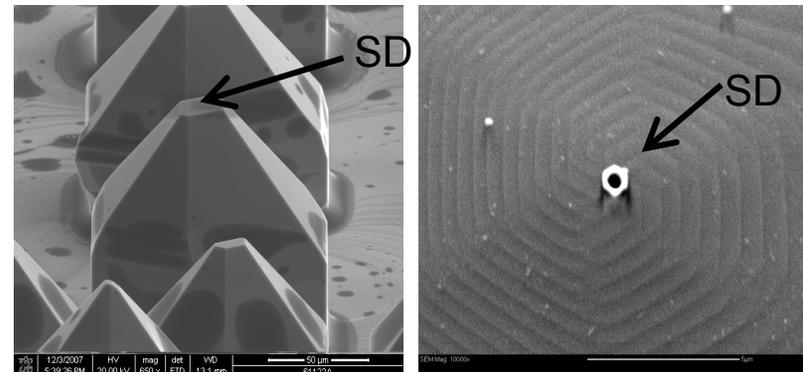
Description of Technology (Fiber Growth)

Solvent-Laser Heated Floating Zone (Solvent-LHFZ)



Works for other materials, but this will be first attempt for single-crystal SiC.

4H-SiC Seed Crystal

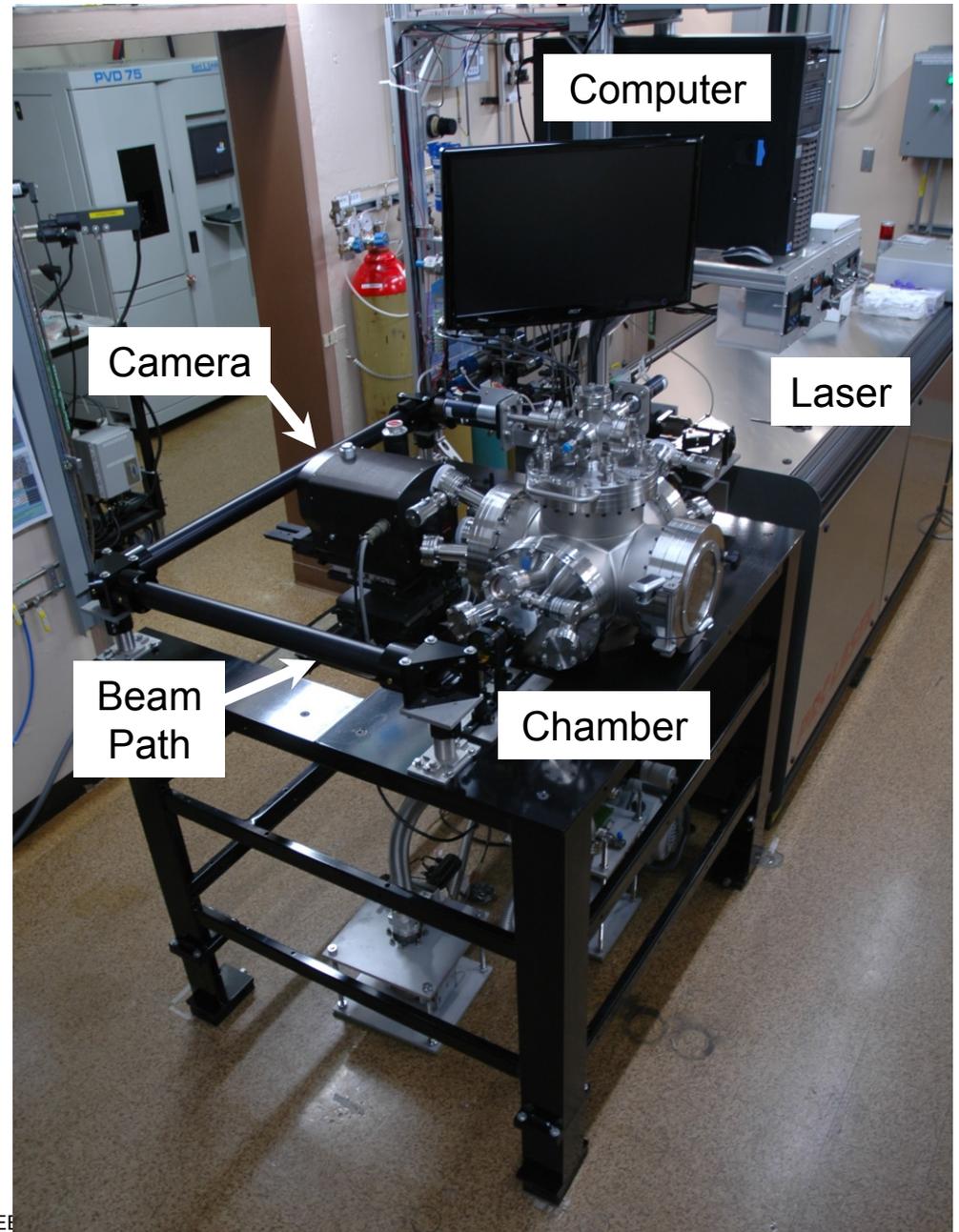


Accomplishments to Date - Overview

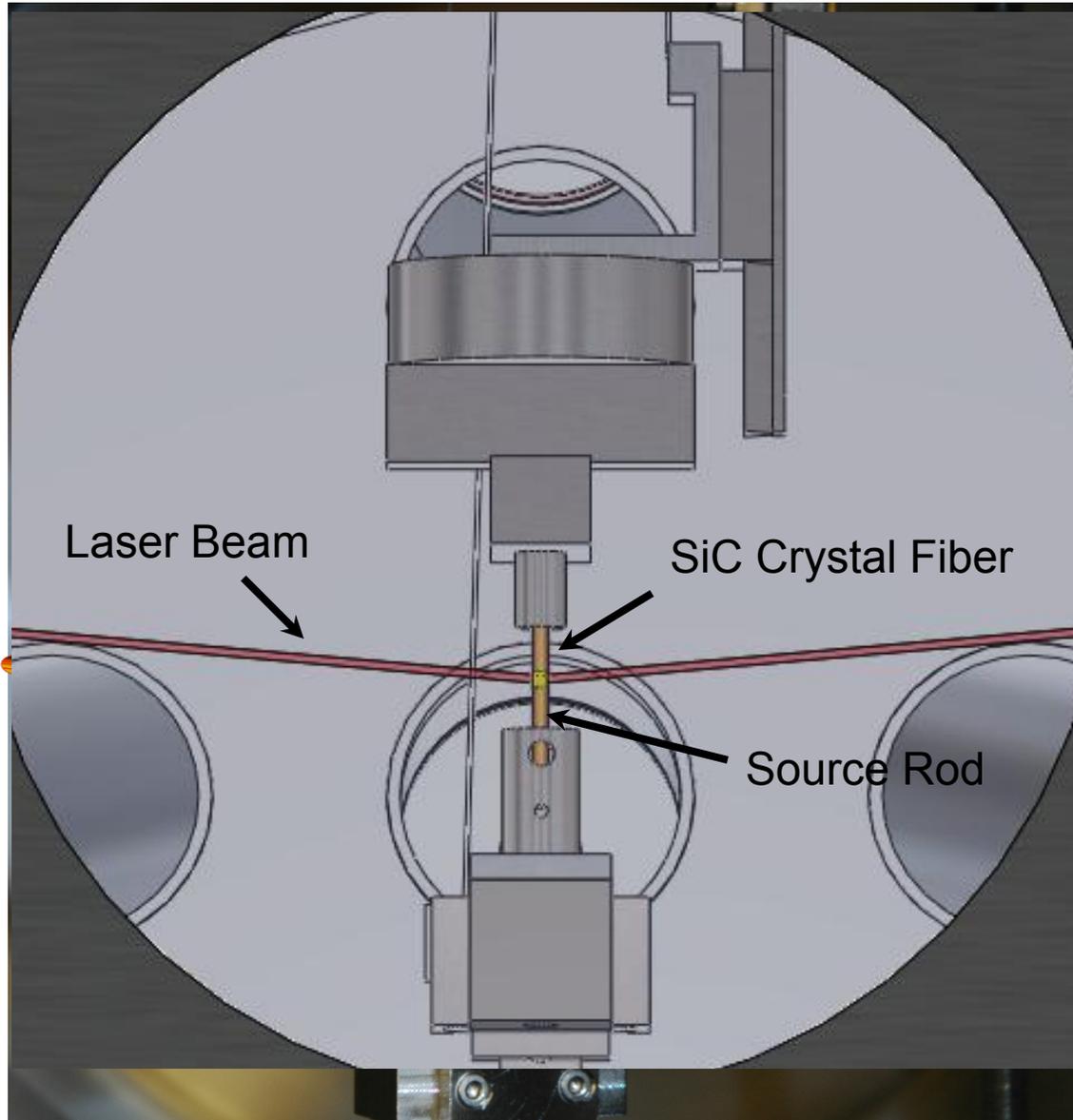
- Funding initiated 2 December 2009 (late start).
- Major modifications to NASA Glenn SiC Growth Reactor #2 have been implemented (95% complete).
 - Needed for experimental demonstrations of LTC radial growth enlargement of SiC fibers into boules.
 - Fundamental change in configuration from cold-wall with pancake coil RF heating to hot-wall with barrel coil RF heating.
 - First growth experiment carried out on SiC saw-cut pseudo-fiber October 2010.
- Design and build-up of laser-heated SiC fiber growth system has been implemented (95% complete)
 - Needed for experimental demonstration of LTC fiber growth process.
 - First growth experiment to be conducted November 2010.

Accomplishments to Date – Fiber Growth

- Fiber Growth System
 - Design - **complete**
 - Purchase/fabricate - **complete**
 - ~\$125K new equipment
 - ~\$140K repurposed NASA equipment
 - Build/assemble - **complete**
 - Control/acquisition software - **in progress**
- Source Material
 - Identify Si-C solvents - **complete**
 - Feed rod creation process - **in progress**
- Seed Crystals – **in progress**



Accomplishments to Date – Fiber Growth



Accomplishments – Radial Growth

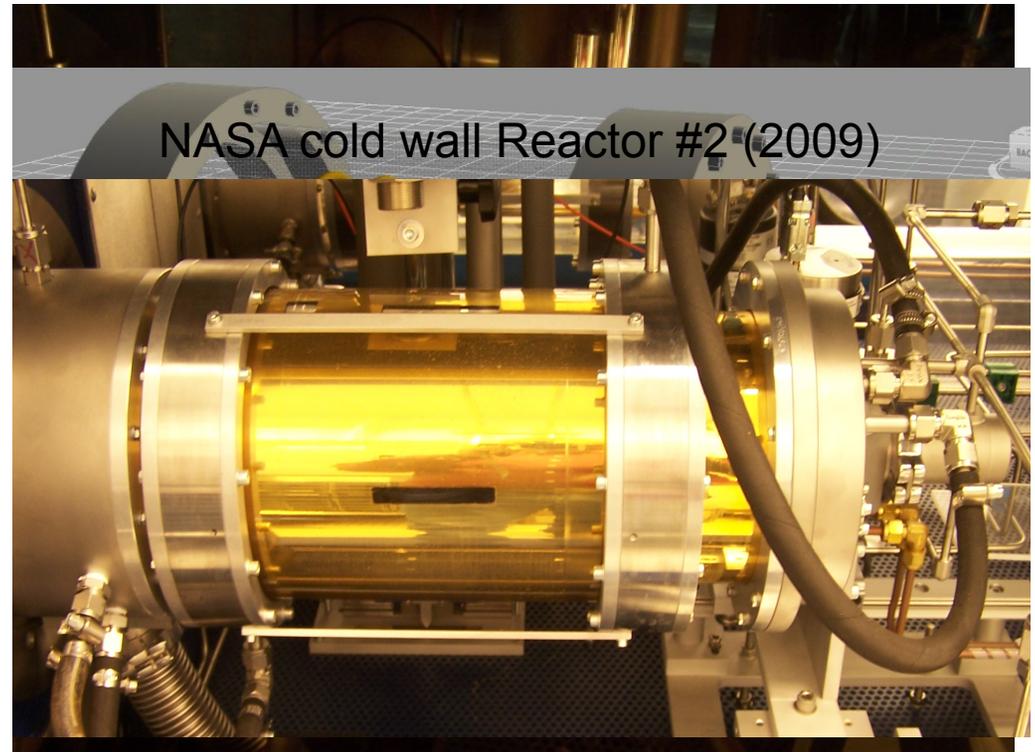
Major modifications to NASA Glenn SiC Growth Reactor #2 to support LTC radial growth demonstrations have been implemented.

Fundamental change in NASA SiC growth configuration from cold-wall with pancake coil RF heating to hot-wall with barrel coil RF heating.

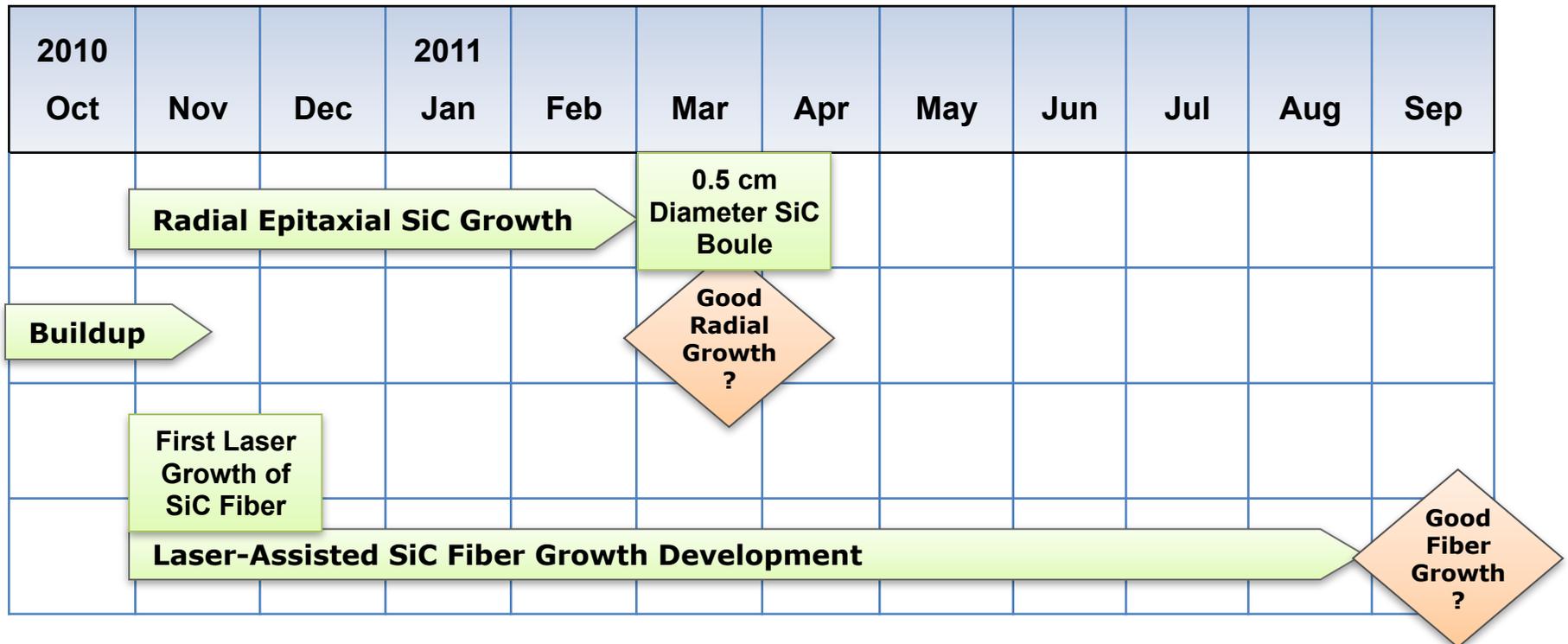
Hot wall system necessary for LTC implementation goals of:

- High growth rate
- Temperature uniformity
- Radial deposition symmetry

Since LHFZ SiC fibers not yet grown, initial radial growth experiments are commencing with thin pieces (flat toothpick-like shape) cut from commercially purchased a-plane and m-plane SiC wafers.



FY11 Approach and Challenges



Go No/Go Decision Point: High quality SiC crystals (of proof-of-principle size) must be demonstrated for **both** radial and fiber growth processes.

Challenges/Barriers: Both growth processes are “first ever” experimental demonstration attempts as methods of SiC growth.

Schedule does not enable major redesign/rebuild of hardware.

Beyond FY11 (Not in present agreement)

- **FY12-13**

- Launch joint development of full prototype LTC SiC growth system (fiber growth + lateral growth) in collaboration with commercial and/or university development partners.
- Projected Go/No Go: High growth rate of nearly defect-free SiC boules & commercial investment.

- **FY13-14**

- Explore GaN LTC experiments.
- Projected Go/No Go: If a high-quality fiber GaN seed crystal cannot be grown in reproducible manner, then GaN LTC growth is not viable.

Questions

