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Growth of Yb:S-FAP Crystals for the Mercury Laser

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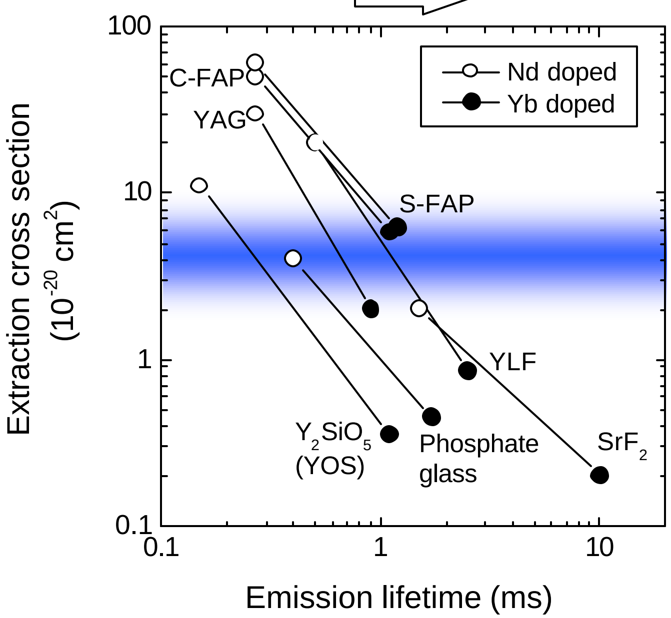
IFE based systems would like both high absorption and emission cross sections and long lifetime

Reduced diode cost due to increased energy storage time



ASE limited

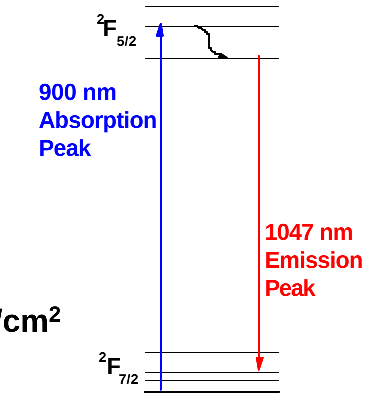
Acceptable range

Laser damage limited

s µ gain
if s is too high then difficult to hold off ASE

output average fluence = 7 J/cm^2
peak fluence = 15 J/cm^2

1/s µ sat fluence,
operate at 2-3x sat fluence
if s is too low then close to damage limit

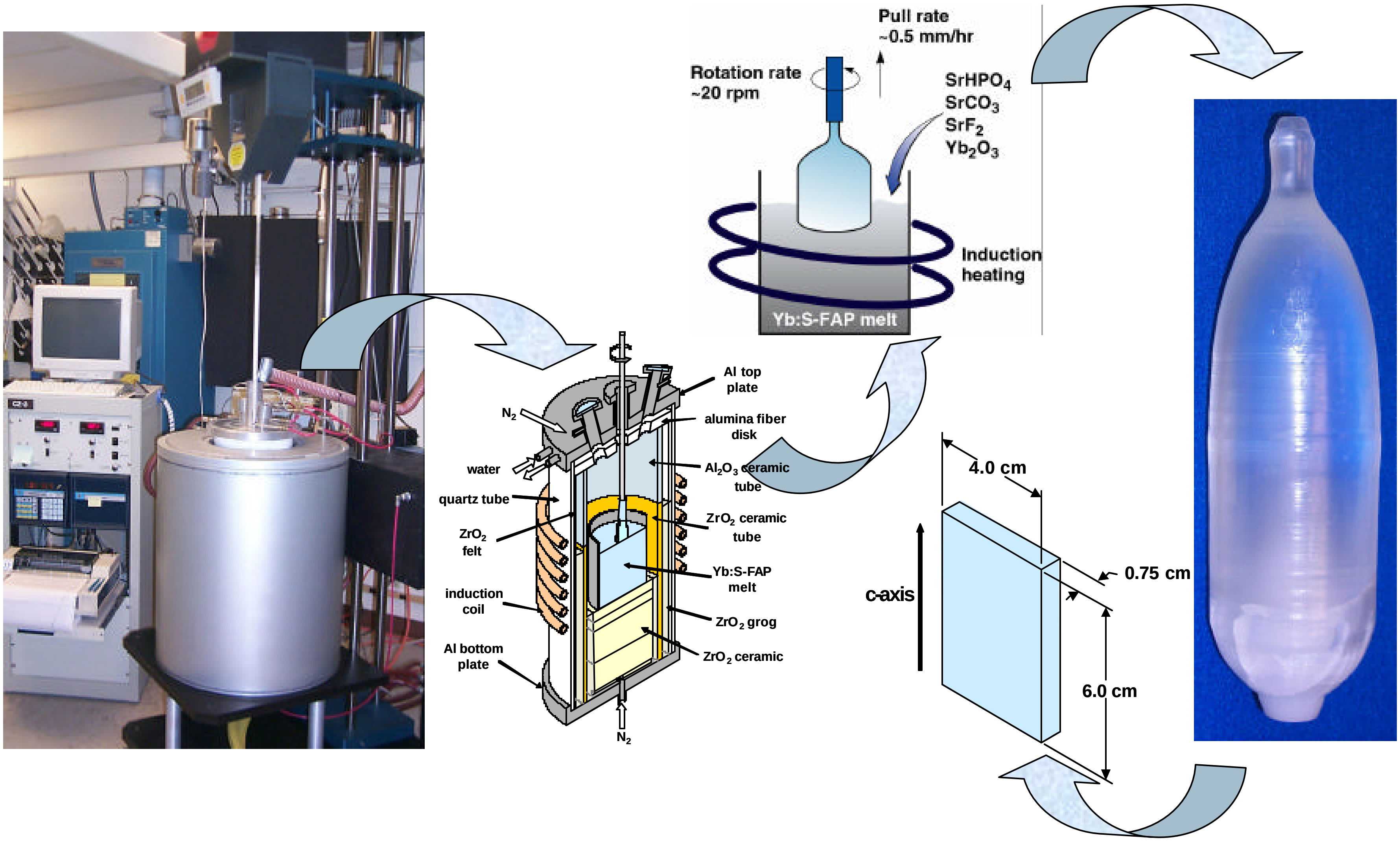


- A long spontaneous emission lifetime allows the diodes to be operated for longer times
- Nd materials require 3-4x more diodes
- High absorption cross section requires less gain medium to efficiently absorb diode light

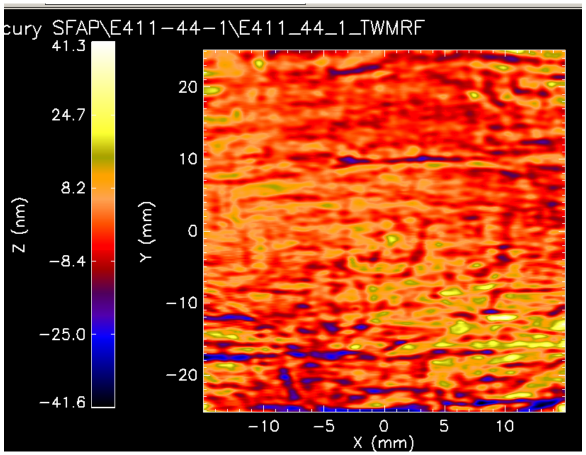
	Yb:S-FAP ~3-level	Yb:YAG (100 K) 4-level	Nd:Glass 4-level	Ti:Sapphire
Lifetime (ms)	1.14	1.0	0.36	0.0032
Absorption cross section (x10^{-20} cm^2)	9.0	0.8	2	6.5
Absorption FWHM (nm)	3.4	15	12.5	-
Peak pump power (GW)	20	20	56	-
Emission cross section (x10^{-20} cm^2)	6.2	8.8	~4	41
Saturation fluence (J/cm^2)	3.1	2.2	0.29	0.64
Thermal conductivity (W/m·°C)	2	58	~1.2	50
¶n/¶T (x·10^{-6}· °C^{-1})	-10	7.3	-6.8	-
Stress fracture (W/cm)	1.2	11 88 (100K)	0.7	-

Crystals of Yb:S-FAP are grown by the Czochralski method to produce slabs for the Mercury Laser

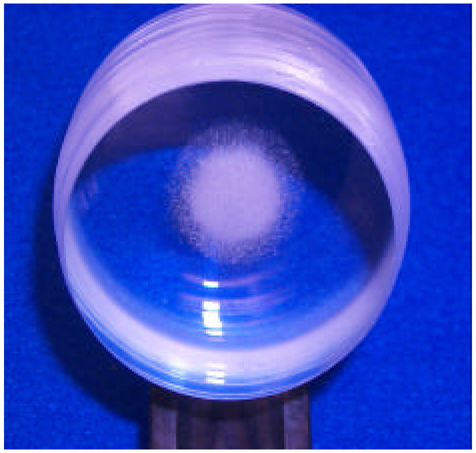
7.0 cm Yb:S-FAP crystals are being grown at LLNL and Synoptics



Three defect issues are being addressed in the growth of high quality, 7.0 cm diameter, Yb:S-FAP crystals



Grain boundaries

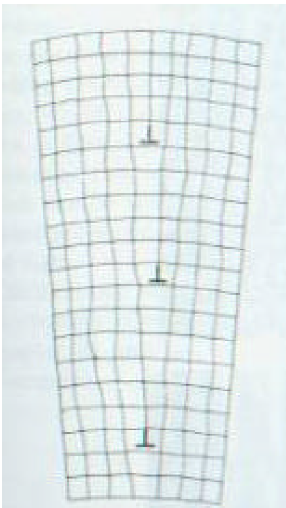


Bubble core

Cracking

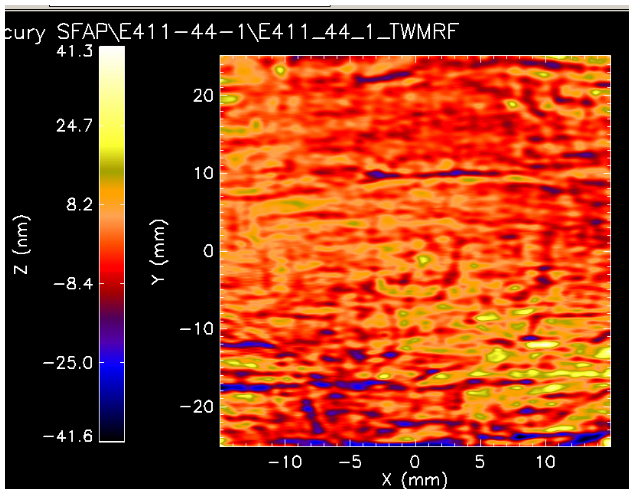
Currently, there is an understanding of each of these defects and methods are being implemented to reduce or eliminate them.

Low-angle grain boundaries are mitigated by profiling thermal gradients around the crystal

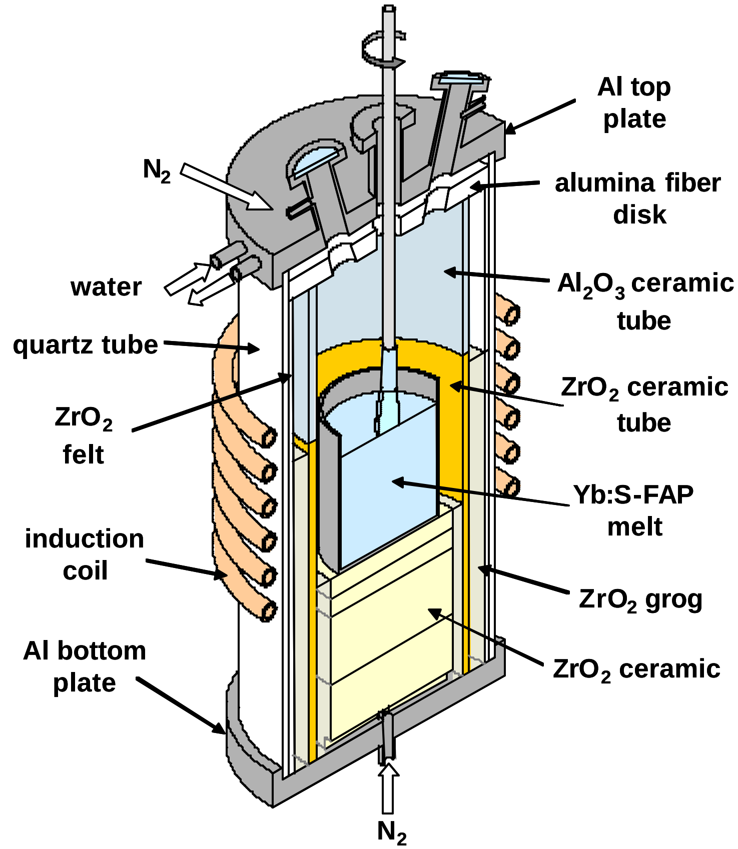


Ref. *Introducion to Ceramics*

- **Formed when defect sites migrate together to relieve thermal stress**



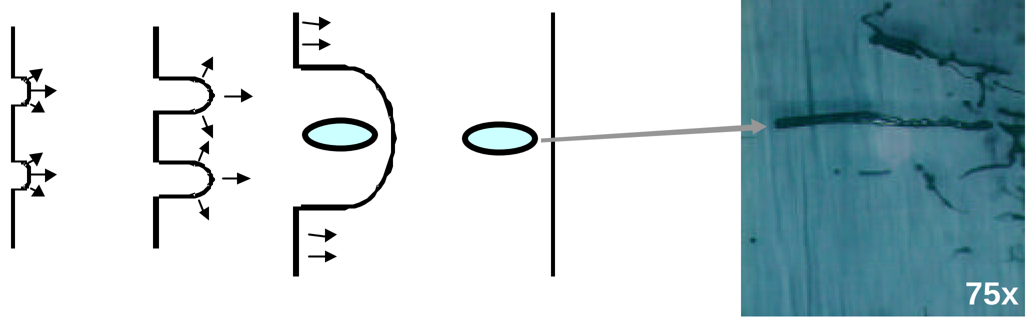
Affects beam quality



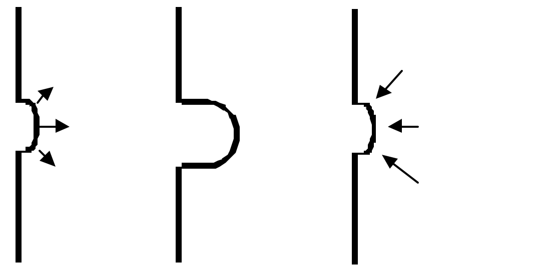
- **How have we mitigated them?**
  - **"Pin" defect sites with a larger cation to prevent migration**
  - **Prevent cool down induced thermal stresses**
    - **A) change N_2 flow around the crystal**
    - **[DECREASE NUMBER BY > 2/3 IN 7 cm DIAMETER CRYSTALS]**

Bubble core is concentrated by stabilizing and changing interface shape

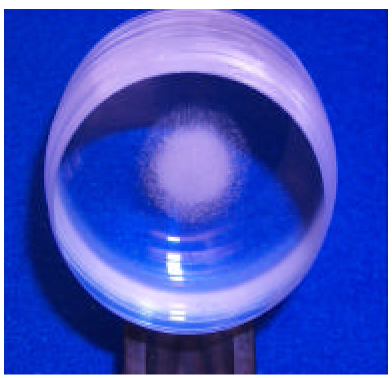
A **Low Temperature Gradient**



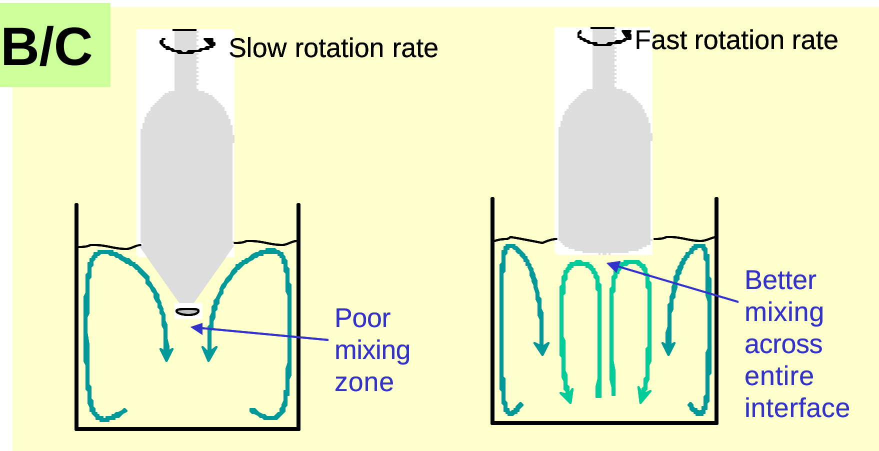
High Temperature Gradient



Nodule forms, then dissipates

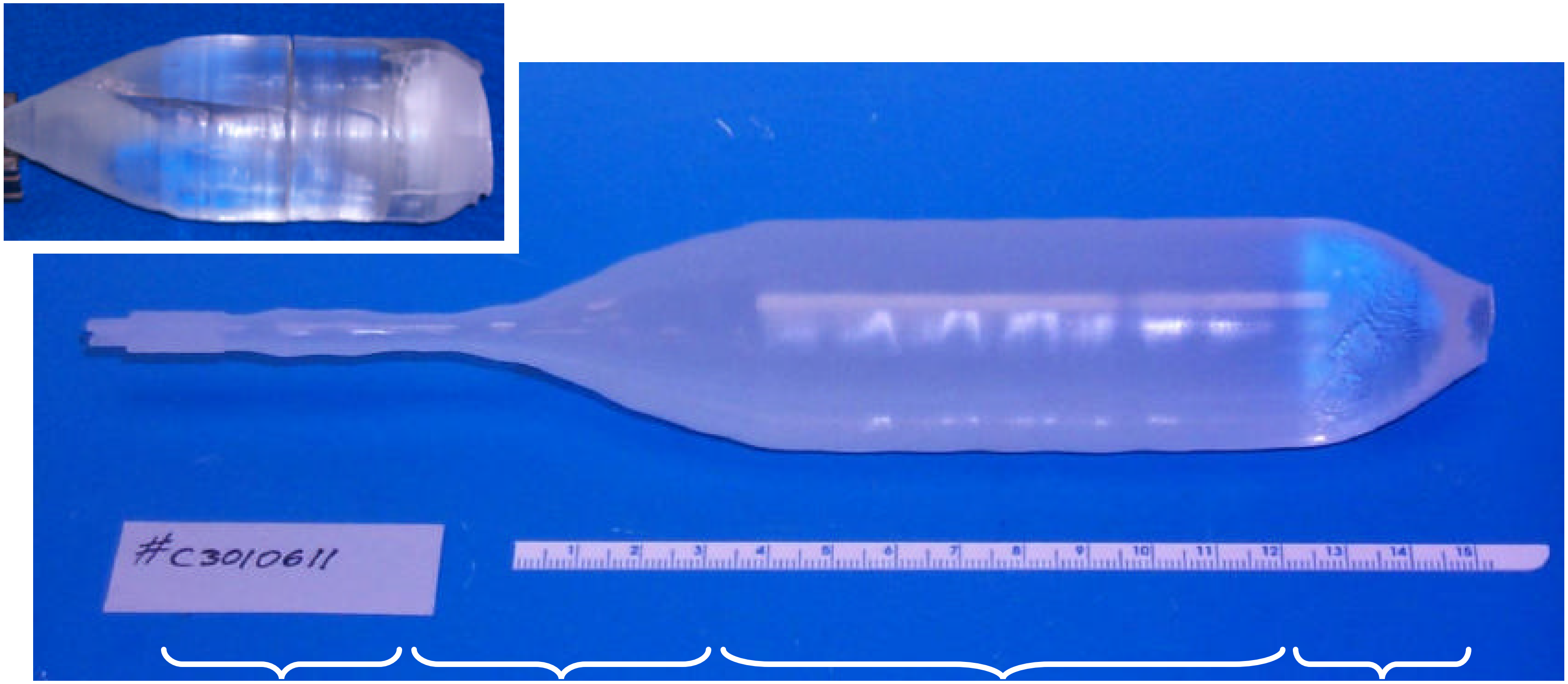


B/C



- **Bubble core is reduced/concentrated by changing the interface shape**
  - **A) Increased thermal gradients to stabilize the inferface (3.5 cm diameter)**
  - **B) Increase rotation rate (being implemented on 7.0 cm diameter)**
  - **C) Lower thermal gradients in melt (7.0 cm diameter)**

Cracking is mitigated through reduced defects (Stages 1-3) and thermal stress (Stage 4)



Stage

1 — Eliminate grain boundaries

2 — Avoid introd-uction of new defects

3 — Maintain stable growth

4 — Slow cool attached to melt to prevent cracks

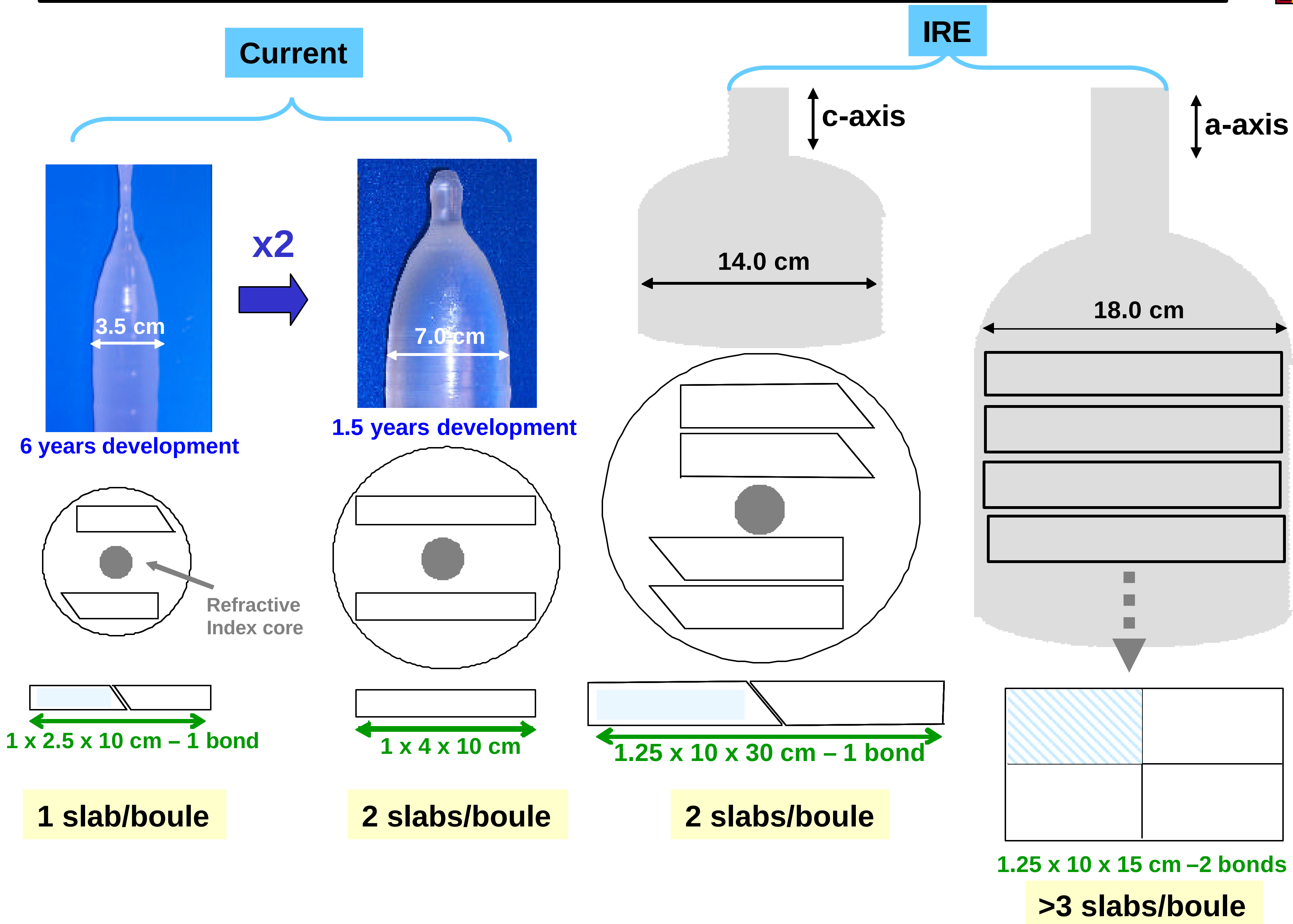
Cracking is currently not an issue in 7.0 cm diameter crystals

Summary

- 7.0 cm diameter Yb:S-FAP crystals are being routinely grown and produce 2 slabs/boule
- Grain boundaries have been reduced by 2/3 by controlling thermal stress
- Bubble core is concentrated by changing interface shape
- 14 slabs are in the laser currently and 20 spares are in fabrication
- MRF is used to improve the wavefront of slabs and remove distortions
- Damage tests show no growth until >20J/cm^2

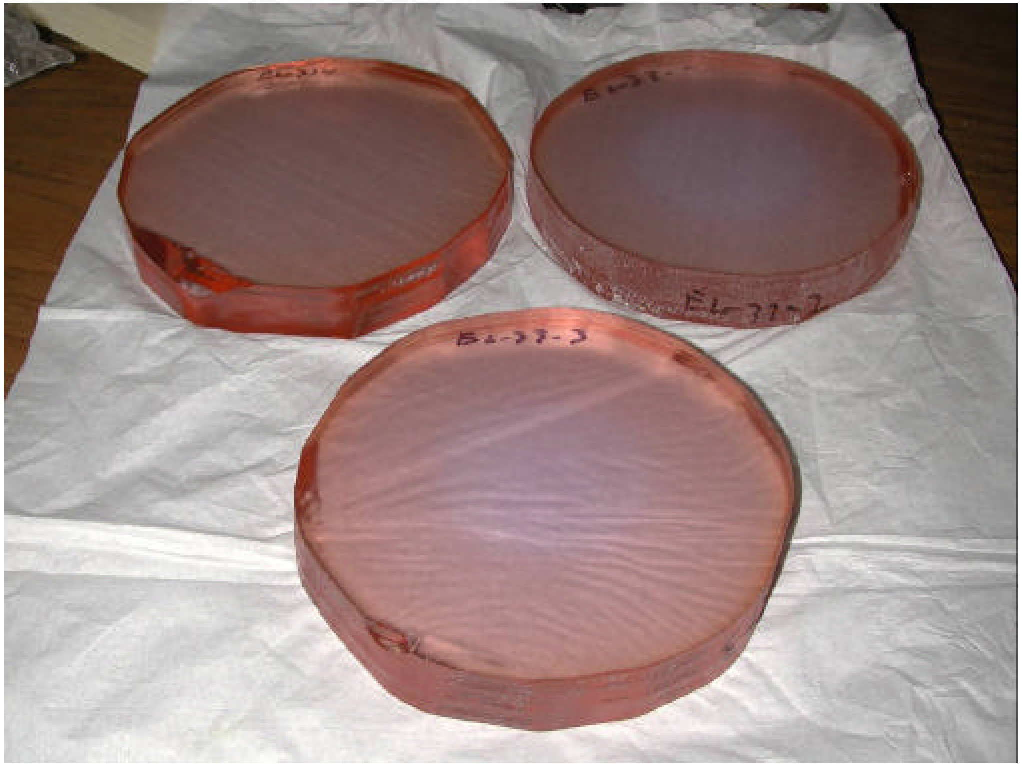
Now that we have a full compliment of spares, we are focusing on better beam quality and scaling concepts for IRE systems.

Pathway for IRE scale Czochralski grown Yb:S-FAP slabs



Northrop Grumman/Synoptics currently has a furnace capable of 14 cm diameter Czochralski growth

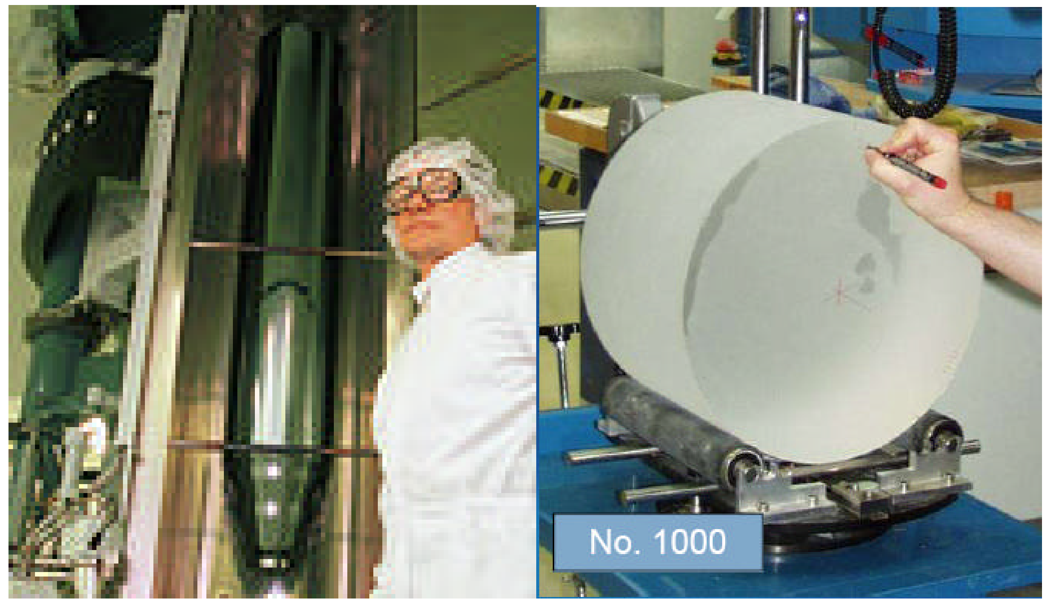
Synoptics GGG growth station



15 cm Nd:GGG blanks

Schott Lithotec has proposed growth and scaling of Yb:S-FAP by the Bridgman Method

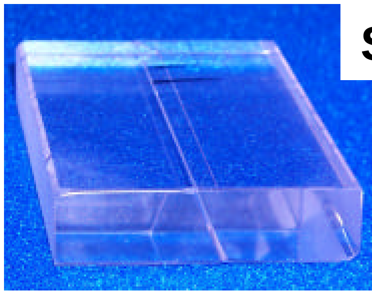
Scaled CaF_2 to 25 x 38.5 cm in 4 years



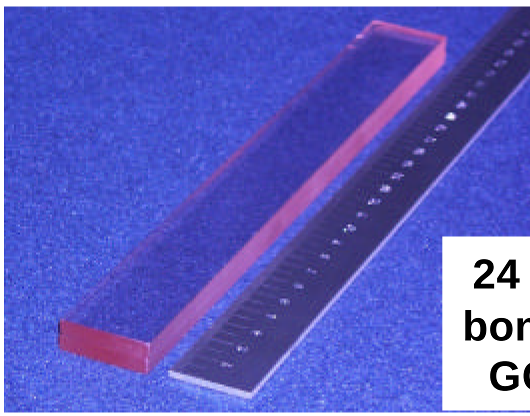
Full size crystals would be produced if this method is successful

Two methods of bonding are being explored

High Temperature Diffusion



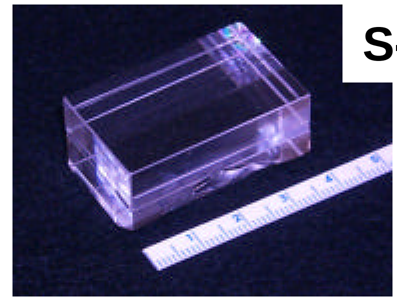
S-FAP



24 cm bonded GGG

- Current method employed for 7 slabs in Mercury
- A long diffusion bond demonstrated with GGG
- Tested in laser up to 55 J with no damage (5 J/cm^2 at 14.5 nsec)

Low Temperature Bonding Solution



S-FAP

Phosphate Glass

4 x 4" to date

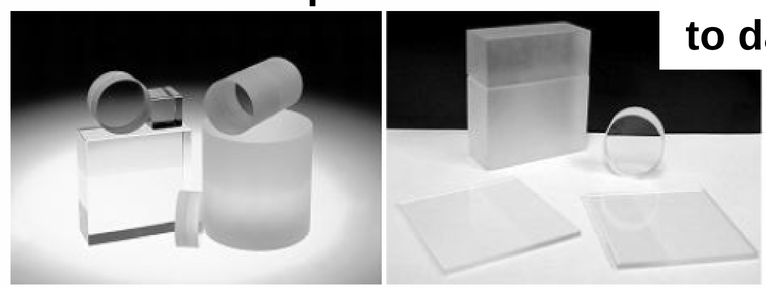


Figure 5 – Examples of phosphate-phosphate glass preforms and substrates prepared by the LTB technology.

- Currently being developed for Yb:S-FAP
- Scalable technology

Recent results:

- Optically clear, R < 0.05%
- Machineable
- Damage threshold, 10-12 J/cm^2

Scaling Yb:YAG ceramics (40 x 70 x 2)

Potential Material Challenges

Scattering losses

- Improved raw materials (morphology and size)

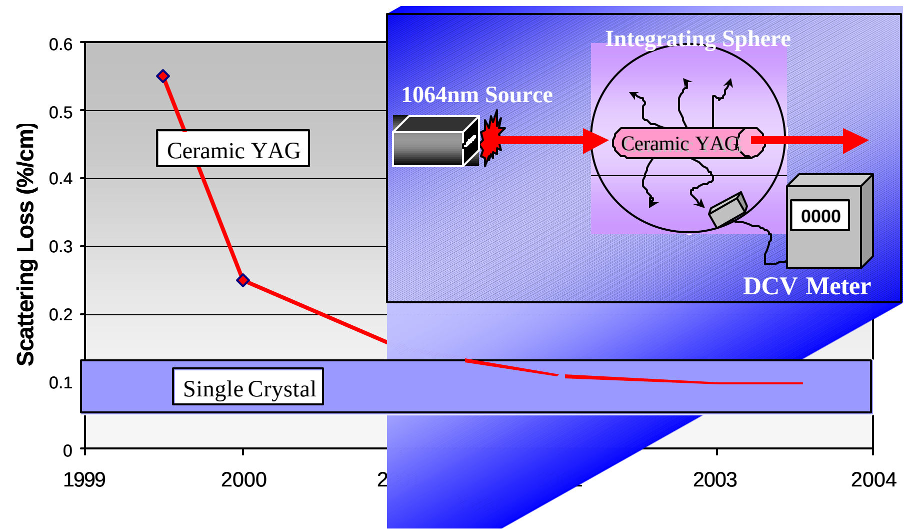
- Improved methods of fabricating pre-sintered form

- Improved sintering

Development Challenges:

- Large capital required to develop process
- Slip casting mold
- YAG ceramic crucible to hold ceramic disk while sintering

Scatter results from pores and bubbles



Bulk scattering measured on 0.6cm Konoshima slab with loss-meter yields ~ 170 ppm.

Scattering in ceramics is now on the order of single crystal

State-of-the-art fabrication of Nd:YAG Ceramics

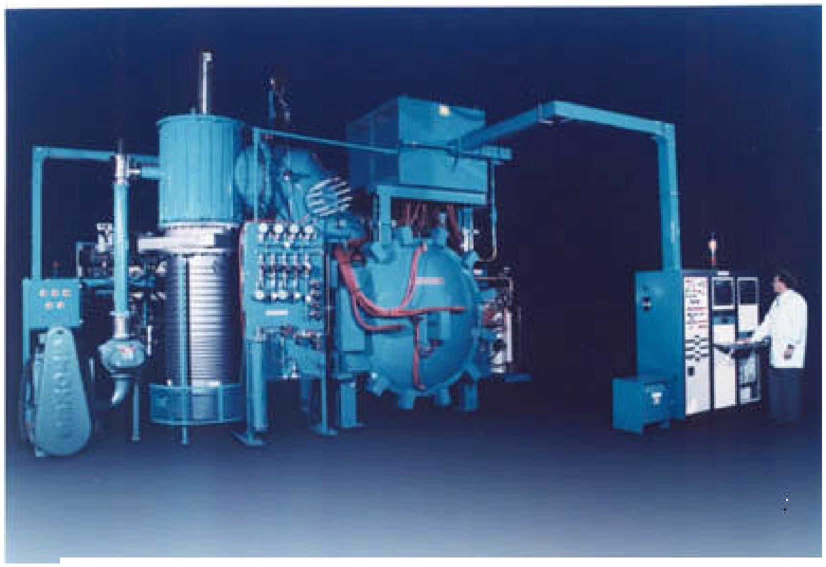
The world's largest Nd:YAG ceramics have been fabricated by Konoshima/Biakowski

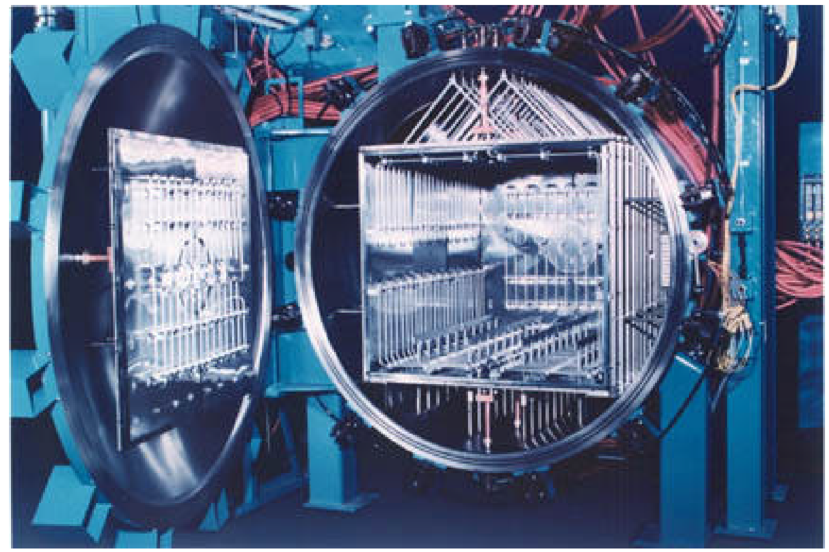
BAIKOWSKI

10x10x2 cm ceramic $YAG:Nd^{3+}$

10 slabs have been fabricated and demonstrated for the HELSTF Laser Project

Large furnaces for producing transparent ceramic YAG (2 x 40 x 70 cm) are currently available





Vacuum tungsten furnace for 100 pieces 40x70x2 cm, 3 days/run

Hot-Isostatic Press
(40 pieces, 1 day/run)

Summary

- Feasible methods for producing IRE size Yb:S-FAP are under investigation
- Bonding technologies have been proven on large optics
- Yb:YAG ceramics look promising for scaling to IRE sizes

Several options look promising for producing large size crystal/ceramic optics for IRE scale systems.