



Paper # 1609





ZINC SULFIDE OPTICS FOR HIGH POWER LASER APPLICATIONS

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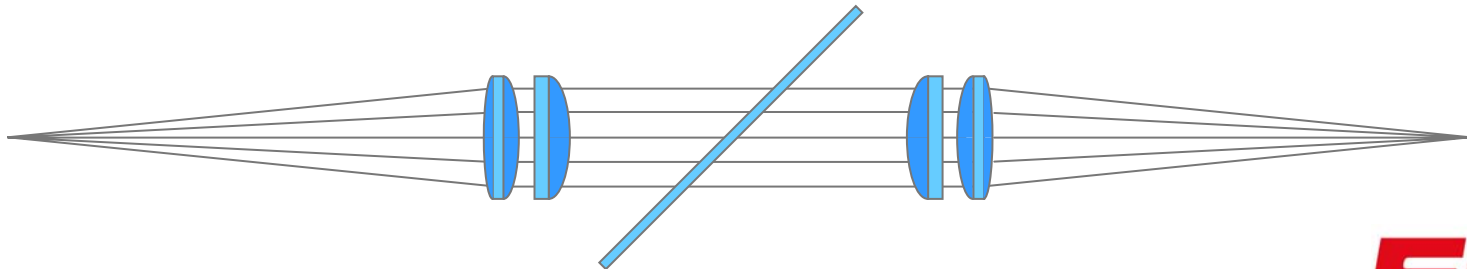
Presentation Overview

- **Background & Motivation**
- **Design Objectives**
- **Testing & Welding Results**

Why develop new focusing optics?

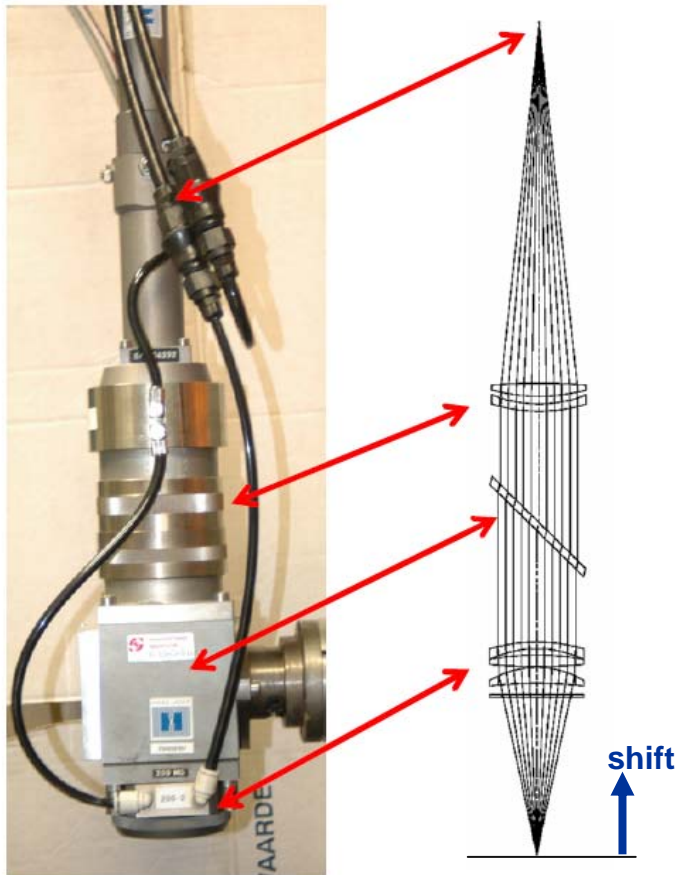
- motivation for a laser process developer -

- Fiber and disc lasers are advancing rapidly in power and beam quality.
- Many existing optics not rated for above.
- Thermally induced focal shift is significant.
- Interest in customized, unique solutions.



Traditional 1 μ m Focusing Optics

- superb designs for low to medium power -



Reported Thermal Shift Testing:

~ 1mm/kW focal shift

~ 500 second time constant

OPTICAL CHARACTERISTICS OF ND:YAG OPTICS
AND DISTORTIONS AT HIGH POWER
Paper #1503

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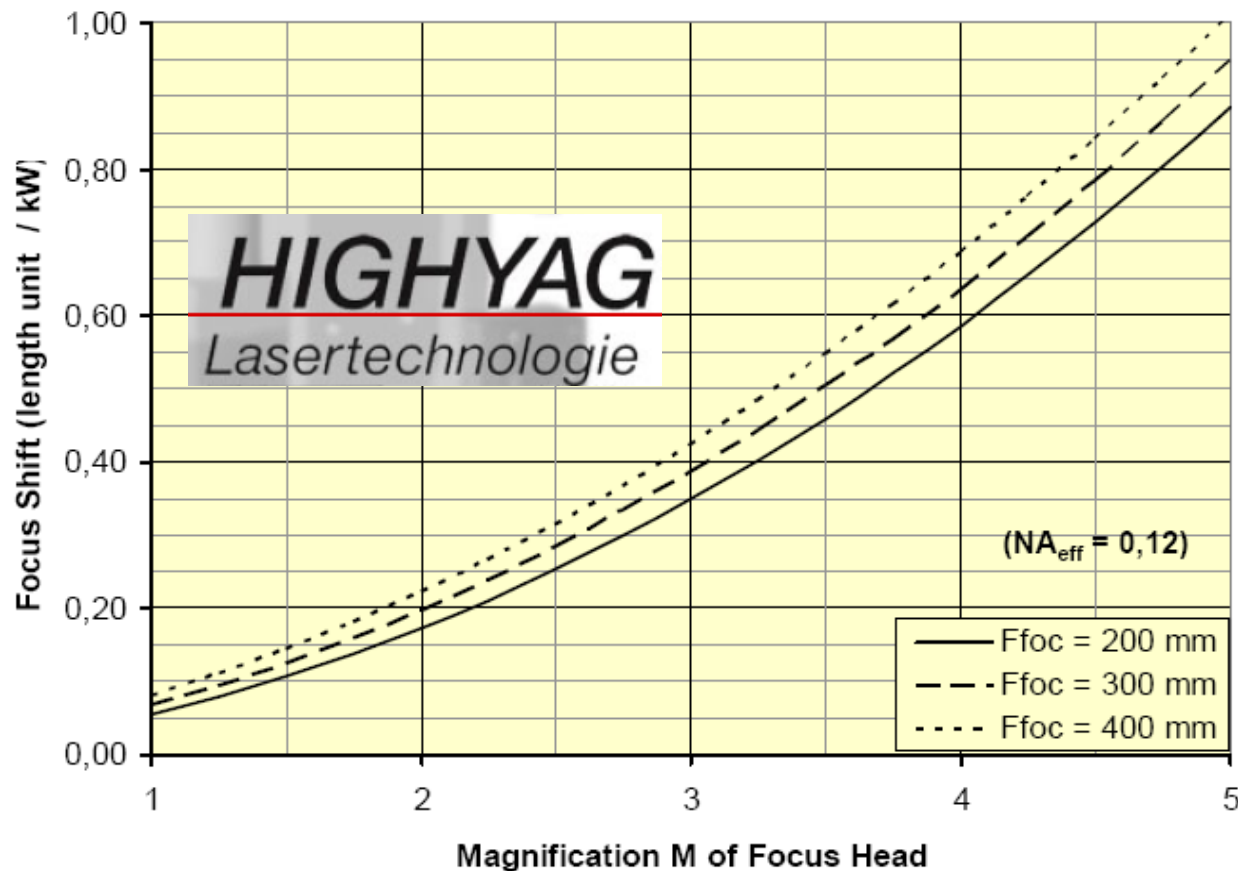
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Fig. 1: Photo of optical system and optical layout (ray path with 100 mm focus lens).

Improvements in Thermal Shift

- *HIGHYAG* report from ALAW '07 below -

- Others also reporting focal shift at ICALEO



Why Try Zinc Sulfide?

- properties and people -

- High thermal conductivity
- Single point diamond machining
- II-VI willingness to assist Really Good People

	Fused Silica	MS ZnS
Density (g/cm ³)	2.203	4.09
Poisson's Ratio	0.17	0.27
Hardness (Knoop)	500	150-165
Rupture Modulus (dyne/cm ²)	5.00E+09	6.90E+08
Young's Modulus (dyne/cm ²)	7.3E+11	7.45E+11
Linear Expansion Coef (x10 ⁻⁶ /°C)	0.55	6.5
Specific Heat (J/g/°C)	0.703	0.527
Thermal Conductivity (W/cm/°C)	0.0138	0.272
Scatter Coefficient at 1.06 μm (/cm)	ND	< 1%
Scatter Coefficient at 0.6328 μm (/cm)	ND	< 10%
Index of Refraction @ 1.06 μm	1.4496	2.287
Temp. Change of Refractive Index(x10 ⁻⁶ /°C) @ 1.06 μm	11	42
Bulk Absorption (/cm) @ 1.07 μm	< 0.0001	< 0.001

Bad

Really Good

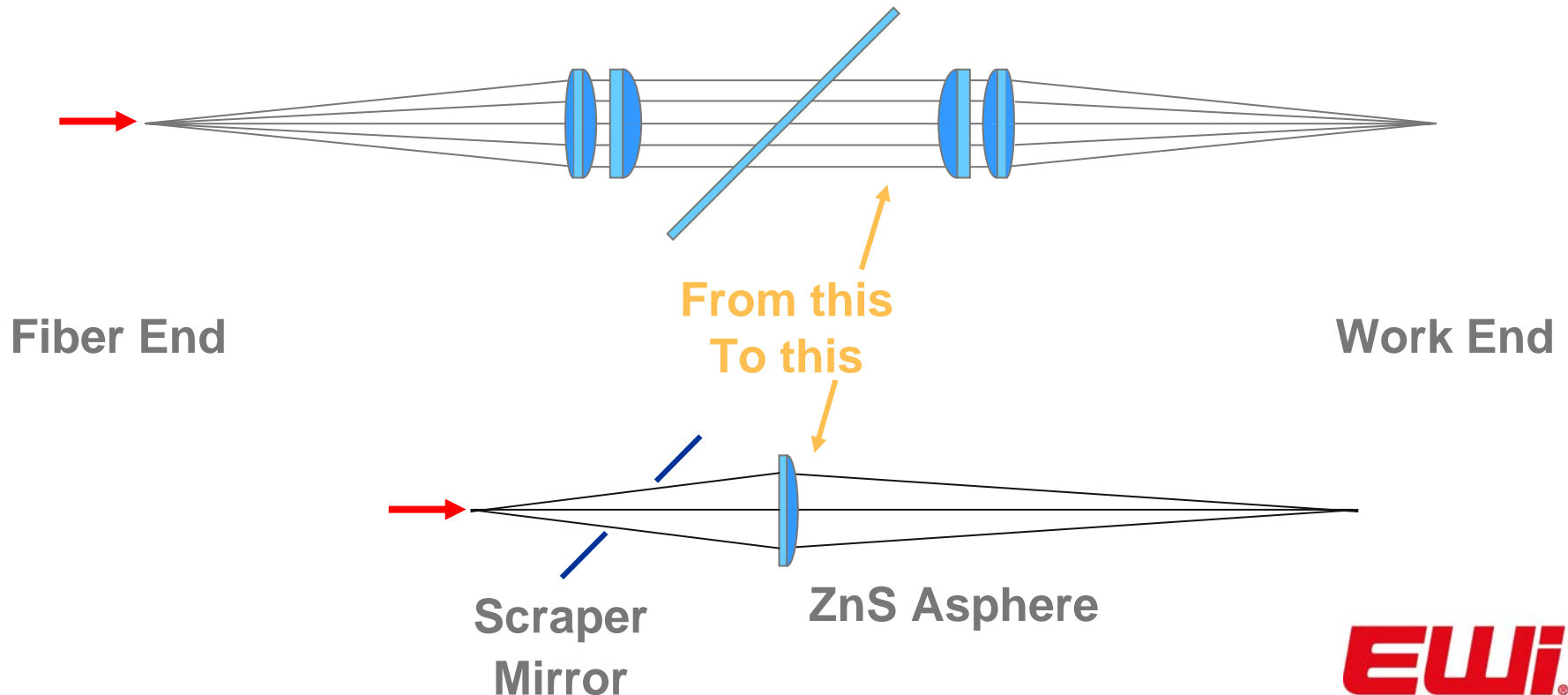
Bad

Not too bad

The Approach

- at least the initial one -

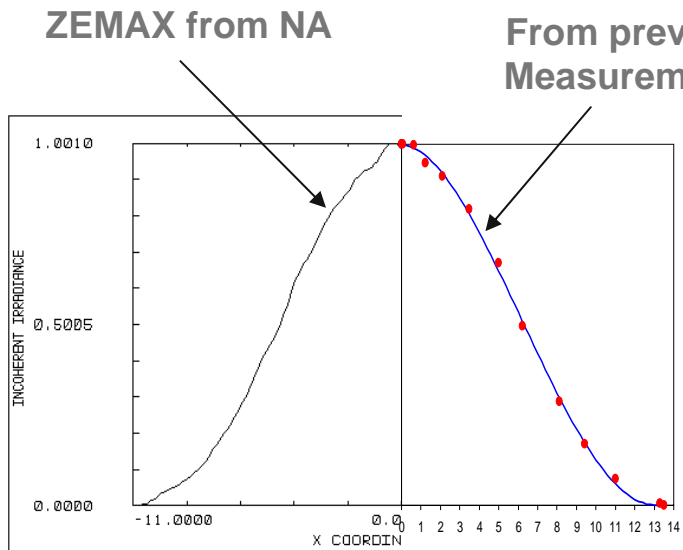
- Replace 4 (or more) focusing elements with 1
- Eliminate all other transmitting optics



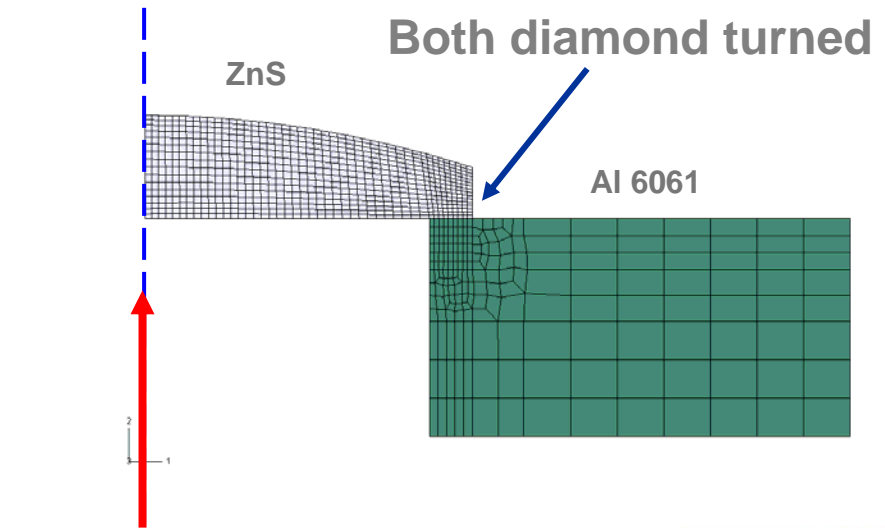
Modeling First

- a few critical input parameters -

- Beam shape
- Surface absorption
- Bulk absorption
- Heat transfer conditions



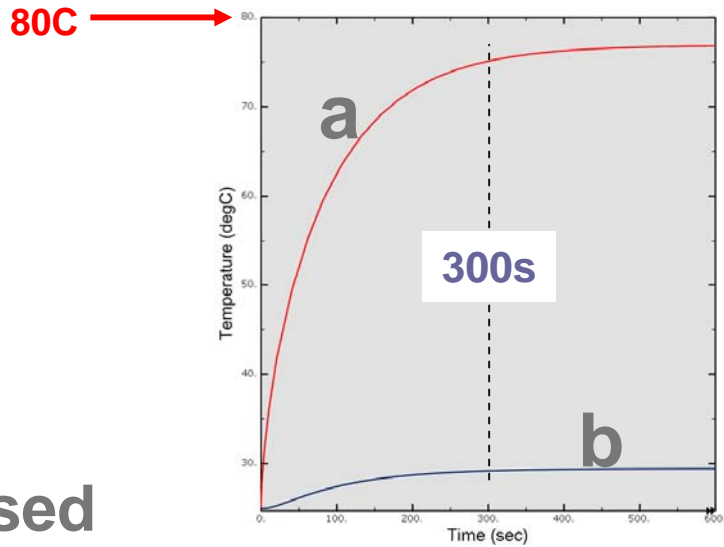
Presumed Beam Shape
At ZnS Focusing Lens



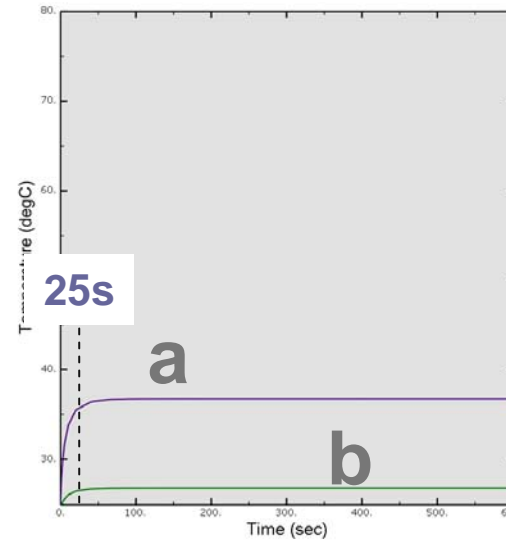
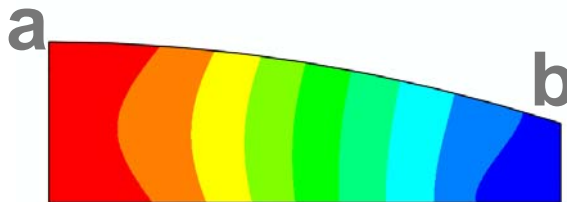
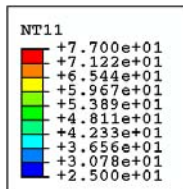
Diverging
Beam Input

First Thermal Modeling Results

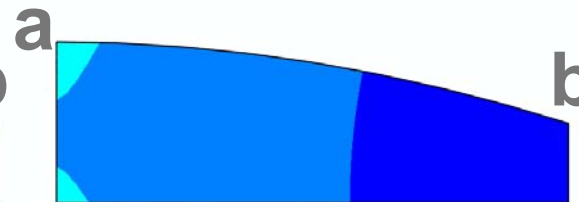
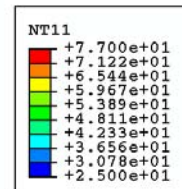
- encouraging enough to continue -



Fused
Silica



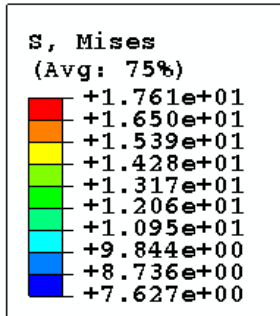
Zinc
Sulfide



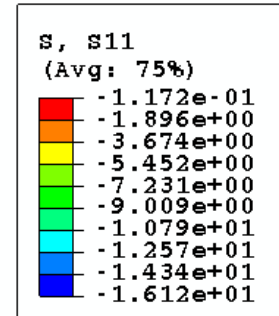
Stress Modeling in ZnS Lens

- *mechanically safe* -

von Mises



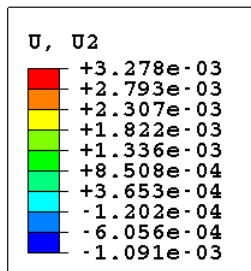
Radial



When the lens expands freely, the magnitude of the maximum stress in the lens is about 16 MPa, significantly below the ultimate tensile strength of ZnS (53 MPa).

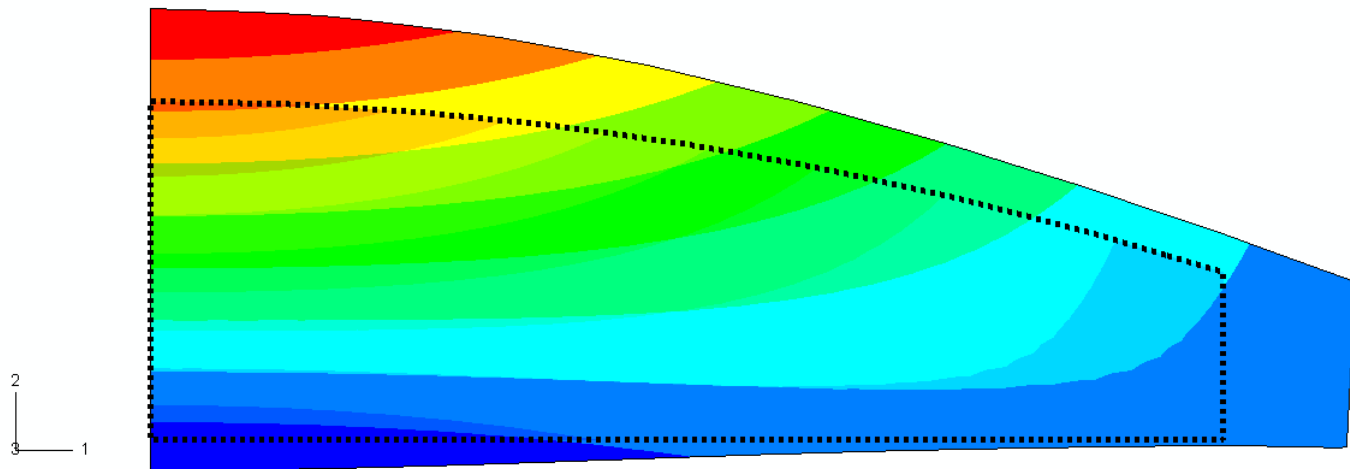
Distortion Analysis

- *can be used to feed revised ZEMAX analysis* -



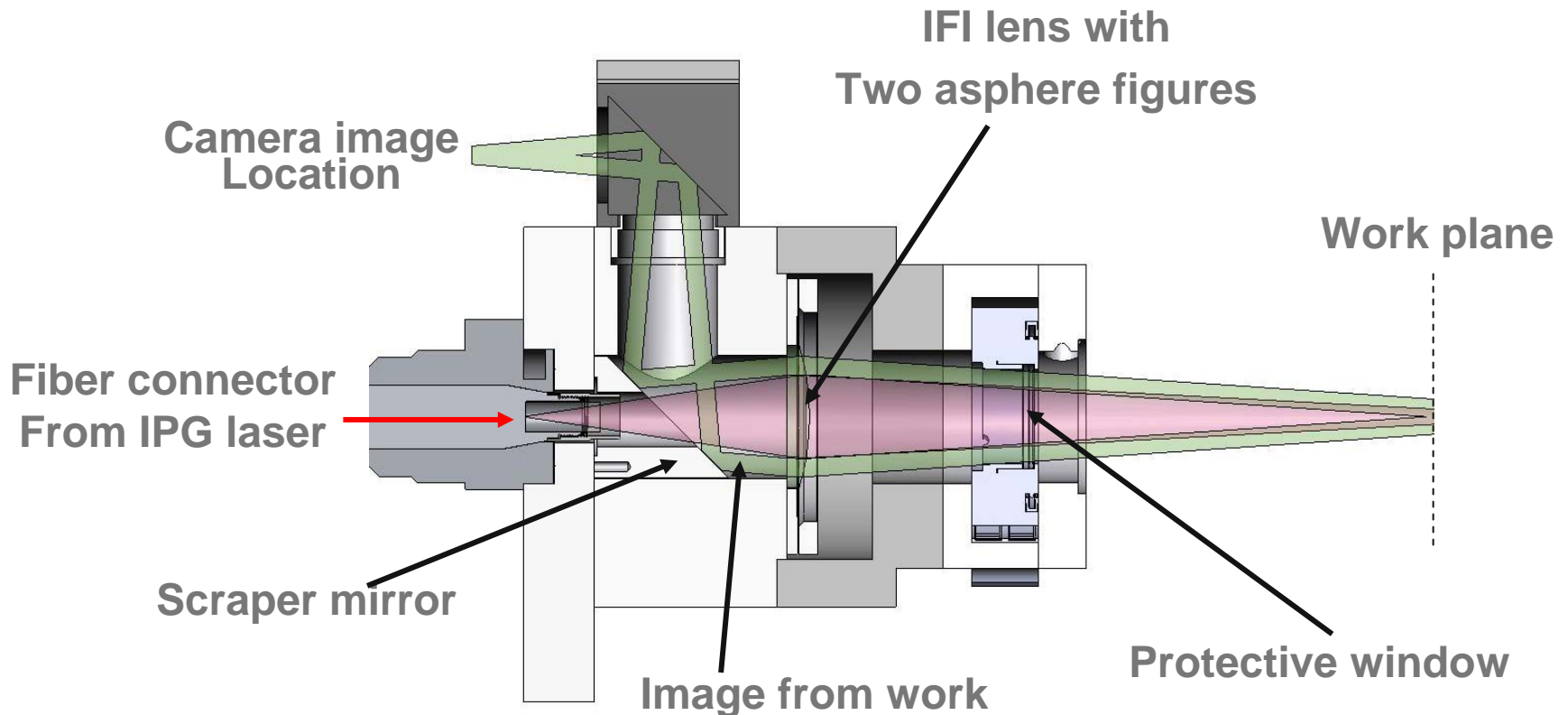
Vertical Displacement (mm)

Magnified 500X in this image



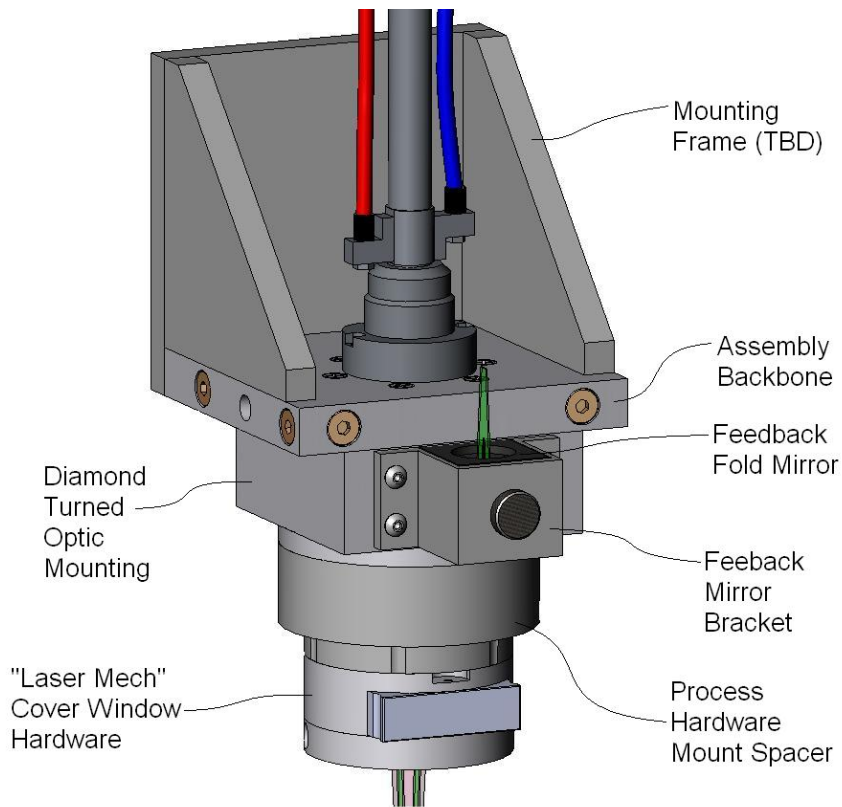
IFI Focus Assembly Design*

- Integrated Focusing and Imaging lens -



From CAD to Assembly

- *IFI** components from multiple suppliers -



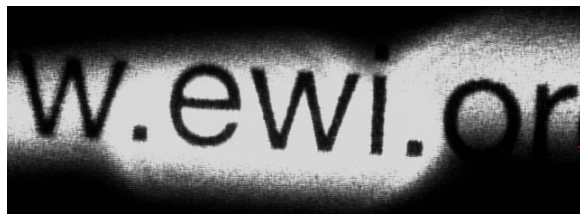
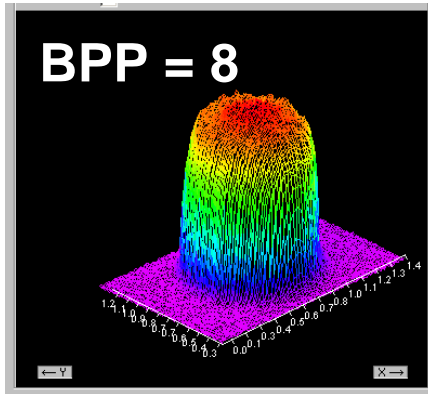
IPG, LaserMech, Thor, II-VI, VLOC, B&G, McMaster Carr

EWI
THE MATERIALS JOINING EXPERTS

* Patent Pending

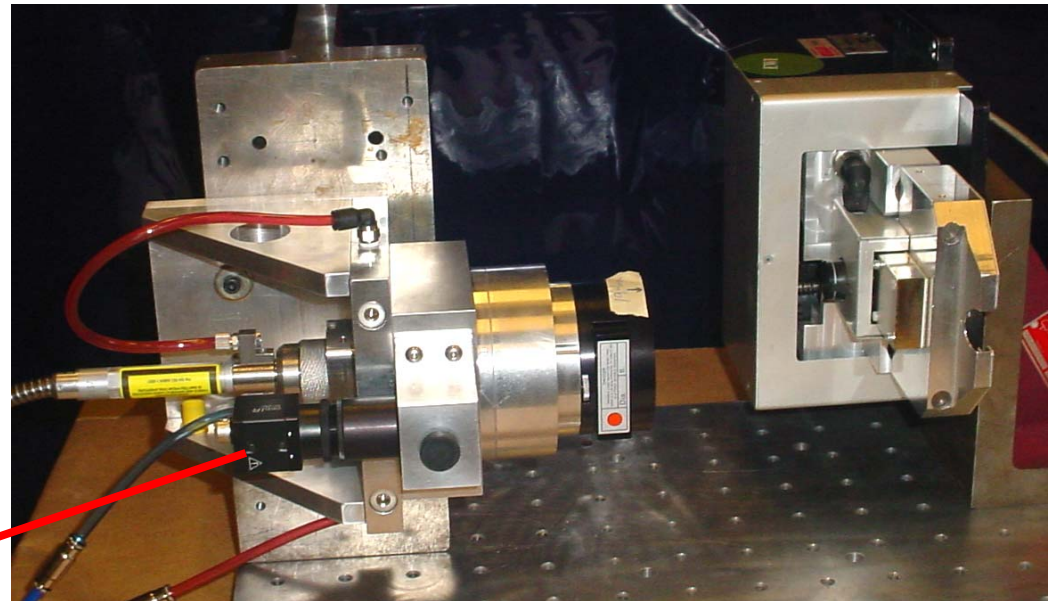
IFI* Beam Quality Testing

- focusing & imaging elements work well -



← 10 mm →

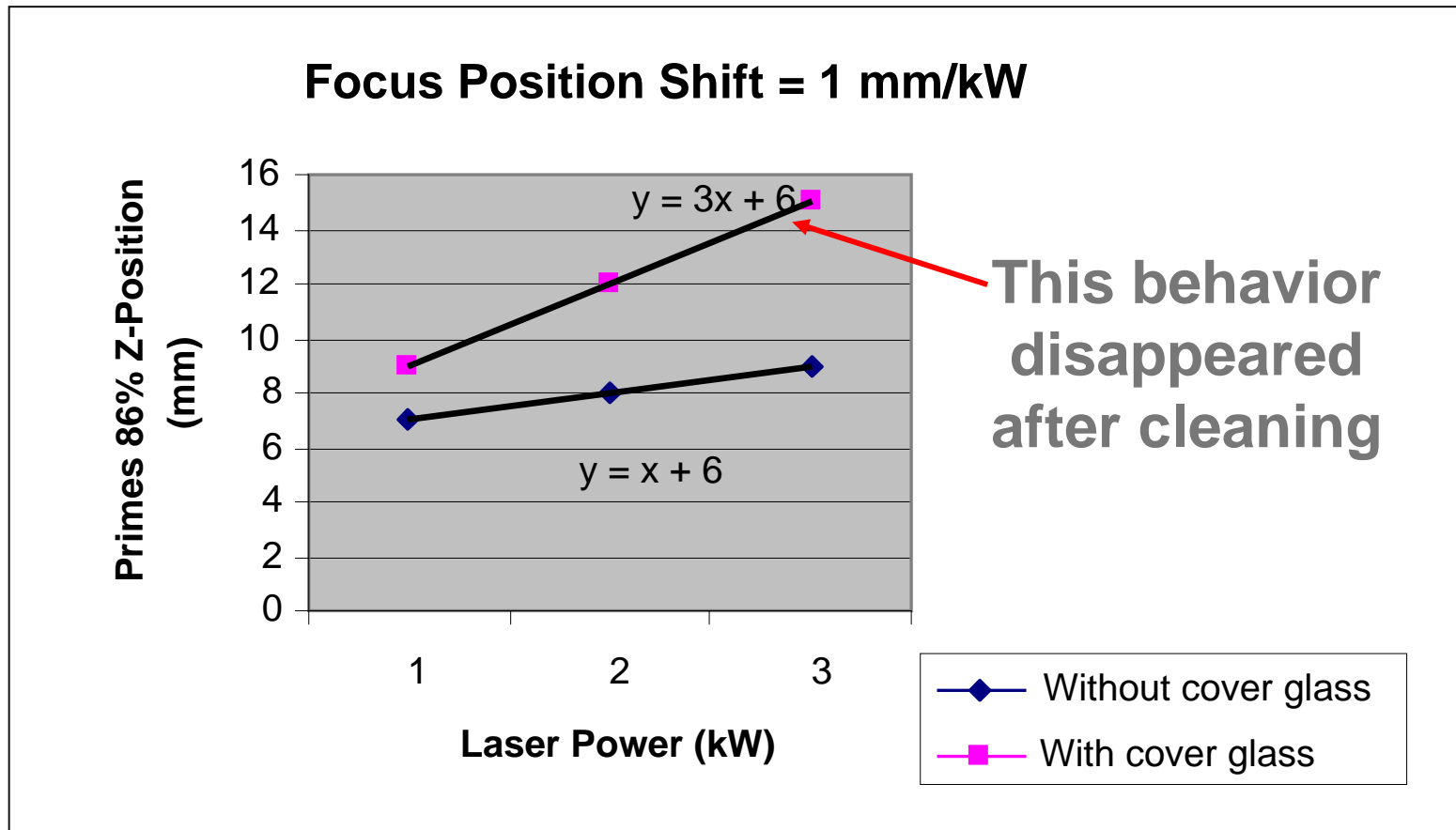
Camera Image



Primes Focus Monitor

Some Early Focal Shift Results

- first experience with “invisible” contamination -

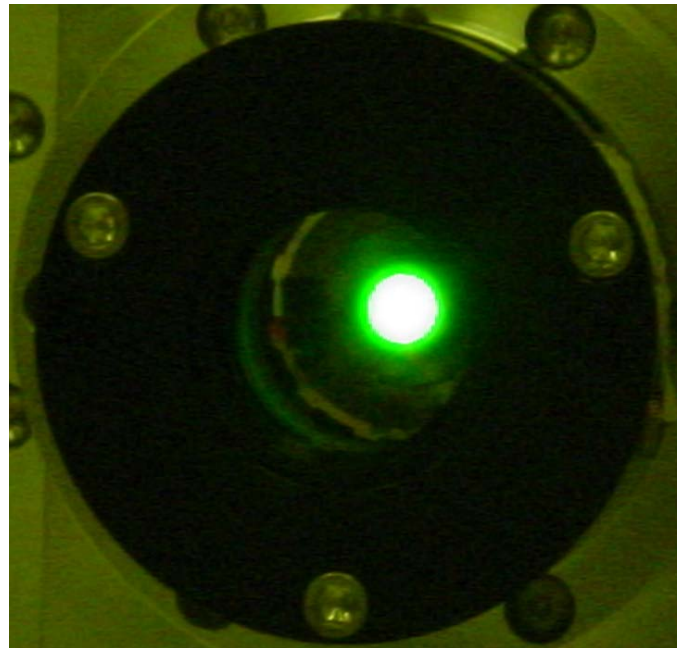


An Interesting ZnS Phenomenon

- *second harmonic generation* -

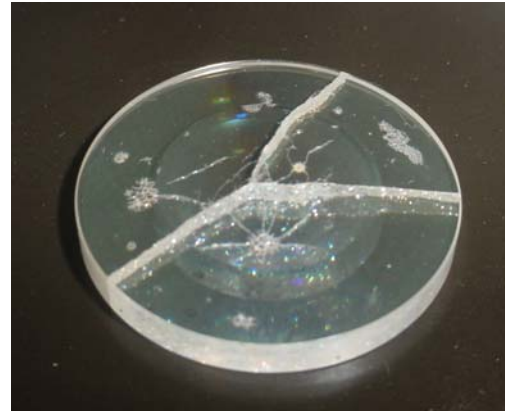
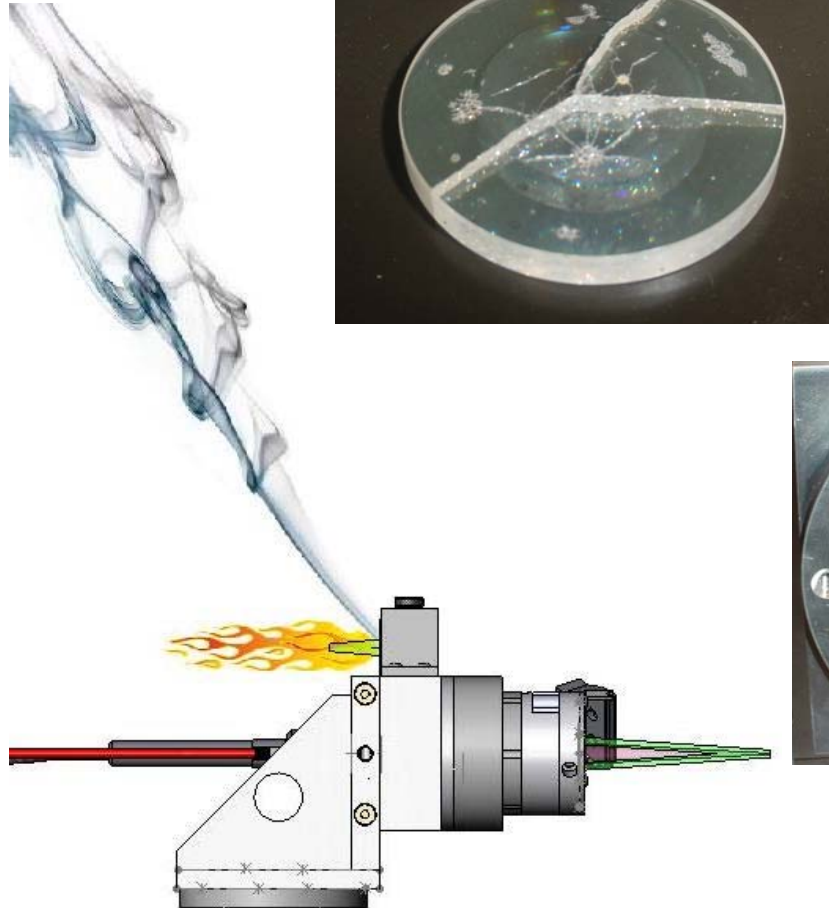
- May be useful for monitoring purposes
- Should have been our clue to actual beam diameter

View looking into IFI lens



During Initial Welding Tests

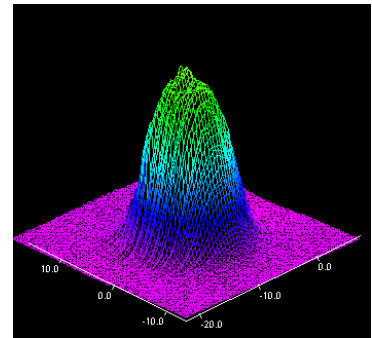
- some minor set-backs -



Plan “B”

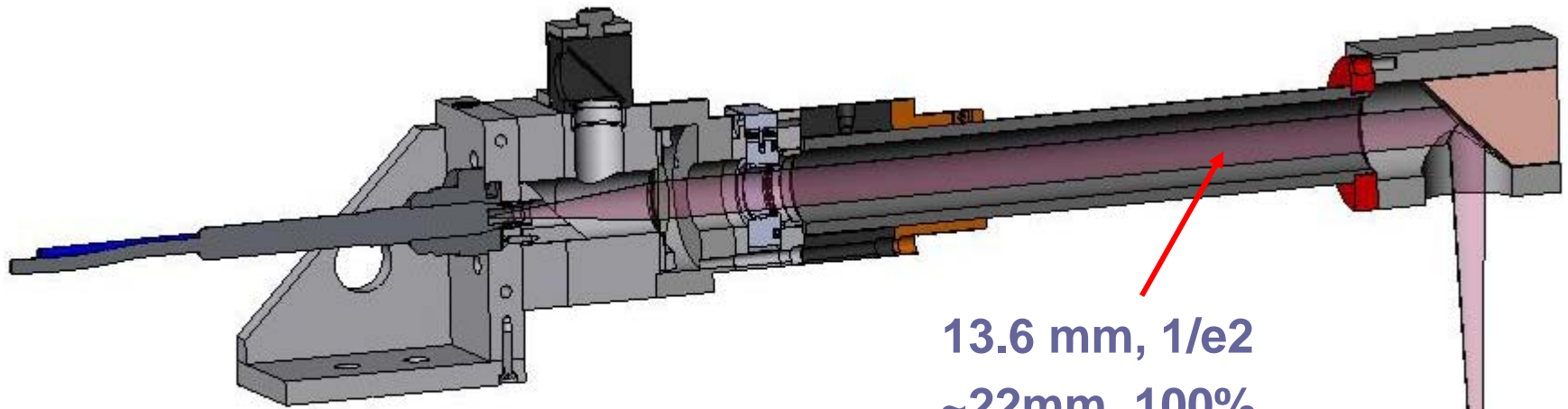
- *revisit initial design assumptions* -

- Re-check actual beam diameter at lens
 - Much smaller than expected, only 10 mm, $1/e^2$
 - Don't use NA for high-power designs
- Spatter generation
 - Much greater than anticipated
 - Optics much too close for comfort
- Move transmitting optics far away from work
 - Keep “invisible” contamination in mind

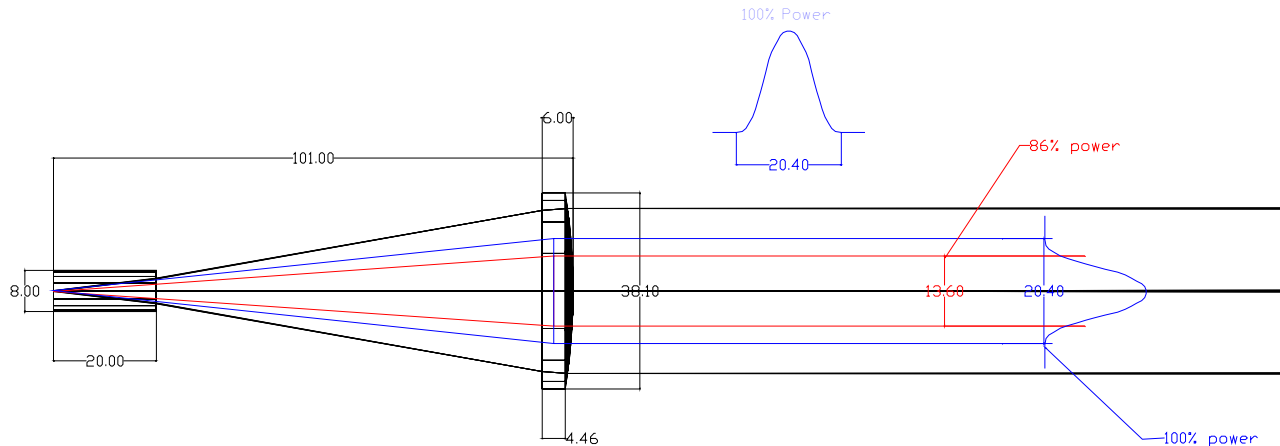


Revised "Hybrid" IFI* Design

- collimate & use copper mirror for focusing -



13.6 mm, 1/e2
~22mm, 100%



250 mm
2.5 X
F-18

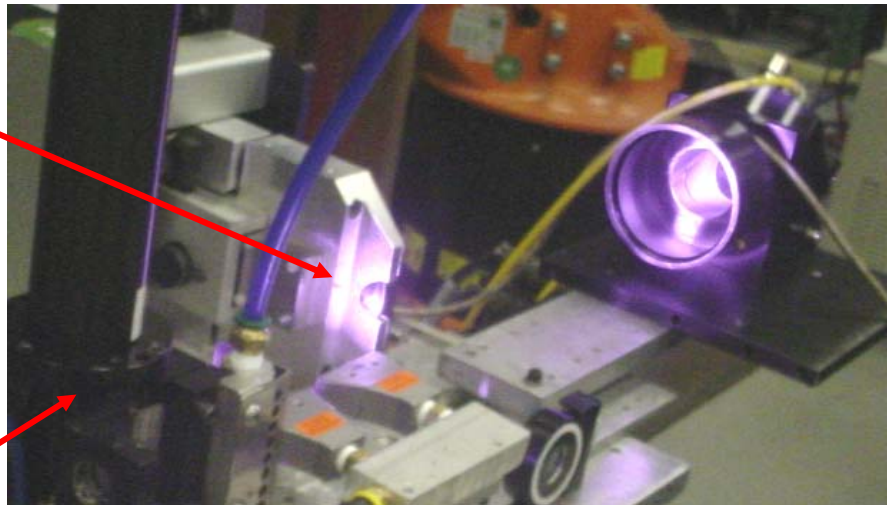
EWi
THE MATERIALS JOINING EXPERTS

* Patent Pending

Measuring Focal Shift Again

- after all our power meters failed -

Primes
Focus Monitor



Flat folding mirror

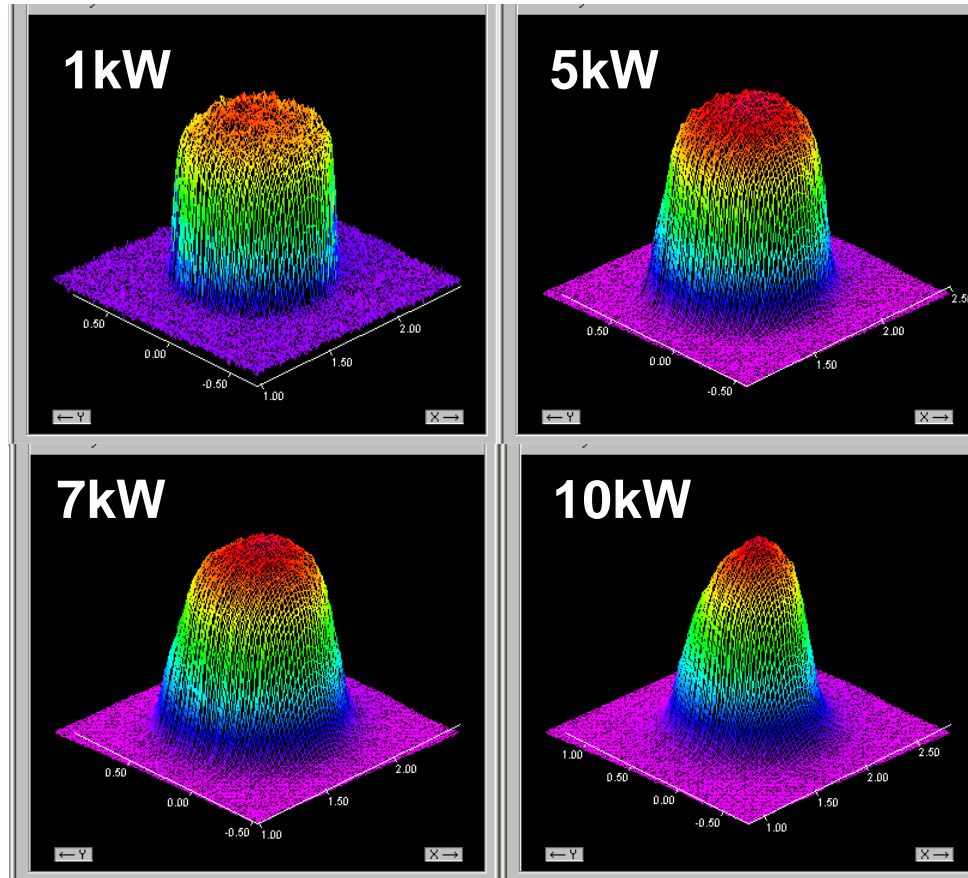
Hybrid IFI
Focus Assembly

Durable, Recyclable
High-tech Beam Dump



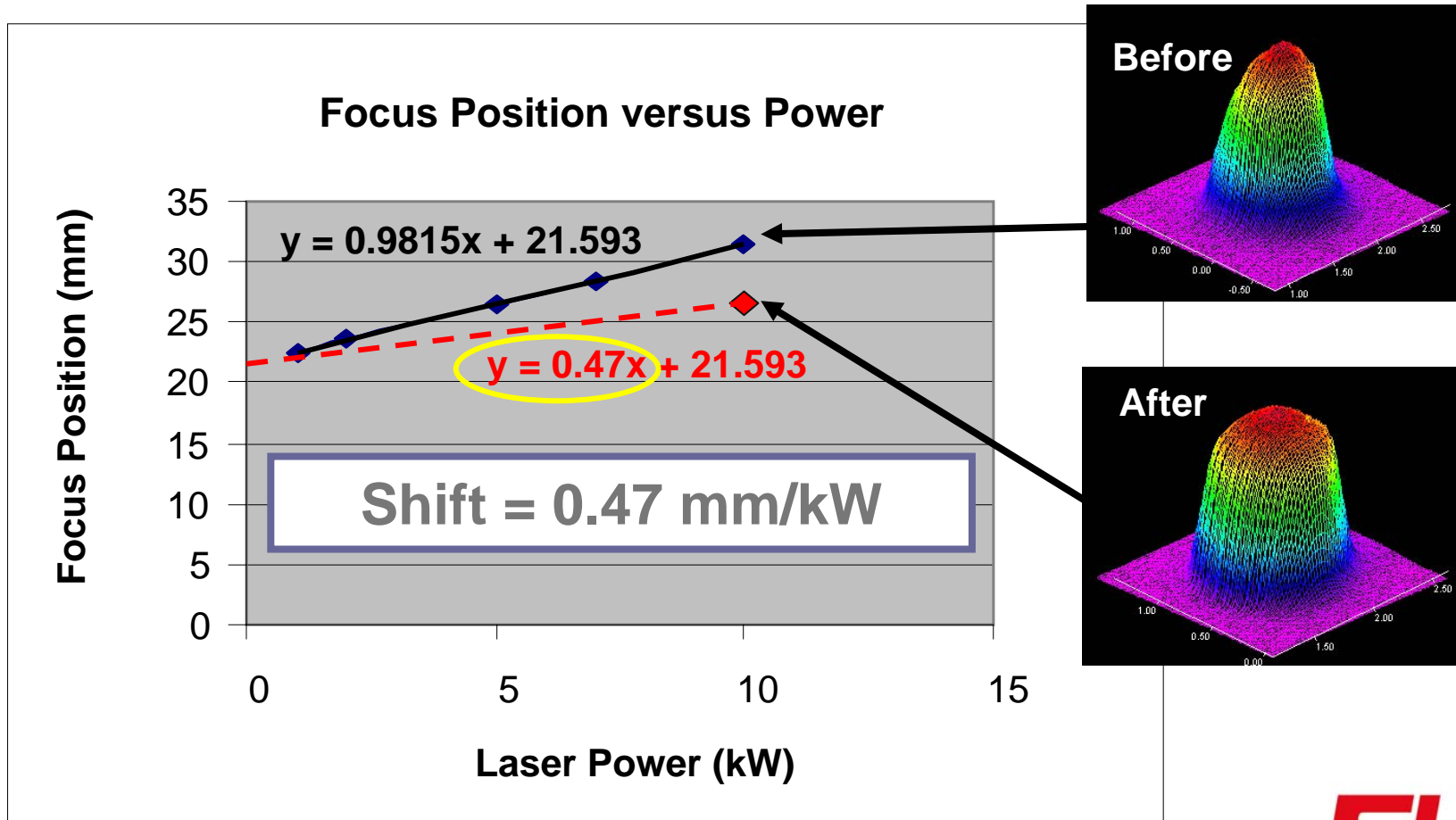
Focal Point Quality Changes

- before cleaning “invisible” contamination -



Focus Shift vs Laser Power

- before & after cleaning “invisible” contamination -

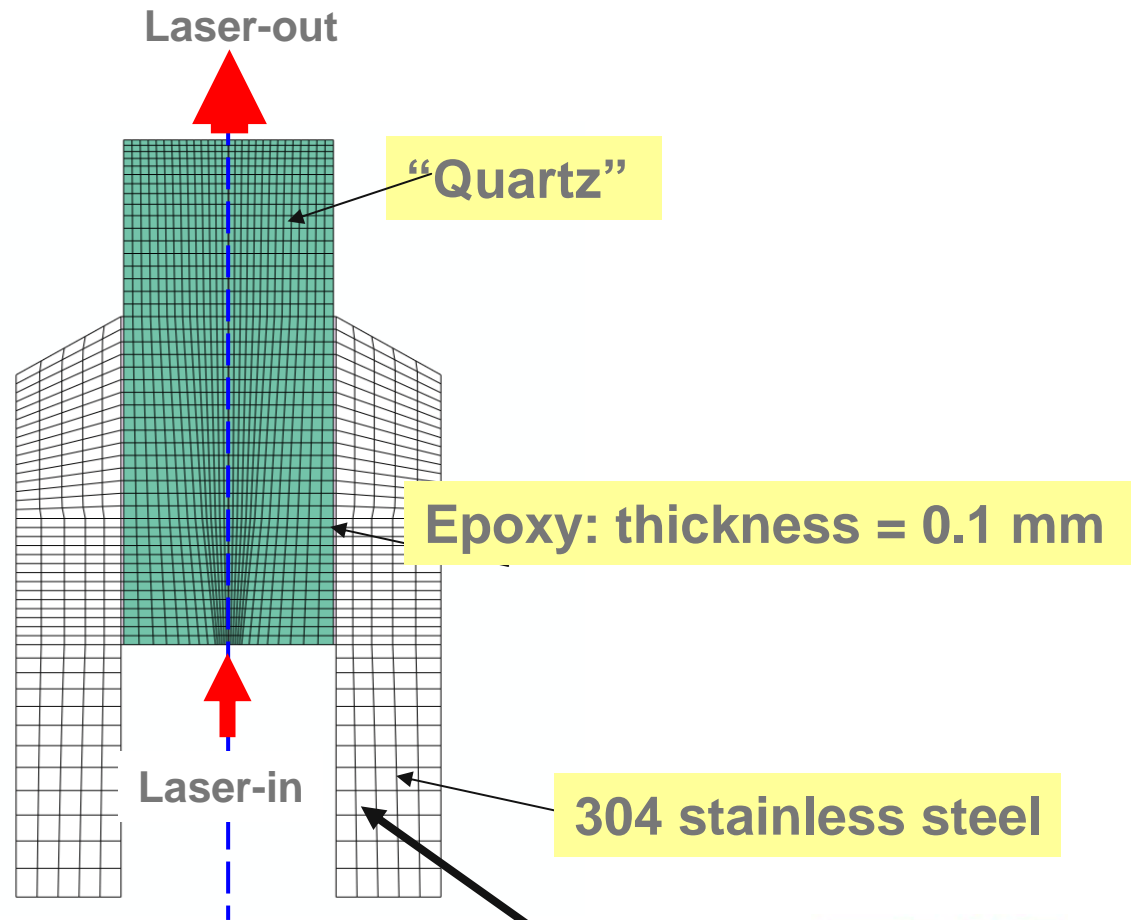


A Lingering Question

- *what does the fiber block end do thermally?* -



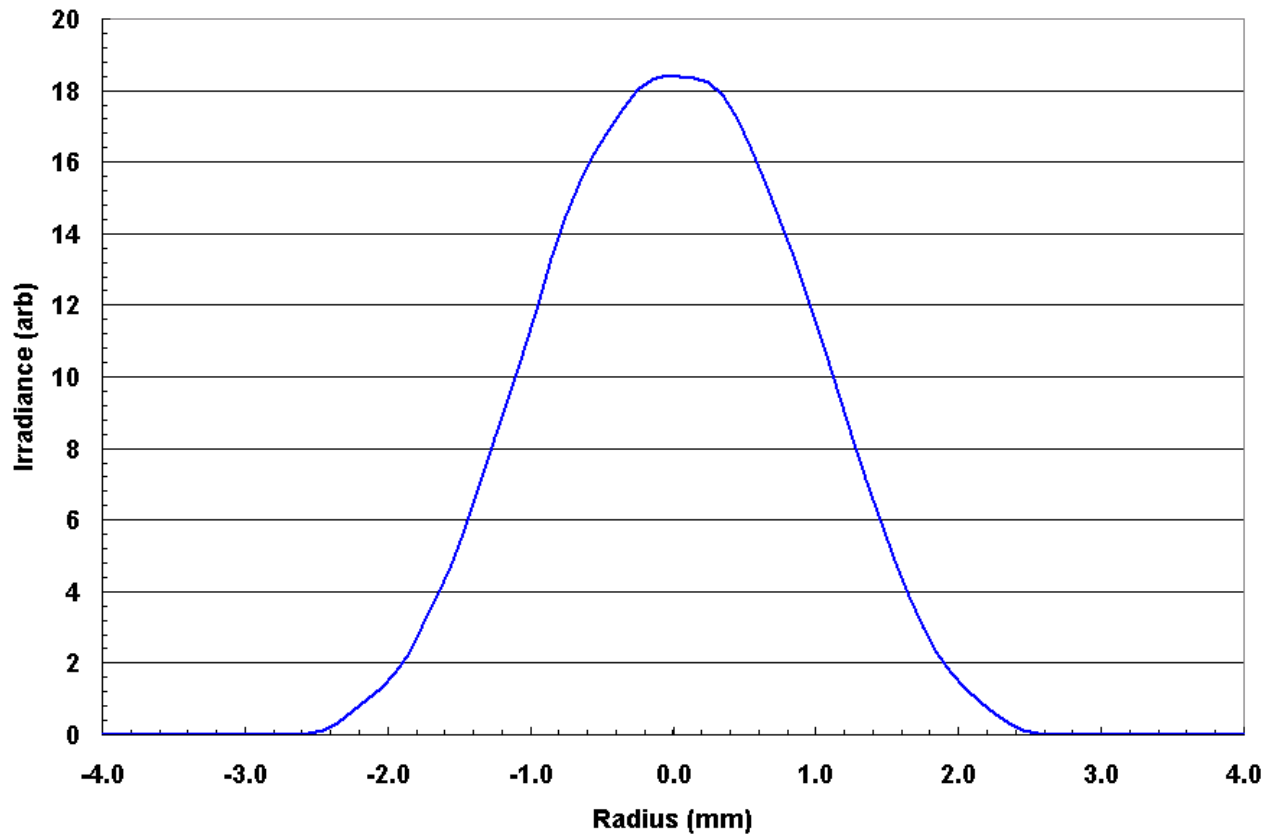
4.0 mm



Not from IPG drawings; just an estimated shape.

Beam Shape at Quartz Block Face

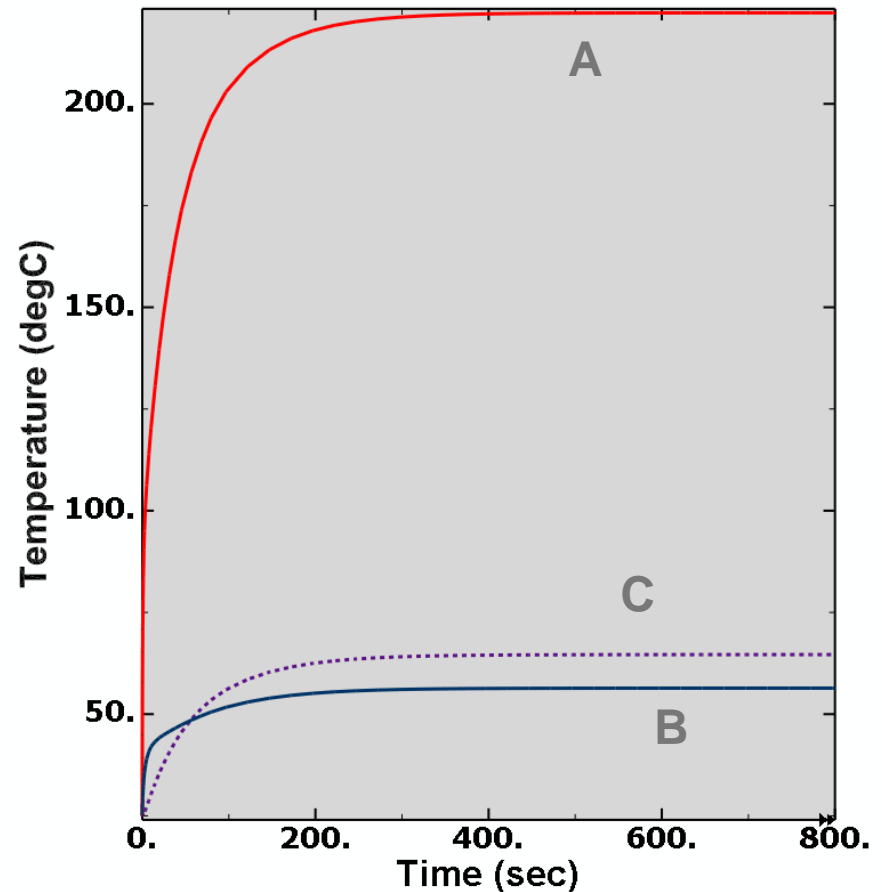
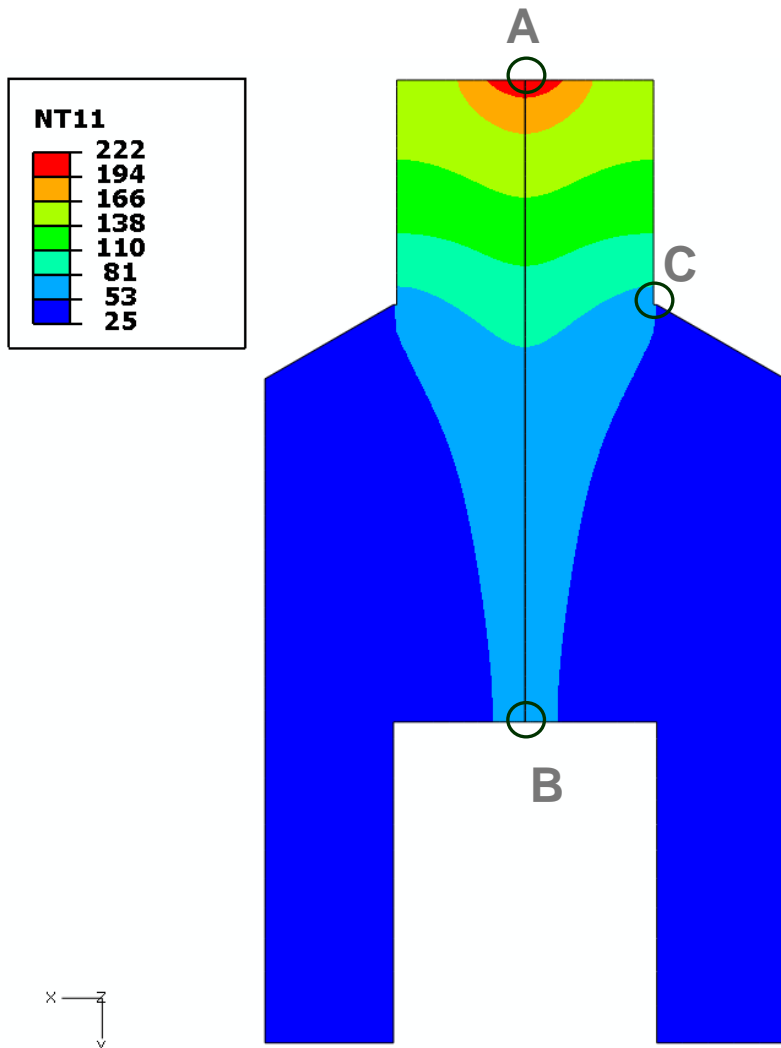
- *best guess for initial modeling* -



- Laser power = 10 kW
- Coating absorption = 0.005% per surface
- Bulk absorption of fused silica $1\text{E-}5 \text{ mm}^{-1}$

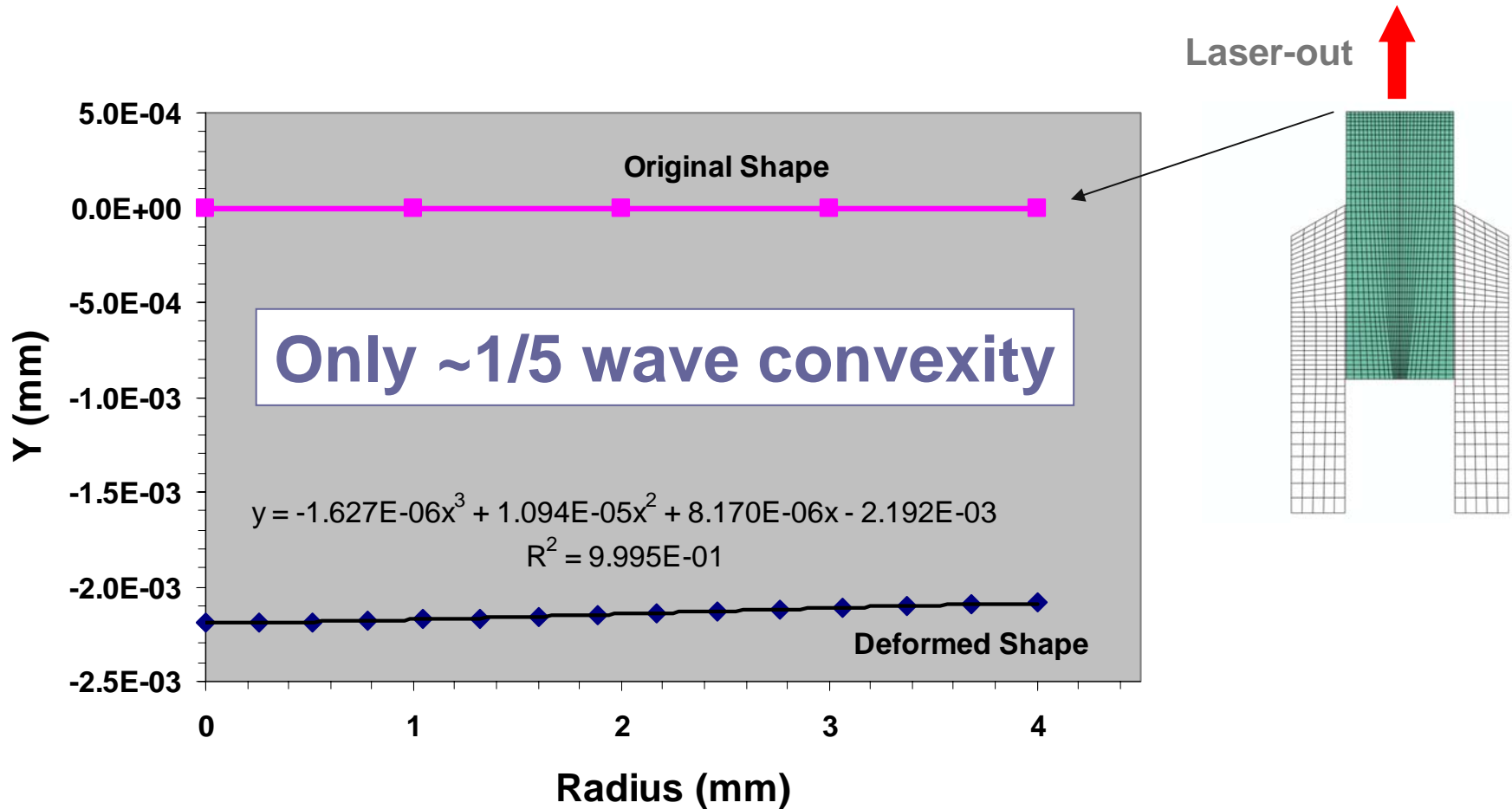
Temperature ($^{\circ}\text{C}$) after 800 Seconds @ 10kW

- not unreasonable, considering T_g of epoxy -



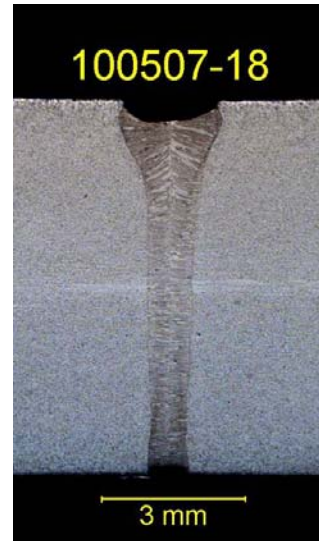
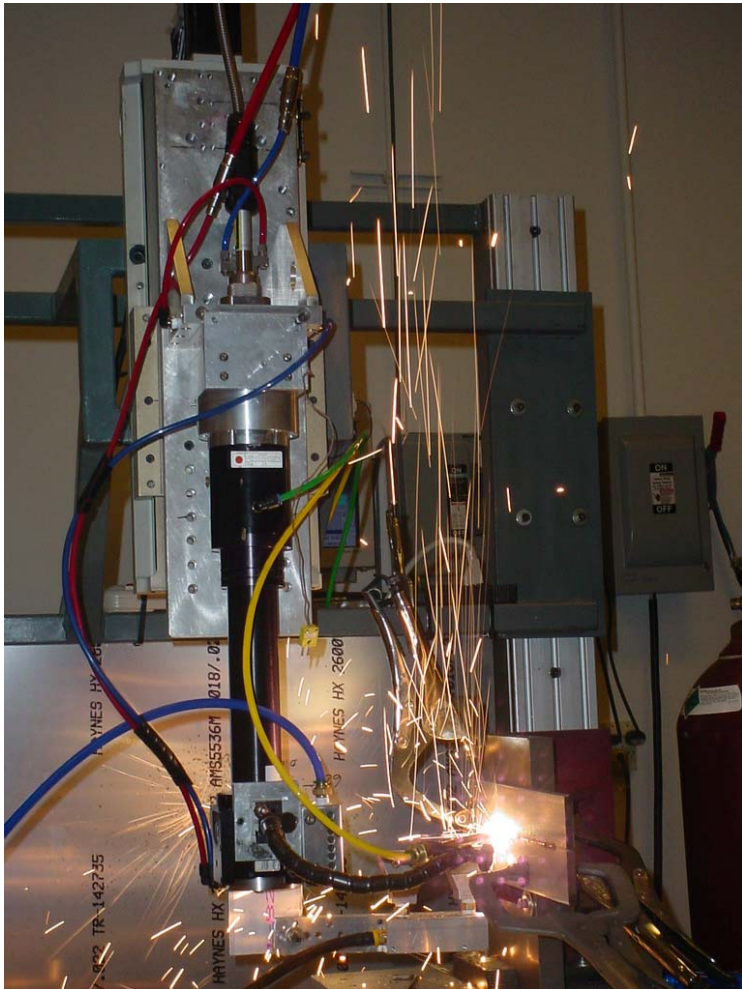
Deformed Shape of Quartz Block End

- negative values are "up" on drawing -



Initial Welding Performance

- spatter still a significant issue -



- Good bead shape
- Good efficiency
- Material ejection
- **Beam path?**



Conclusions

- Zinc Sulfide transmitting optics can tolerate very high laser power density.
- Single element, diamond turned, ZnS aspheres can produce excellent imaging (focusing) performance.
- Single surface of ZnS, IFI* optic can perform both focusing and imaging functions.
- Thermal shift of ZnS optical solution is similar to that reported for multi-element, fused silica optics.
- Surface contamination (visible & invisible) plays a major role in thermally induced focus shift.
- “Hybrid” transmitting/reflecting focusing designs can provide robust solutions for high power laser welding.



**Thanks, and
good luck with your optics**

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