



Optical Coatings Under Load

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The Boeing Company



Outline

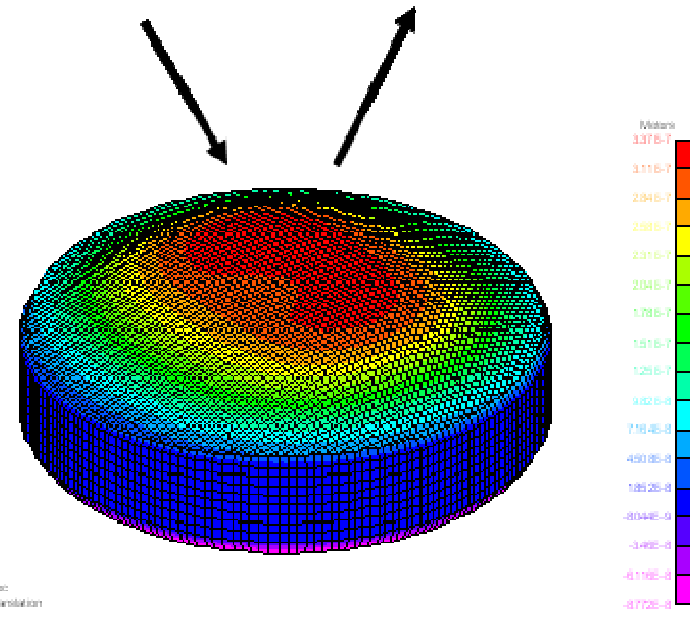
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- Modeling of optics under average power loading
 - Models do predict performance
 - Induced temperatures
 - Deflections
 - Beam quality
 - Damage does not always correlate to the models
- High Power testing of Coatings
 - Methods and Results
- Interesting Phenomena

Performance of A Coated Substrate Under Load - Reflected

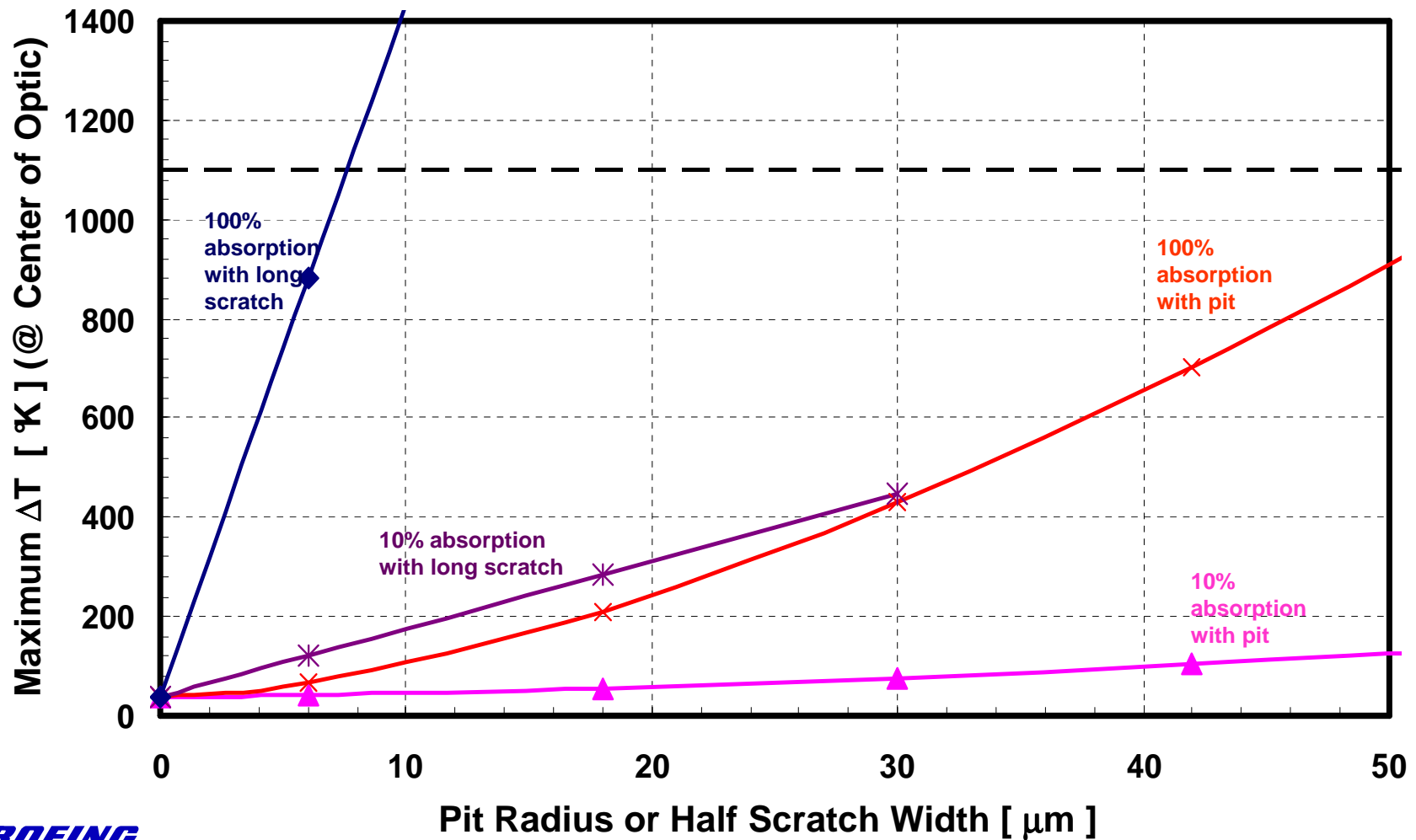
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- Absorption leads to localized heating on top surface
- Top surface expands more than bottom surface
- Surface bows
 - Lower conductivity - larger differential in temperature between front and back
 - Higher CTE - more bowing



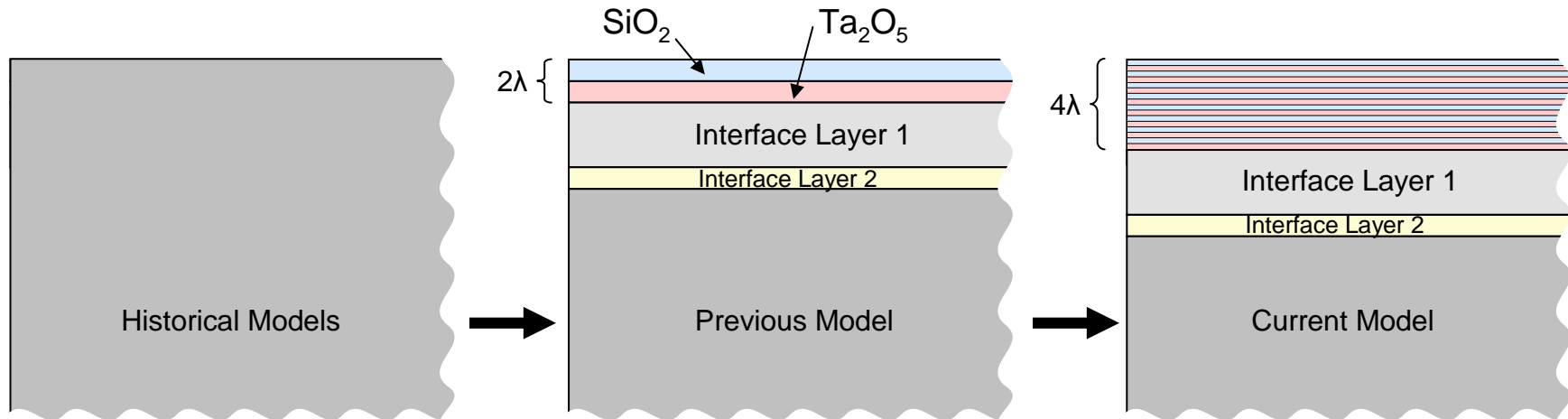
Fused Silica Optics ΔT [$^{\circ}\text{K}$] vs Scratch $\frac{1}{2}$ width and Pit Radius

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Evolution of Modeling Approach

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Boeing models have evolved to account for the elastic gradients present *near* the surface.

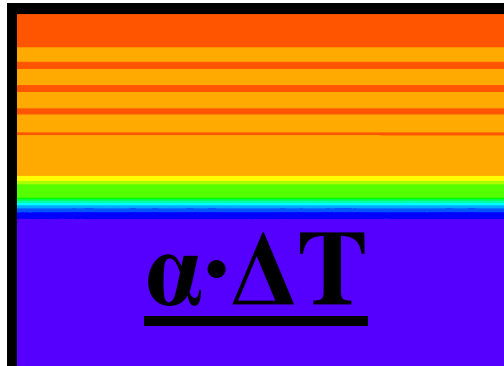
Current model includes:

- 16 layer coating stack
- Interface layer 1: Insulation layer or placeholder for additional coating layers
- Interface layer 2: Subsurface damage layer with reduced mechanical strength

Translation from Temperature Gradients to Stress Tensors

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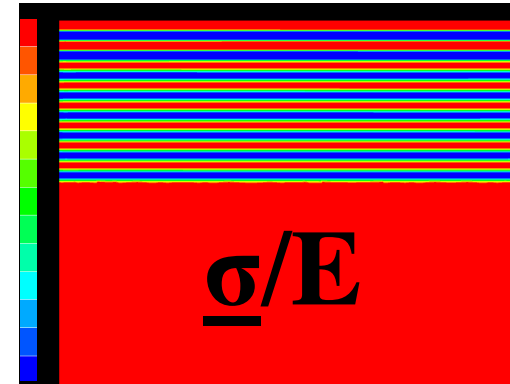
Positive strains from thermal expansion



Residual negative surface strains from coating deposition

$$+ \underline{\epsilon}_{\text{pre}} =$$

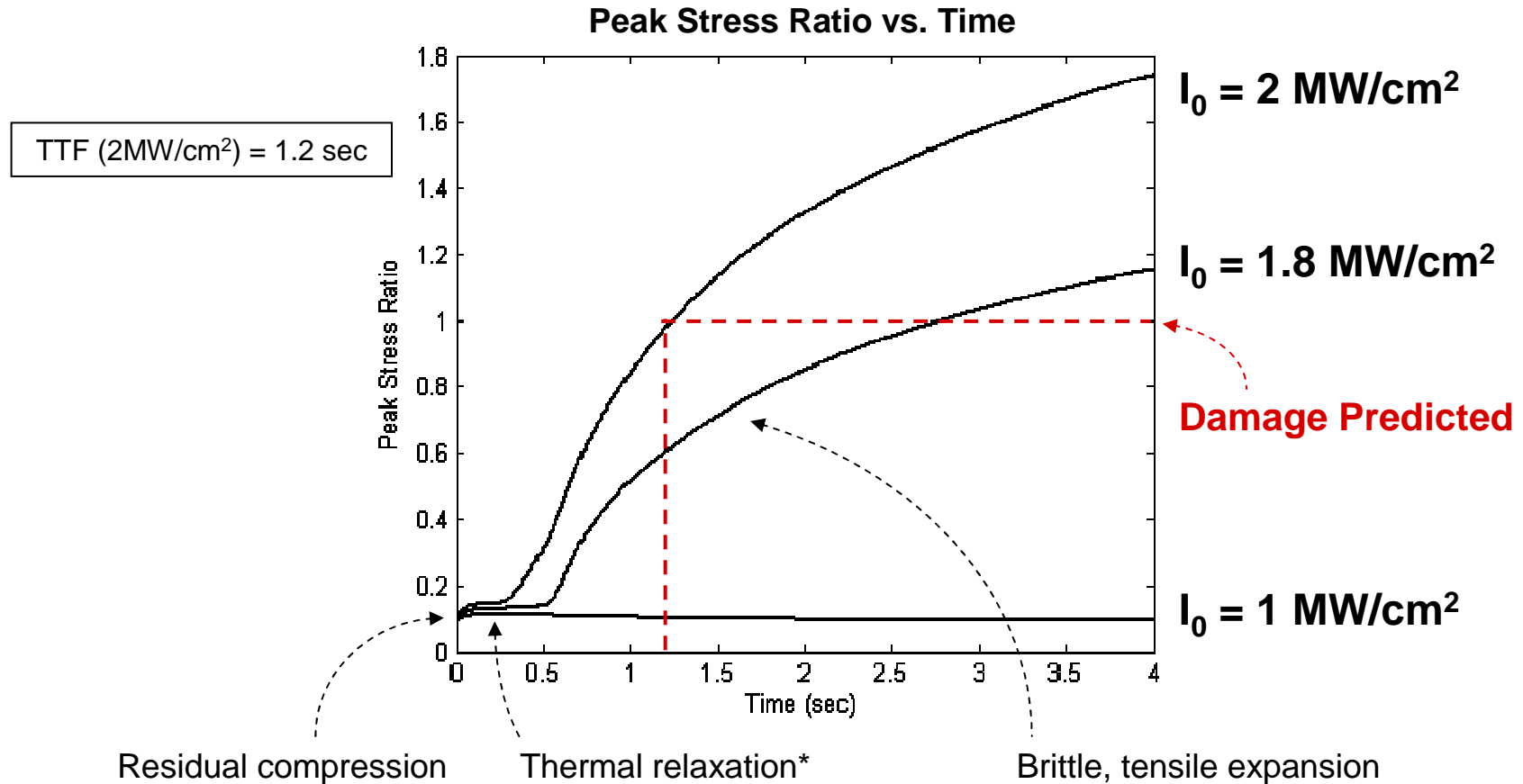
3D stress tensor profile



- Optical materials are typically > 10X stronger in compression than tension.
- Stress ratios must be computed for both stress components. The larger (absolute) represents direct proportion to damage thresholds.

Temporal Evolution of Elastic State

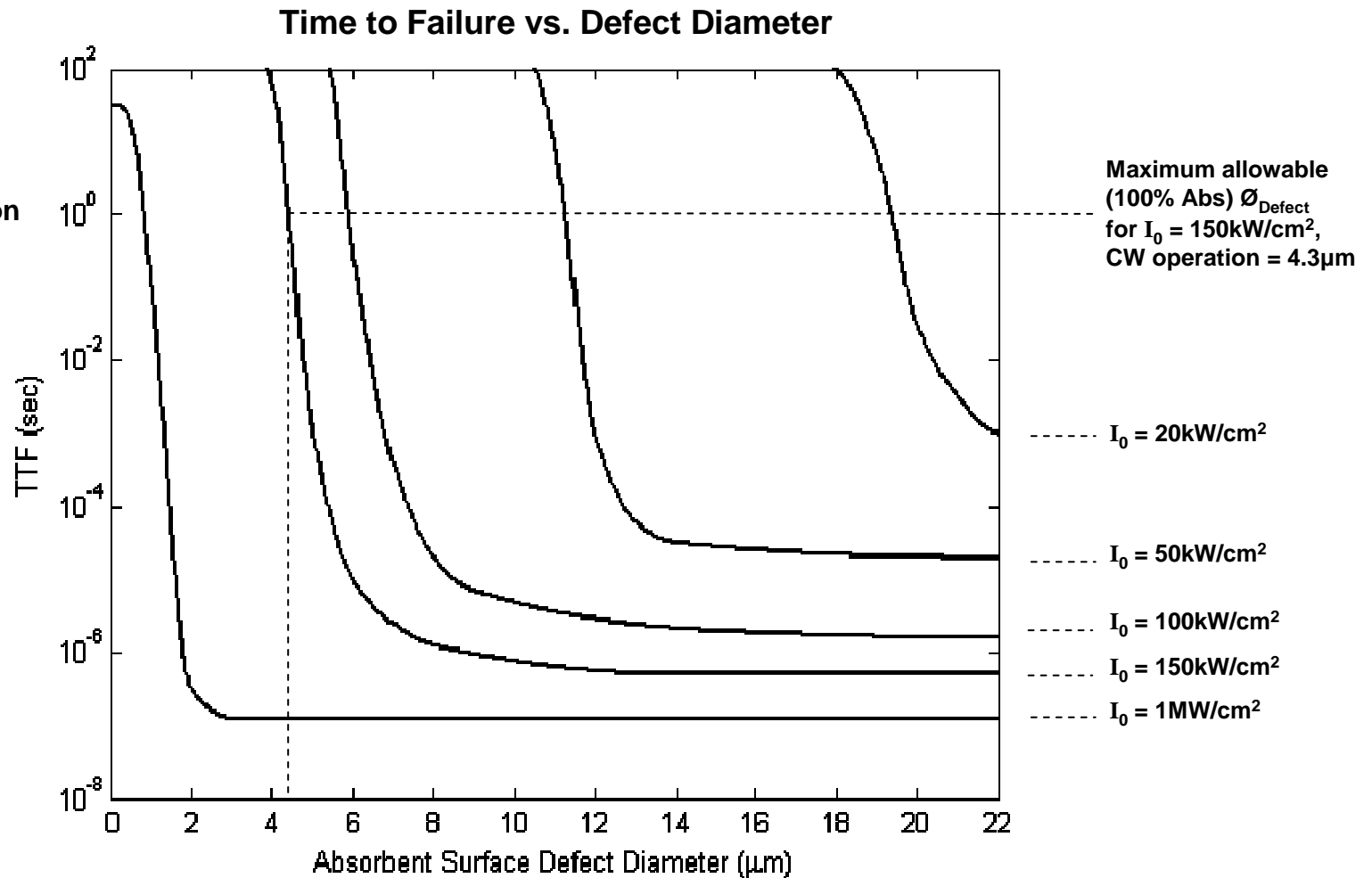
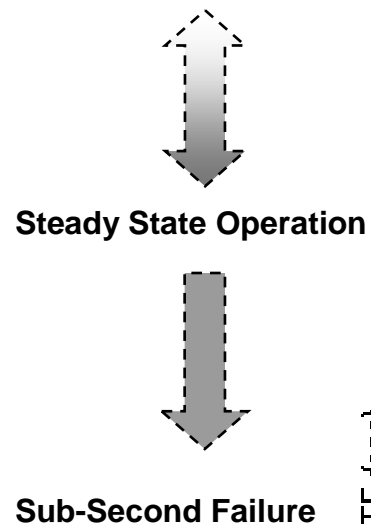
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* Duration of relaxation period is directly related to both the rate of heat deposition and the thermal resistance of the coating materials.

Micro-Defect Stress Damage Thresholds for SiO₂/Ta₂O₅:SiO₂

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Coatings Fail - in spite of the Models

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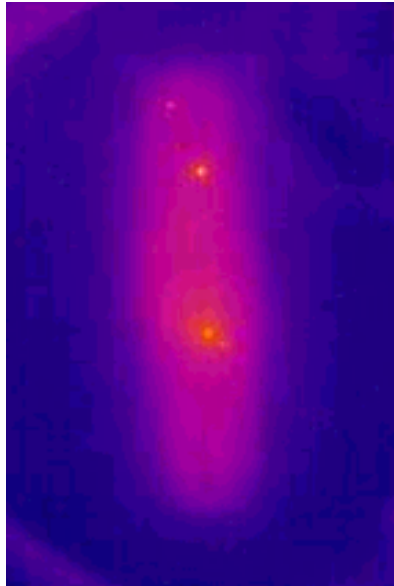
Laser Damage has been observed in all high power systems

- Models predicting thermal loads exist and work
- Causative agents are:
 - Contamination
 - Stress/strain mechanical failure
 - Hot spots in the beam
- Damage thresholds may exceed $1\text{MW}/\text{cm}^2$
 - But this may be true for a limited time
 - Fatigue

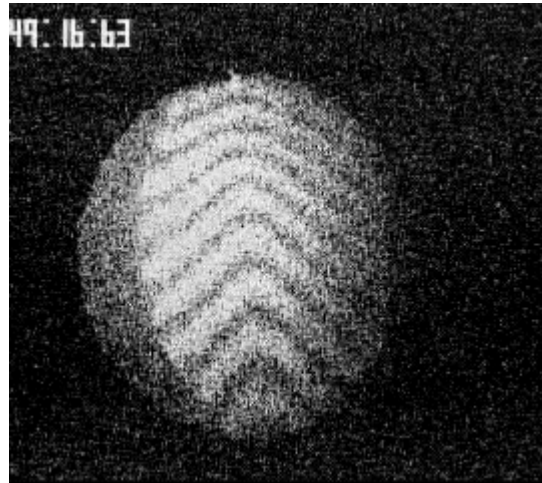
What other observations might lead to a better understanding?

Data Set From a Test at 14 KW/cm²

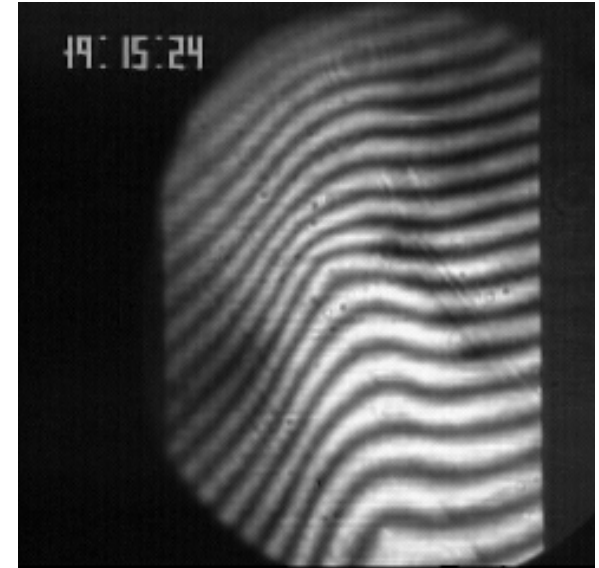
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Thermal Image
avg. ΔT in footprint
pred. 2.4°C
meas. 2.4°C



Front Surface Fizeau
RWE
0.67 μm p-v
~0.6 μm p-v

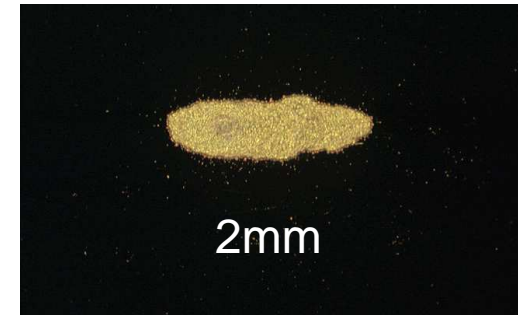


Back Surface Fizeau
TWE
0.13 μm p-v
~0.1 μm p-v

Phenomena Related to High Power

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Laser damage that is self limiting



Light emission from surfaces without damage

Surface Contamination or Cleaning

Surface Charge/activation

White Light Emission from Surfaces is Common

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White light emission is common

Typically match blackbody temp. $>1000\text{K}$

What is emitting?
oxidation
quenching

Enhanced Surface Contamination

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As we watch our optics -

- Contamination is driven right onto the surface!
 - Laser manipulation of particles is a well known technique
- Changes in Work function
 - Hydrophillic → Hydrophobic
 - Hydrocarbon deposits on CO2 laser cavity mirrors
 - Brewster window contamination in ion lasers

Effects -

- Drop in power output, increase in temperature of optics
- Fluorescence from deposited material

For high power systems – same mechanisms probably apply but run times are limited and so may not be observed

Charge Accumulation and Separation Induced by E Fields

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Dielectric surfaces become charged by:

- photoelectric effect

- changes in the work function

- charge separation

Activation of TiO_2 and Ta_2O_5 coatings under illumination

- Excitation does not require high illumination levels
($<1\text{W}/\text{cm}^2$)

- high attraction to particles

- chemical activity of surface



Average Power Loading of Optical Coatings

Summary Comments

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Models for Performance do exist

- Coatings and coated optics do what the models say they should do
 - wavefront distortion
 - damage threshold trends
- Predictive models for failure show trends but at reduced levels

Measured Performance

- Measurements and testing may indicate but do not guarantee survivability
 - too many other factors
- Current thresholds are unforgiving
 - 10x to 100x improvement desired
 - “robustness” missing

Phenomena

- Defects and Contamination will always be there, deal with it
- Understanding and control of surface activation/chemistry and emission sites will offer some unique opportunities