

Sapphire Development Program

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LSC meeting

LIGO Livingston Observatory

Mar. 15, 2001

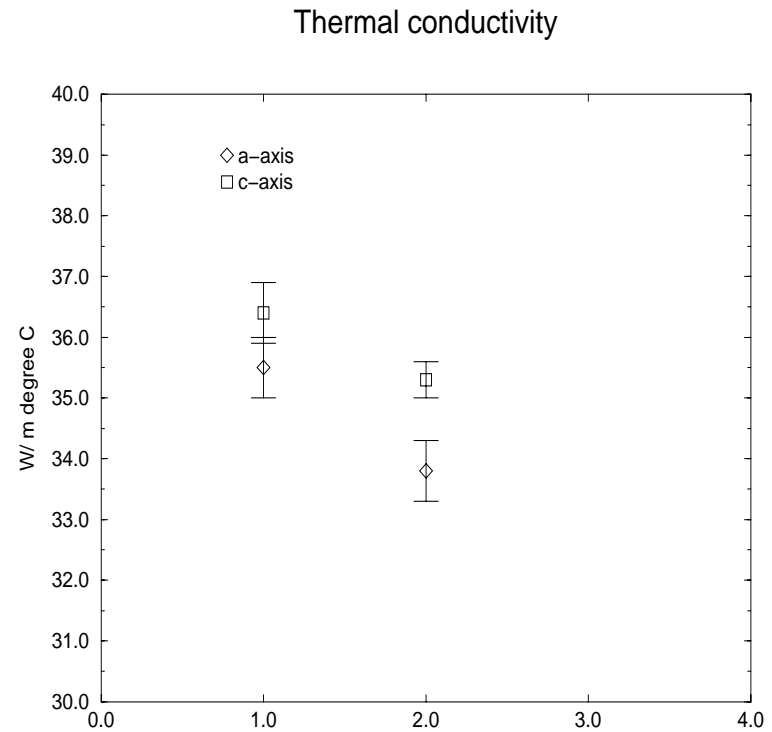
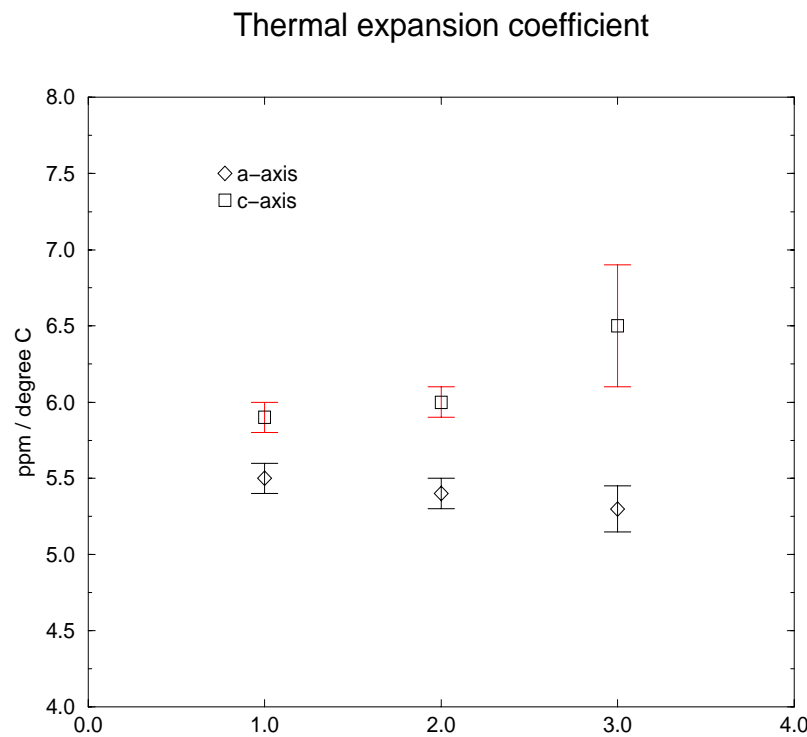
Why Sapphire ?

- Sapphire performance comparable to fused silica
 - ›› ~ 200 Mpc range for NS inspiral from sapphire (165 Mpc for fused silica)
 - ›› sapphire narrow-band sensitivity ~ 2 x higher than fs from 500-1000 Hz
 - ›› Thermoelastic damping noise is limit to sapphire performance
- Sapphire much better material for high power
 - ›› Thermal conductivity 30 x higher than fused silica
 - ›› Rayleigh scattering ~ 30 x lower than fused silica
- R&D effort for both sapphire, fused silica continues
 - ›› effect of coating, bonding on thermal noise of materials
 - ›› other surface effects, absorption, etc.

LSC Sapphire Test Program

- Measure thermophysical constants
 - ›› establish thermoelastic damping noise for sapphire
- Measure optical and mechanical characteristics
 - ›› absorption (Stanford, Southern University)
 - ›› polishability (Caltech)
 - ›› optical homogeneity (Caltech)
 - ›› mechanical Q (Stanford, U. Glasgow)
 - ›› birefringence (Caltech)
 - ›› low frequency losses (Syracuse)

Sapphire Thermophysical Constants



- thermoelastic damping noise $\sim \alpha^2 \sigma / w_0^{3/2}$

Sapphire vs. Fused Silica Thermal Noise

- Fused Silica

- ›› Q of 3×10^7

- ›› thermal noise tail from mechanical resonances

- Sapphire

- ›› Q of 2×10^8

- ›› thermal noise from low-frequency temperature fluctuations coupling to material expansion

- Ultimate NS inspiral sensitivity achievable with these optical materials is very close (within 20%)

Thermal Distortion in Advanced LIGO

| Source of Absorption | Test Mass Optical Distortion (nm) | |
|--|-----------------------------------|--------------|
| | Sapphire | Fused Silica |
| Substrate (Sapphire: 20 ppm/cm) (Fused Silica: 1 ppm/cm) | 40 nm | 40 nm |
| Coating (0.5 ppm) | 25 nm | 400 nm |

- Design optic sag of 60 nm
- Arm cavity stored power ~ 800 kW
- Thermal distortion could also be lowered by reducing coating absorption, or implementing thermal compensation

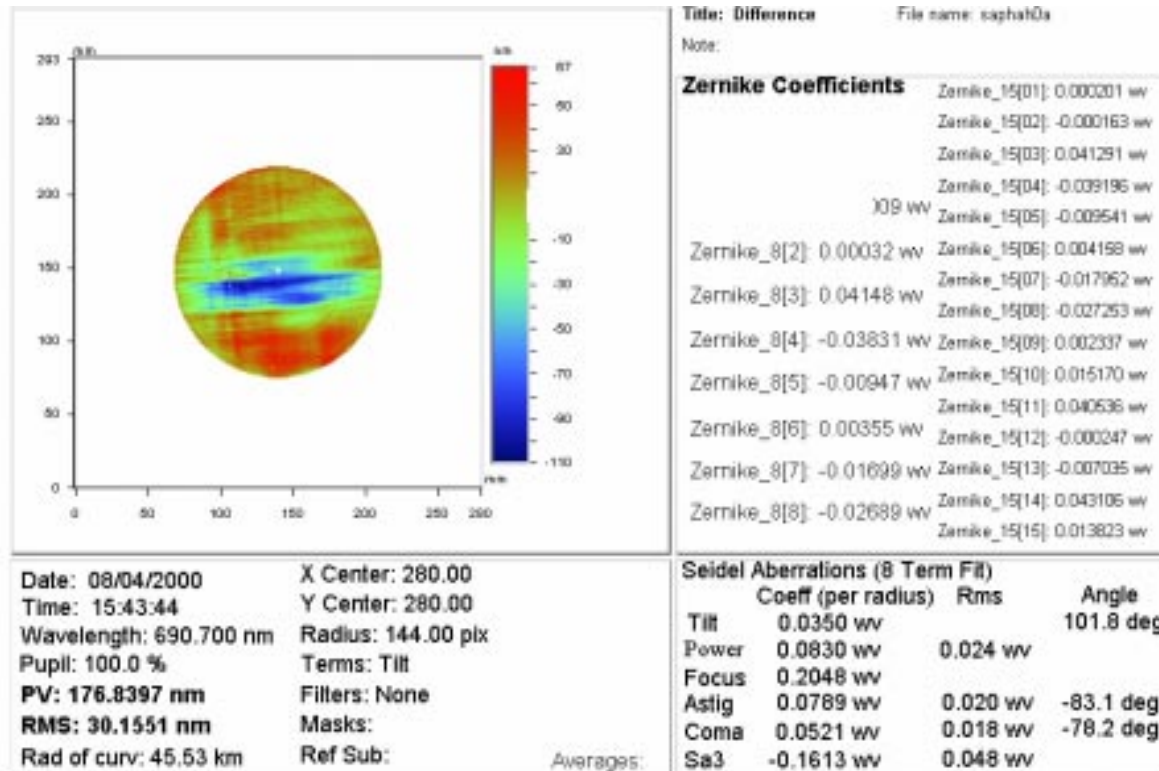
Sapphire Absorption

- Nominal CS sapphire absorption 80 ppm / cm
- Attempt to identify impurities
 - ›› 15 ppm / cm seen in one high purity starting material at one boule location
 - ›› most starting materials show no correlation with absorption
- Annealing study undertaken to reduce absorption
 - ›› 1600 C air bake gives 20 ppm / cm absorption uniform through sample
 - ›› tests to continue at higher bake temperatures

Polishing Tests

- CSIRO surface polish of 15 cm x 8 cm test piece: preliminary results meets advanced LIGO requirements
 - ›› < 1 nm rms surface figure
 - ›› 0.2 nm rms microroughness
 - ›› ROC target of 50 μm +/- 10 μm
- Additional effort underway at General Optics

Polishing Tests: Optical Homogeneity



- need factor 5 - 10 reduction of inhomogeneity
 - ›› spot polish by Raytheon-Danbury

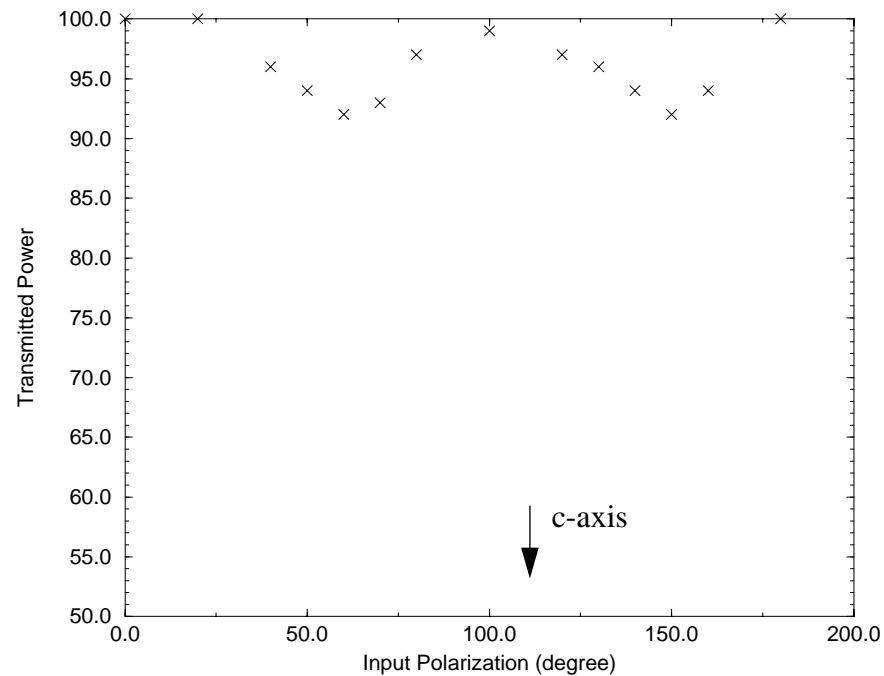
Mechanical Q

- Mechanical Q's of $> 2 \times 10^8$ confirmed for variety of sapphire substrate shapes
- Tests underway for effect of (lossy) coating on thermal noise
 - ›› preliminary result: coating has effect on Q (both fs and sapphire)
 - effect of order tens of %
 - ›› thermal noise of coating itself ?
- Other effects: surface loss, bonding effects, etc.
 - ›› TNI
 - ›› Syracuse low-frequency anelastic loss measurements

Birefringence

- Surface of m-axis crystal has anisotropic properties
 - ›› light not precisely aligned with optical axis will suffer polarization rotation
 - ›› result is power loss at beamsplitter
 - ›› birefringence in both coating and substrate
- Test measurement of birefringence of 3" x 1.5" sapphire
 - ›› monitor transmission of high finesse Fabry-Perot cavity as function of input polarization of light
 - ›› compare coating optical axes with substrate optical axes

Birefringence



- Alignment of input polarization within 10 degree of c-axis of crystal gives recycling gain loss of < 5% in advanced LIGO

Sapphire Summary

- Absorption at 20 ppm / cm, almost OK
 - ›› annealing direction established, will try to push absorption lower
- Polish OK
 - ›› need to demonstrate spot polish, but expect to work
- Birefringence OK
 - ›› need to measure full size optic, expect to work
- Mechanical Q: coating, bonding effects under study
- Sapphire performance comparable to fused silica, but significantly less thermal distortion
 - ›› this is present picture, but R&D continues

What's Next

- Futher sapphire tests
 - ›› quantify effect of coating on thermal noise
 - ›› drive substrate absorption lower
 - ›› measure birefringence of full size part
 - ›› lab test of spot polish
 - ›› grow 35 cm dia. substrate
 - ›› attempt large crystal growth at SIOM (alternate sapphire vendor)
 - ›› direct thermal noise measurements at TNI, Syracuse
- Fused silica tests
 - ›› verify low absorption for large substrates
 - ›› effect of coating on Q

What's Next (cont.)

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- Test Mass material selection 6/02: sapphire or fused silica
 - ›› performance, cost of both materials
 - ›› R&D to lower coating absorption
 - ›› thermal compensation system performance