

Core Optics

Requirements and Design Breakout Presentation
NSF Review of Advanced LIGO Project

Gregory Harry
LIGO Lab – MIT

April 27, 2006

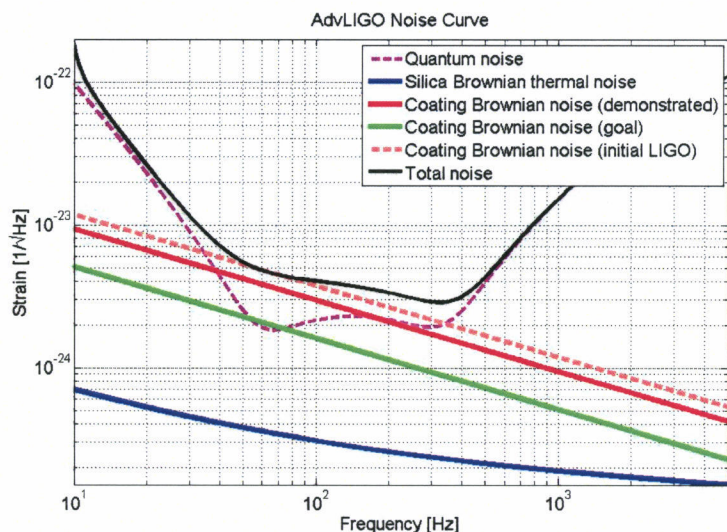
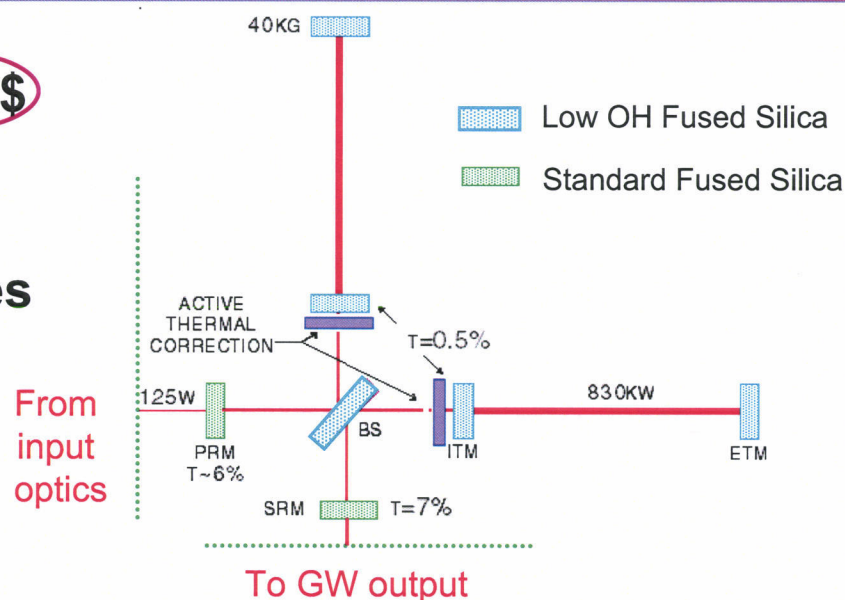
LIGO-G060209-00-R

- **Serve as test masses for interaction with gravitational waves**
- **Creates high finesse optical cavities to increase signal**
 - » Radius of curvature and surface figure must match to the TEM_{00} spatial mode of the input light
 - » Reflectivity must be high enough on end test masses to achieve required finesse
 - » Reflectivity of input test masses must allow for specified finesse
 - » Microroughness must be low enough to limit scatter losses to acceptable levels
 - » Optical homogeneity of the transmitting optics must be good enough to preserve the shape of the incident wavefront
- **Minimize thermal vibrations and other noise sources in gravitational wave band**
 - » Materials used for coating and substrate must have low enough mechanical loss to limit in-band thermal noise to acceptable levels
 - » Mass must be high enough to keep radiation pressure noise low
 - » Charge buildup must be low enough to keep charging noise to acceptable levels
- **Minimize problems acquiring and keeping the interferometer locked**
 - » Interaction between optical cavity mode light and mirror mechanical modes must be controlled to keep parametric instability from causing difficulties
 - » Substrate and coating optical absorption must be low enough to limit the effects of thermal distortion on the interferometer performance

Core Optics Requirements

Mass	40 Kg
Dimensions	340 mm x 200mm
Surface figure	< 1 nm rms
Micro-roughness	< 0.1 nm rms
Optical homogeneity	< 20 nm rms, double pass
Bulk absorption	< 3 ppm/cm
Bulk mechanical loss	< 3×10^{-9}
Optical coating absorption	< 0.5 ppm (required) < 0.2 ppm (goal)
Optical coating scatter	< 2 ppm (required) < 1 ppm (goal)
Optical coating mechanical loss	< 2×10^{-4} (required) < 3×10^{-5} (goal)
Arm cavity optical loss / round trip	< 75 ppm

- **Fused silica will be used as substrate for all core optics** **5.2 M\$**
 - » Four 40 kg Input Test Mass blanks provided by University of Glasgow
- **Polish using initial LIGO techniques over larger area** **6.4 M\$**
- **Connection with suspension to be done with silicate bonded “ear”**



- **Coating with low optical absorption ion beam sputtering** **1.6 M\$**
 - » Silica/titania-doped tantala coating for input and end test masses
 - » Ongoing research into other options
 - » Silica/tantala coating for other optics

- **“A presentation at a major SPIE or OSA coatings conference ...”**
 - » OSA Topical Meeting - Optical Interference Coatings, Tucson, 2004, Boulder Damage Symposium – Boulder CO, 2003, Materials Research Society - Boston 2003, 2004, SPIE General Meeting – Denver 2004, SPIE North – Ottawa 2004, American Society for Precision Engineering, Connecticut, 2005, SPIE Regional Conference – San Jose, 2006
- **“Establish close contact with academic thin film research community ...”**
 - » Angus Macleod, University of Arizona; Doug Wolfe, Penn State; Ian MacLauren, Glasgow University; Pierre Khuri-Yakup, Stanford University; Steve Bull, University of Newcastle; Kyrstyn van Vliet, Franz Kaertner, Yoel Fink, MIT; Hai Ping Cheng, University of Florida; Donna Hurley, NIST; Ping Hou, Nortel Networks
- **“Test of other high index materials”**
 - » Hafnia, Titania-doped Tantalum, Lutetium-doped Tantalum, Cobalt-doped Tantalum, Silica-doped Titania
- **“Not narrowing vendor options ...”**
 - » Continuing to work with both CSIRO and LMA on research, roughly three other vendors who do ion-beam deposition
- **“Continue to run long term exposure tests on the optics ...”**
 - » Long term contamination cavity test runs at Caltech
 - » Have witness samples in Hanford vacuum chambers
 - » High power test facilities being developed at both LIGO Livingston Observatory and Perth Australia

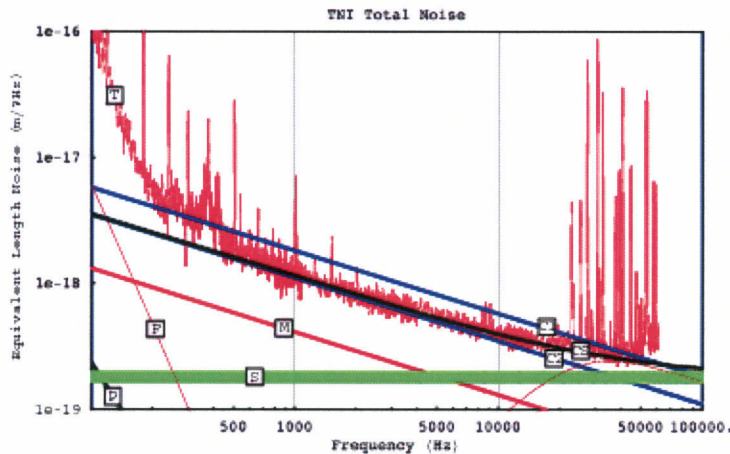
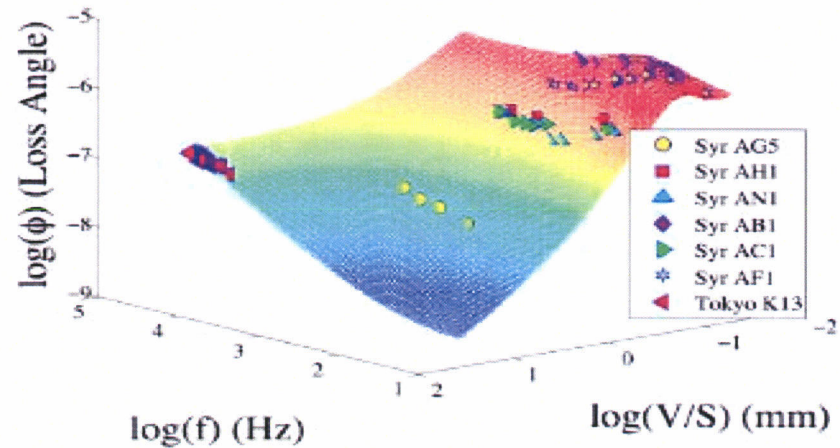
April 27, 2006

LIGO-G060209-00-R

- **“Ensure that silica has been adequately characterized ...”**
 - » Optically well understood
 - » Thermal noise – Comprehensive paper *Penn et al, Physics Letters A, 352, (2006), 3-6.*
- **“Explore possible gains to be made in stabilization of the feedback loops if the present quadrant detectors were to be replaced by ones with larger arrays”**
- **“Continued develop of active thermal compensation”**
 - » Currently working on initial LIGO
 - » See Auxiliary Optics talk by P. Willems for Advanced LIGO plans
- **“Rather than spending money on developing a second source for the sapphire ... do designed experiments in process parameters and starting material”**
 - » Lower priority since silica has been chosen
 - » Low level research continues on sapphire both in LIGO Science Collaboration for third generation and possible fallback and in larger community
- **“Continue efforts to obtain improved quality of both TGG and RTP”**
 - » See Input Optics talk by D. Reitze

Silica

- Mechanical loss modeled from Q data
- Polishing will use initial LIGO technique
- Metrology close to adequate to guide polishing
- Substrate optical absorption less than coating and acceptable with planned thermal compensation
- Silicate bonding acceptable for connecting “ears” with suspensions



April 27, 2006

LIGO-G060209-00-R

Coating

- Low mechanical loss silica/titania-doped tantala demonstrated on small test samples
- Direct observation of thermal noise from silica/titania-doped tantala coatings confirms thermal noise reduction
- Optical absorption near required level
- Silica/silica-doped titania also shows improved mechanical loss
- Scatter requires improvement over initial LIGO levels