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Core Optics

Requirements and Design Breakout Presentation

NSF Review of Advanced LIGO Project

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LIGO-G060209-00-R

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Core Optics Functions

- **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

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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	$< 3\times10^{-9}$
Optical coating absorption	< 0.5 ppm (required) < 0.2 ppm (goal)
Optical coating scatter	< 2 ppm (required) < 1 ppm (goal)
Optical coating mechanical loss	$< 2\times10^{-4}$ (required) $< 3\times10^{-5}$ (goal)
Arm cavity optical loss / round trip	< 75 ppm

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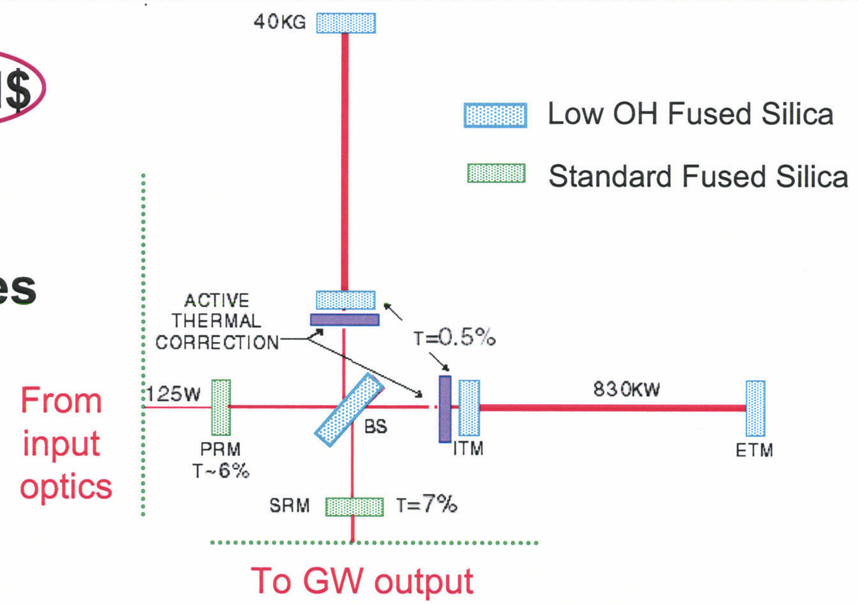
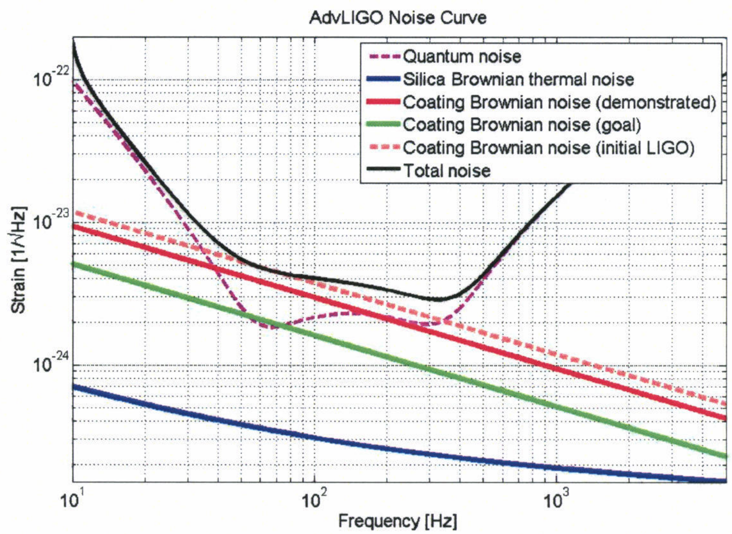
Core Optics Baseline Design

- **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

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Response to 2003 recommendations - 1

- **"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 Tantala, Lutetium-doped Tantala, Cobalt-doped Tantala, 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

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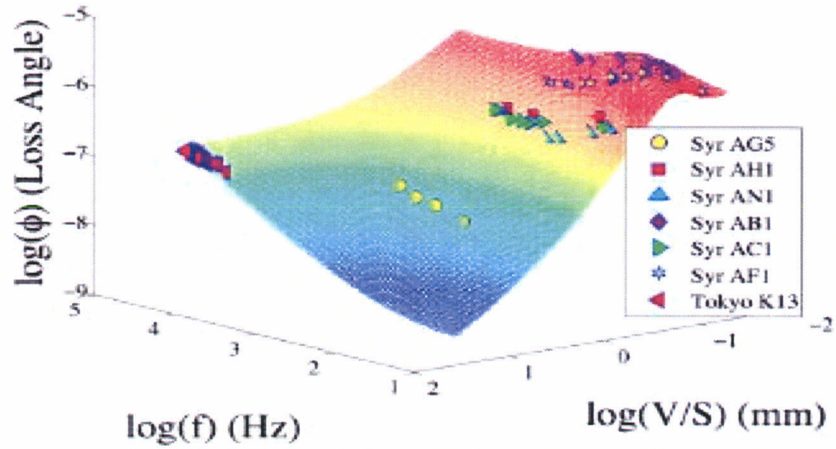
Response to 2003 recommendations - 2

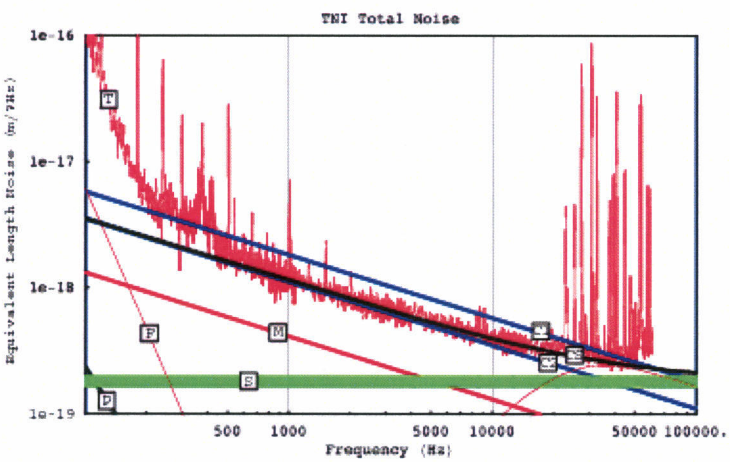
- **"Ensure that silica has been adequately characterized …"**
  - Optically well understood
  - Thermal noise – Comprehensive paper *Penn et al, Physics Letters A, 352, (2006), 3-6.*
- **"Explore possible gains to be made in stabilization of the feedback loops if the present quadrant detectors were 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

Core Optics development status

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





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

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Challenges

- **Coating thermal noise and heating**
  - » Further reduction in coating mechanical loss and optical absorption
  - » Ensure a working plan to maintain cleanliness of optics during installation and handling
- **Observed high scatter in initial LIGO optics**
  - » Investigate cause of scatter in initial LIGO
  - » Work with coating vendors to insure low scatter coatings
- **Polishing**
  - » Modeling work to determine effect on sensitivity and performance
  - » Improved metrology – development of Shack Hartmann sensors at Adelaide University
  - » Thermal compensation as partial mitigation
- **Parametric instability**
  - » Further modeling and prototyping
  - » Investigate possible mitigation – spoiling Q, lower power, moving modes, etc.
- **Noise effects of charge**
  - » Continuing Kelvin probe work to determine level of expected noise
  - » If needed, explore changes in surface conductivity through ion implantation, etc.
- **Silica thermal noise**
  - » Measure mechanical loss at lower frequencies and at different sample sizes
  - » Investigate annealing

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Development work plan

- Qualify vendor(s) with demonstration of polishing
- Work with pathfinder optic blanks obtained by University of Glasgow
  - Finalize polishing and coating over large area
- Obtain noise prototype for engineering and noise tests in MIT test interferometer (LASTI)
- Continuing research and development on coatings and silica
- Demonstration of coating stress effects on beam splitter
- Continue to develop plans to maintain optic cleanliness from coating through installation