Core Optics Components

Technical Status
NSF Review of Advanced LIGO Project
April 2011

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LIGO

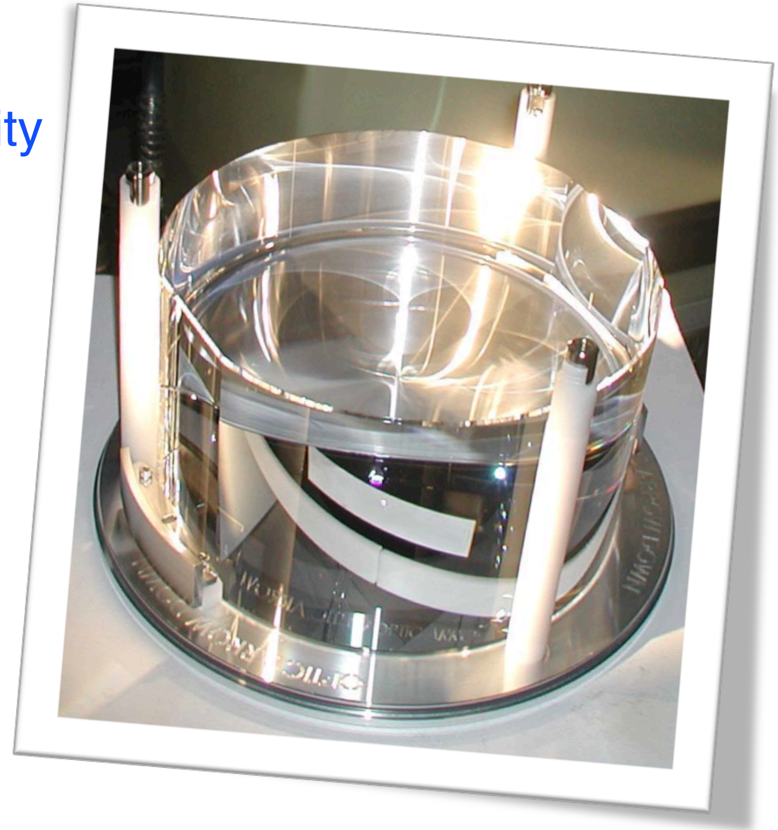
Subsystem cost : $18M

Core Optics Functions

- Design, fabricate and characterize the Core optics
  - » Test Masses (20ea) – Fabry Perot arm cavity surfaces are the most critical in LIGO.
  - » Recycling Cavity optics (27ea) - compensation plates, beam splitter, recycling mirrors and folding mirrors
- Fabrication
  - » Procure substrates
  - » Procure polishing services – qualify with in house metrology
  - » Procure coating services – characterize with in house metrology
- Provide transport and handling equipment
- Prescribe cleaning and handling

Design approach

- Fused silica substrates
  - Low OH Fused silica used for in-cavity optics:
    - Beam Splitter
    - Input Test Mass
- Two step polish:
  - Superpolish: ~1 Å microroughness, within 100nm of figure
  - Ion Beam Figuring: Corrects figure, maintains microroughness
- Ion Beam sputtered coating
  - Coating performance at multiple wavelengths to support control system



LIGO

Arm Cavity Loss: Early results are in line with budget

Total cavity loss requirement < 75 ppm

Cavity loss – 2 surfaces (ppm)	Budget 2010 based on specifications (ppm)	Actuals 2011 based on (n of 20) (ppm)
Microroughness scatter (>1/mm)	8	4 (avg. of 12)
Defects (Polish, Coating, Contamination)	26	8 (1) pol, coat
Coating Absorption	0.6	0.6 (1)
Surface Figure Error & Diffraction	24	7 (max of 12) polish only
ETM Transmission	5	No data yet
Total	64	25

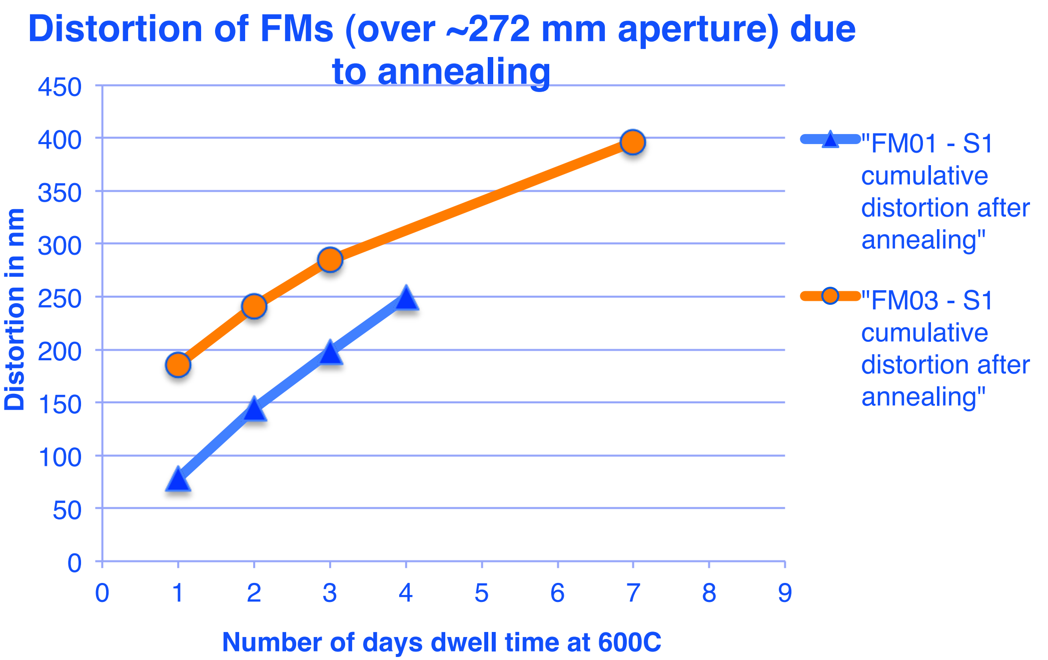
50ppm budget remaining for contamination and coating induced surface figure error.

Project phase status
Material

- All original orders are filled and met specification
  - Heraeus
    - 11 Input Test Masses (ITM)
    - 4 End Test Masses contributed by U.K.
    - 6 Beam Splitters (BS)
    - 9 Compensation Plates
  - Corning
    - 9 Recycling Telescope #3 (R3)
    - Stability problems with:
      - 6 of 10 End Test Masses (ETM)
      - 3 Fold Mirrors (FM)

Project phase status
Material

- Corning 7980 substrate material is not stable at typical annealing temperatures.
  - » 6 of 10 End Test masses
    - – 4 were Heraeus 311
  - » 3 Fold Mirrors
  - » 9 R3, - not a problem
  - » No instability seen on prototype
- Heraeus Suprasil 311, 312, 3001 have all tested as stable.
  LIGO-T1100162
- Reordered material for FM and ETM-Heraeus 312



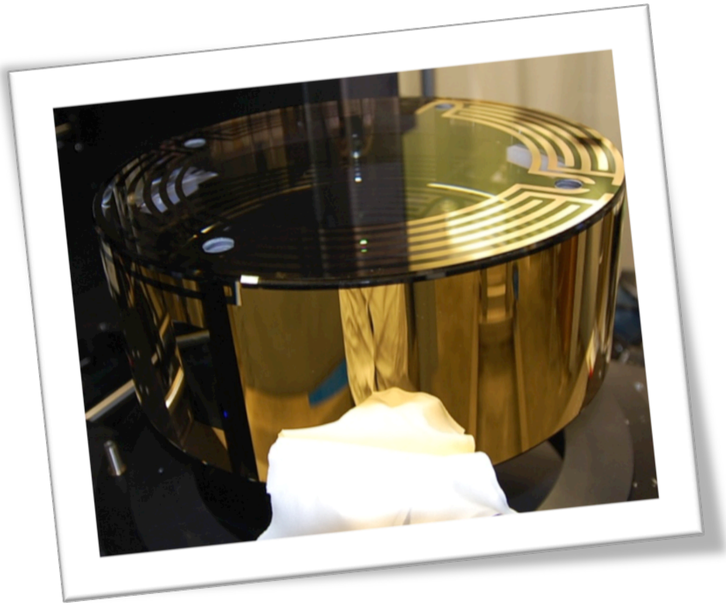
8 nm stability is required for most large COC elements (except R3 400 nm)

Project phase status
Polishing

- All original mirror blanks have been received
- One year delay in delivery due mostly to contamination leaving etching reliefs on the Test Mass surfaces
- Polishing is in process, 23% remaining are:
  - » 2 Compensation Plates
  - » 3 Fold Mirrors
  - » 8 Test Masses
- Exceptional control of figure
  - » 0.6 meter standard deviation on 1938 meter ROC (9 pieces)
  - » 0.12 nm rms average figure error over 160 mm diameter (9 pieces)

Project phase status
Recycling Cavity Coating

- Recycling Cavity – CSIRO
- All fixtures in place
  - » Final Beam Splitter and Fold Mirror coating designs are pending
    - (additional accommodation for Hartman Wavefront Sensor)
  - » End Reaction Masses are complete
  - » Compensation plates next
- AR coating absorption is found to be extremely sensitive to surface contamination and annealing temperature.
- Thinner layers of Tantala crystalize at lower temperature.

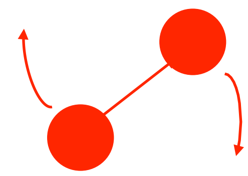


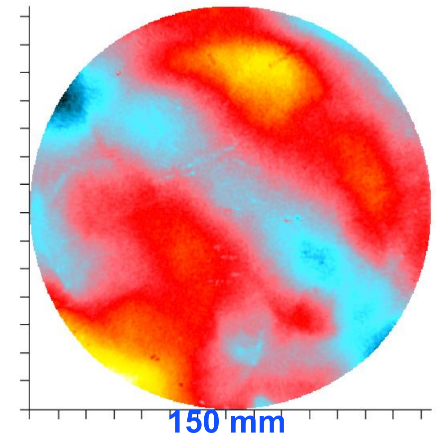
Project phase status
Arm Cavity Coating

- Arm Cavity – LMA
  - » All designs approved
  - » Test masses will be coated with an “optimized” design of silica and titania doped tantala. This results in the lowest thermal noise performance demonstrated to date.
  - » The ITM for the single arm test is at Hanford with bonds curing
- All parameters are reported by the vendor as being within specification with the exception of figure change due to coating uniformity.
  - » It is well known that IBS coatings stress substrates and impart a change in saggita . For the LASTI prototype this change was measured at 3 nm.
  - » Uniformity requirement: …not change the Sagitta more than 8 nanometers, …Zernike terms …amplitude < 0.5 nanometer

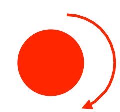
Project phase status
Arm cavity coating continued

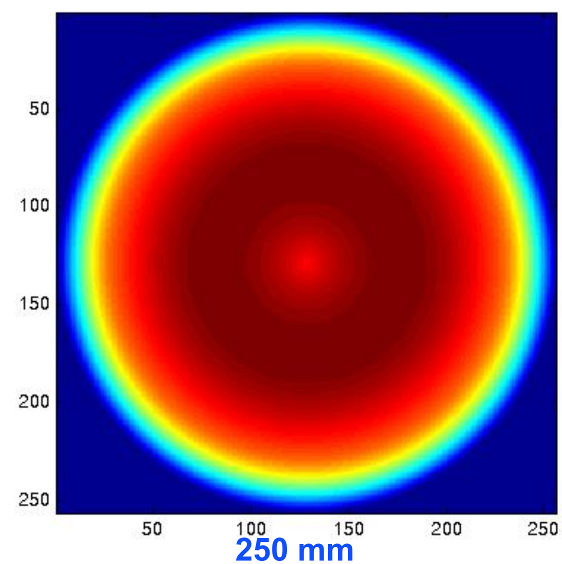
- **Trial one coating uniformity:**
  - » **Using a Corning ETM**
  - » **Coat two optics at once to match transmission**
  - » **11nm Peak to Valley**
  - » **Estimated Cavity loss ~200ppm**





- **Trial two coating uniformity:**
  - » **Model based on witness samples**
  - » **Coat one optic, spinning in center**
  - » **2nm Peak to Valley over beam size**
  - » **Estimated Cavity loss ~55ppm**



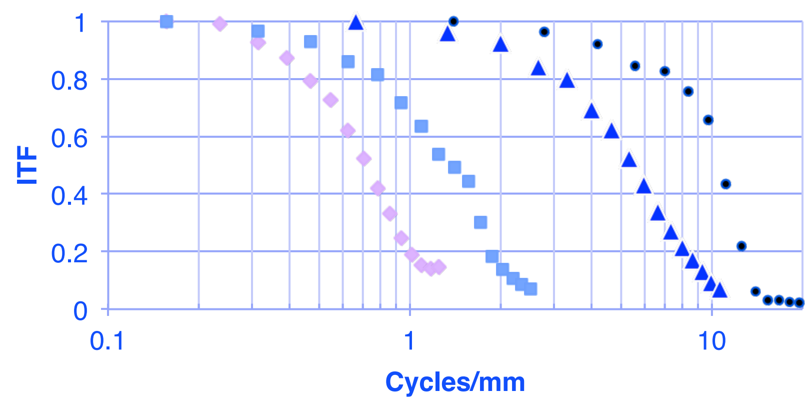


Project phase status
Arm cavity coating continued

- Better Uniformity: two approaches in parallel
  - » Remaining information on this slide is removed at the request of the vendor

Project phase status
Metrology

- Zygo full aperture interferometer is installed and operating at Caltech
- All metrology flats are complete, the Test Mass reference sphere is complete
  - » R3 measurement spheres finish in May 2011
- The instrument and environment are quite stable, showing a uniform noise floor of 0.1 to 0.15 nm rms.
  - » Polishing requirement is 0.3 nm rms
  - » Vendor reports some surfaces at 0.08 nm rms



Instrument transfer function using the four apertures is >50% out to > 10/mm

Challenges, risks, and mitigations

- Risk Registry – Major Threats - COC
  - » If coating vendor cannot meet overall COC specs, then performance will suffer.
    - – Control of figure for optics remains a concern
    - – LIGO is seeking a back up coater for arm cavity optics
      - CSIRO has most all infrastructure (would need tooling for thicker pieces) short on labor.
      - Other vendors – pending meetings
        - » REO – is cautiously interested
        - » ATF
        - » MLD
    - – LMA is pursuing near and mid-term modification to improve uniformity

Subsystem Project organization

- LIGO staff manage the procurement and test of the core optics
  - » Procure blanks – Corning and Heraeus (Billingsley)
    - – Inspection at LIGO (Billingsley, Zhang)
  - » Procure polishing services – Tinsley (Billingsley)
    - – Qualification tests at LIGO (Billingsley, Zhang)
  - » Procure coating services – LMA and CSIRO (Billingsley, Harry, Phelps)
    - – Qualification tests at LIGO (Zhang, Phelps)
  - » Cleaning process qualification at LIGO (Phelps, Zhang)
  - » Final Metrology/Characterization at LIGO (Billingsley, Zhang, Phelps, Murphy)
  - » Characterization data to model interferometer performance (Kells, Yamamoto)

Core Optics Development Status

- Advanced LIGO Development phase is complete
  - Final Design Review October 17, 2008
  - Actively supporting our coating vendors with absorption studies.

Ongoing Coating development

- *Recommendation from December 2010 review: Mirror coating and suspension noise. We continue to support the idea of an ongoing, and perhaps increased, research effort to study the science and technology of the thermal noise in optical materials and the fabrication and processing methods. This should include basic material science and theoretical analysis to develop a deeper understanding of the fundamental science and ultimate physical limitations. Risk reduction and performance improvement research and development on mirror coatings should continue through aLIGO*

- Recently Presented at the March LSC Meeting – emphasizing first principals analysis.
  - Zirconia Coatings, S. Penn
  - Thermorefractive Noise Update, A. Gretarsson
  - Effective Medium Theory, I. Pinto
  - Thermal Noise in Optimized Mirror Coatings, M. Gorodetsky
  - Glasgow Coating Research, M. Abernathy
  - Linear and Non-linear Optical Properties of Coatings, I. Bilenko
  - Coating Modeling, Y. Wu
  - Glasgow Coating Modeling Work, K. Evans

LIGO

Core Optics Near term activities

- Working with vendor to improve coating uniformity
- Prepare for incoming mirror test
  - » Dummy dress rehearsals
- Now preparing for characterization testing:
  - » First coated ITM has arrived, is bonded, will ship to Caltech for characterization.