LIGO Laboratory

California Institute of Technology
MC 18-34, 1200 E. California Blvd.
Pasadena CA 91125 USA
TEL: 617.395.2129
FAX: 617.304.9834
www.ligo.caltech.edu

LIGO Livingston Observatory
P.O. Box 940
Livingston LA 70754 USA
TEL: 225.686.3100
FAX: 225.686.7189
www.ligo-la.caltech.edu

LIGO Hanford Observatory
P.O. Box 159
Richland WA 99352 USA
TEL: 509.372.8106
FAX: 509.372.8137
www.ligo-wa.caltech.edu

Massachusetts Institute of Technology
MIT NW22 – 295, 185 Albany St.
Cambridge MA 02139 USA
TEL: 617.235.4824
FAX: 617.253.7014
www.ligo.mit.edu

Date:	3 April 2008
Refer to:	L080031-02
Subject:	Review Committee Report on the Preliminary Design Review (PDR) and Glass Final Design Review (FDR) & Procurement/Fabrication Readiness Review (P/FRR) for the Advanced LIGO Core Optics Components (COC)
To:	David Shoemaker, Carol Wilkinson
cc:	Helena Armandula, GariLynn Billingsley, Gregg Harry, Bill Kells
From:	AdL COC PDR & Glass FDR/PRR Committee: Doug Cook, Dennis Coyne (chair), Peter Fritschel, Eric Gustafson, David Reitze, Norna Robertson, Ken Strain, Bill Tyler, Hiro Yamamoto

Background

A Preliminary Design Review (PDR) for the advanced LIGO Core Optics Components (COC) subsystem has been concluded. In addition to the PDR, a Final Design Review (FDR) and Procurement/Fabrication Readiness Review (P/FRR) for the glass blanks for the COC elements was also conducted at the same time.

The review committee and the design team met Feb 14th, 15th, 21st,Mar 3rd and 5th to discuss the documents and questions and issues arising from the committee's review. The committee's detailed comments on the DRD are covered in L080029-00. The committee's detailed comments on the PDD are covered in L080019-01. In addition, L080032-00 presents a current status on the actions from the DRR/CDR.

Recommendation

We find that the Core Optics Components subsystem (COC) has successfully completed preliminary design. We also find that COC has completed final design and procurement readiness with regard to substrate material selection and is ready to proceed with the procurement process for the glass blanks.

Scope

The documentation reviewed is the following:

- T080026-00 (to be re-numbered T000127-03) Core Optics Components Design Requirements Document (DRD)
- E080033-00 Core Optics Components Preliminary Design Document (PDD)
- Final Design Specifications and drawings for material (glass) procurement (found on the Adv. LIGO wiki page for this review):

Optic	Specification	Drawing
ITM	E080031-A	D080039-A
BS	E080035-A	D080050-A
CP	E080037-A	D080051-A
PRM or SRM	E080028-A	D080038-A
RM2	E080039-A	D080052-A
RM3	E080041-A	D080053-A
FM	E080045-A	D080054-A
ETM	E080047-A	D080055-A

Supporting documentation♦ includes:

- C070214-00 ETM material Recommendation
- C070187-00 Heraeus measurement of 3001 material homogeneity
- T040009-00 Report of the Core Optics Components Design Requirements Review Committee
- L040025-00 Action Items from the COC Design Requirements Review and Conceptual Design review (DRR/CDR)

Findings

The review committee charge is documented in L080010-00. The review committee also considered the review checklists given in the "Guidelines for Advanced LIGO Detector Construction Activities" document (M050220-07). The committee's response to the charge is as follows:

1) With regard to requirements:

a) determine whether the requirements identified in the Design Requirements Document (DRD) are complete (including functional, performance and interface requirements); if needed, recommend additional requirements to be specified;

The call-outs, or template, for requirements is basically complete. However:

i. Limits on the astigmatic error resulting from the BS wedge angle needs to be incorporated into the requirements. An acceptable Radius Of Curvature (ROC) lower limit must also be placed on the BS and FM (based on resulting astigmatic error). (see L080029-00, #11.c, #11.d, #13 and #30)

ii. There is some evidence in the literature, and LIGO test results, suggesting that high performance, ion beam deposited dielectric coatings add to the scatter loss intrinsic to the substrate polish. In the final design phase, scatter loss from coatings should be taken into account in the overall budget and final requirements.

iii. In the final design phase, re-look at thermal birefringence to insure that the effects are small relative to beam heating OPD phase distortions (see L080029-00, #29)

iv. There are numerous clarifications needed as well as a need for supporting derivations or motivations for the requirements; Specifics are defined in L080029-00.

♦ Note that (a) the wiki requires a password and (b) C070214-00 and C070187-00 are on the internal (non-public) side of the LIGO Lab document control center.

b) advise whether proposed requirement values are appropriate;
   i. *Polishing errors are specified as rms values in discrete spatial frequency bands (much as was done in initial LIGO and the Pathfinder). While this is acceptable we encourage the COC team to strongly consider specifying families of limiting Power Spectral Density (PSD) curves. The motivation is that the polishing vendors provide PSDs, all simulation to date has been done with a particular PSD model and this may better facilitate the trade-off between errors at different spatial frequencies. (see L080029-00 #26 and #32)*
   ii. *In the final design phase the COC team needs to show results of Pathfinder surface error PSDs in FFT simulations before finalizing the polishing specifications.*
   iii. *A discussion of the (in)sensitivity of various sources to arm cavity loss should be included in the DRD in order to put the loss budget goal of 75 ppm into proper context. The DRD should also state that the motivation for the 75 ppm loss budget is that this is the best that we might reasonably expect to achieve from the current state-of-the-art (see L080029-00, #35 and L080032-00, #5).*

c) advise on whether any significant proposed changes to the requirements, since the Design Requirements Review, are well motivated and appropriate.
The only significant changes in requirements since the DRR are the following:
   i. *A decision was made, after careful review, to use fused silica for the test mass substrates instead of sapphire (see M040405-00 and T020103-08).*
   ii. *The Systems decision to change from marginally stable to stable recycling cavities. COC will take the lead responsibility for the requirements definition for all recycling cavity optics. COC and IO will collaborate on the design of the recycling cavities. IO will procure the small recycling cavity optics and COC will procure the large recycling cavity optics. (The scope, responsibilities and naming conventions are defined in RODA M080038-03.)*
   iii. *COC proposes to use some of the Thermal Compensation System (TCS) range to correct as-polished ROC errors at all power levels. The committee thinks that the interferometer should be able to operate in a sensitive state with as-polished ROC for cold (low power) operation. An analysis should be presented at the Final Design Review (FDR) to justify any bias (shift) in the nominal polished ROC value based upon achievable (minimal) absolute polished ROC uncertainty.*

2) With regard to the preliminary design:
a) evaluate the Preliminary Design Document (PDD) to determine if it is consistent with the DRD, on the basis of any supporting analysis/modeling/simulation or test data,
We see no fundamental or serious problems arising from our review, however:
   i. *The inclusion specification should be revised to be consistent with our loss budget and the vendor's standard practice (see L080019-01, 3.b)*
   ii. *SUS should make provision to adjust for variation in the TM mass at the penultimate stage (see L080019-01, #8.e)*
   iii. *There are numerous inconsistencies which were identified during the review (specifics defined in L080019-01).*
   iv. *The DRD lacks sufficient background or motivation for the chosen design parameters and a summary of the pathfinding (prototyping) efforts for polishing and coatings (L080019-01, #9.a, #10 and #11.a).*

b) advise whether the design is sufficiently developed to proceed with the Final Design phase, in particular is the following information provided:
The committee thinks that the COC team are ready to proceed into final design. The suggested corrections to the DRD (L080029-00) and PDD (L080019-01) should be completed soon.

i. resolution of DRR/CDR action items,
Most of the action items from the DRR/CDR report (T040009-00, which were assigned in L040025-00) have been completed. A few that were not closed are re-iterated in the actions resulting from this Preliminary Design Review (see L080032-00 for details). The outstanding actions can be resolved in the COC final design phase.

ii. preliminary drawings and specifications,
Only drawings and specifications for the glass blanks were provided for the PDR (i.e. not shaping, polishing, coating, metrology, etc.) All other specifications will be developed in the final design phase. The glass blank drawings and specifications are covered under 3.b below.

iii. personnel and equipment safety approach to handling, processing, transport and storage,
We find the description of the contamination requirements & control, handling and processing a little sparse and suggest that this be fleshed out further. (see L080019-01, #26 through #29 and L080032-00, #9 and #17)
However the shipping containers, ergonomic arm, barrel friction grip lifting tool and the use of First Contact™ are all well designed and seem to cover most if not all COC handling and processing needs. A hazard analysis should be included early in the final design phase.

iv. quality assurance and testing approach to assure conformance with key performance requirements/specifications
QA and testing considerations are adequate for a preliminary design level.

c) advise whether the criteria and plan for test mass material selection is appropriate and complete.
The plan and criteria used to select the core optics materials is appropriate and complete. In particular the switch to low absorption fused silica for the test mass substrates, after evaluation of homogeneity, was well motivated.

3) With regard to the Final Design Review (FDR) and Procurement/Fabrication Readiness Review (P/FRR) for the glass blanks:

a) Is there high confidence that the selected materials and overall dimensions for the COCs are correct and will not need to change as the design is finalized?
The committee has high confidence that the proposed substrate material choices are appropriate, after resolution of action (i) below in the very near term:

i. Systems and COC are to verify that the Optical Path Differences (OPD) in the wavefront transmitted through the End Test Mass (ETM) and the ETM reaction mass (both proposed to be Corning 7980, grade 5F, or equivalent, fused silica) are acceptable for centering the arm cavity beam, injecting a Hartmann probe beam and injecting an arm length stabilization beam (aka Seismic Platform Interferometer (SPI) beam). (see L080029-00, #27).

ii. The proposed low absorption test mass material (Heraeus 3001) has not been tested for mechanical loss to date. Since coating loss dominates, and variations

in other grades of fused silica are only on the order of a factor of 2 (resulting in a ~1 Mpc BNS range change), testing for mechanical loss in the 3001 material is not considered a priority. The University of Glasgow expects to measure samples in a few months time for characterization and confirmation.

iii. The slight differences in chemical composition between glasses under consideration are not expected (by bond experts) to impact the hydroxy-catalysis bond performance (strength and loss). SUS has a low priority task to demonstrate that bonding to Corning 7980 and Heraeus 3001 is acceptable (or slightly alter the process to make it acceptable). (see L080019-01, #6.b).

b) Are the specifications and drawings complete, correct and ready for release into configuration control?
The specifications and drawings are complete and ready for release.

c) Are the number of optics to be procured sensible given the intended number of delivered optics and expected need for in-process spares?
The spares policy applied is essentially identical to that employed in Initial LIGO, with the added benefit that there are no longer two optical configurations (2 km and 4 km), so there are in effect more test mass spares. The committee thinks that the planned spares are adequate. We should however keep a careful watch on success rate for processing the optics during LASTI and during the initial phases of assembly/ installation, to determine if it is warranted to use contingency to purchase more spares.

Note that, per the charge, the following factors are <u>not</u> part of this review:

1) cost schedule, long lead procurement, and procurement strategies, as they have been handled in separate management reviews with the COC team leaders;
2) charge mitigation, except as it might influence interfaces, since this is an element of the Auxiliary Optics Subsystem (AOS);
Note that the committee did not consider any interface issues related to charge mitigation. However it should be noted that the charge mitigation research being undertaken by the LSC (under the auspices of the AOS subsystem) are addressing the potential deleterious effects of UV radiation (one possible mitigation approach) on the coatings. Other interfaces of realistic charge mitigation approaches are likely to have more impact on other subsystems (e.g. SUS).
3) proposed (but <u>not</u> baselined) gold coatings on the barrel of the test masses and compensation plates