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Date:	28 March 2008
Refer to:	L080019-01
Subject:	Response to Comments and Questions on the COC Preliminary Design Document (PDD)
Authors:	Helena Armandula, GariLynn Billingsley, Bill Kells, Gregg Harry (COC PDR team) and the COC PDR review committee: Doug Cook, Dennis Coyne (chair), Peter Fritschel, Eric Gustafson, David Reitze, Norna Robertson, Ken Strain, Bill Tyler, Hiro Yamamoto

The review committee and the design team met Feb 14th, 15th, 21st,Mar 3rd and 5th to discuss the COC Design Requirements Document (DRD, T000127-02) and the COC Preliminary Design Document (PDD, E080033-00). This document covers the review of the Preliminary Design Document (PDD) as part of the preliminary design review of the Core Optics Components (COC) subsystem of Advanced LIGO. There is a companion document covering the Design Requirements Document (DRD), which is L080029-00. There is also a committee report on the COC PDR and Glass Procurement/Fabrication Readiness Review, which is L0800xx-00.

While there are many comments and questions, the documents are clearly well developed and nearly complete for the PD stage.

The comments/questions below are presented in sequential order by document section. This document captures the questions and comments of the review committee, as well as the subsequent initial responses to these questions by the design team and final resolution reached after discussion with the committee. The committee's original comments and questions are given below in un-highlighted text or with grey highlighting to signify potentially controversial or uncertain items.

Unless underlined below, all Design Document questions/comments are accepted and will be incorporated into the next revision of the document. Underlined items needed discussion or clarification.

Where needed to bring closure on an issue or discussion topic, magenta highlighting signifies the committee's resolution.

COC Preliminary Design Document (PDD)

1) Section 2.1, 2.1.1.4 and other sections throughout the document: Delete reference to borosilicate glass (BK7); All optics will be fused silica
2) Section 2.1.1.1. The last sentence is confusing. We suggest the last two sentences be re-worded to something like: “The level of low OH content in the 3001 material should lead to absorption of less than 0.02ppm/cm (based on an extrapolation of the measured correlation of absorption with OH content; see section 7.0).”
3) Sections 2.1.1.1 and 2.1.1.2:
    a. The statements about the material being spec'd with zero inclusions, then giving inclusion areas, is confusing. Please clarify.
    b. How is the inclusion specification derived and how is it consistent with the scatter requirements of the DRD? This should be stated here or in a cited reference.

    Response: This is historically based on best vendor specification. A calculation indicates that the worst case bubble occlusion could be 1,300ppm in the ITM material. Since the CP and BS are similar, we will need to change our loss budget or obtain a specification from SUS on the allowable loss. We will then have to negotiate with vendors on what is obtainable.

    The loss associated with the inclusion specification of 0.03 $mm^2/100\ cm^3$ is 60 ppm (not 1300) and this is close to the requirement of < 50 defined in the DRD.
    This section of the PDD should be written to state that the COC plan is to ask Heraeus what they expect their process to yield in terms of scatter (based on measurements to be made soon) and have them confirm that their process is highly repeatable. Individual pieces will be measured, but the measurement will be to a more relaxed requirement (too onerous and expensive to check at the level required).
4) Section 2.1.1.2: Table 1 says OC and text says OAA. Please clarify.
5) Section 2.1.1.2 and other section throughout the document: Delete reference to PRM, PR2, SRM and SR2 since these are now defined to be IO design scope.
6) Section 2.1.1.3:
    a. Should note parenthetically that we already have 4 of the 10 ETM blanks and these are comprised of Heraeus 311 material.
    b. If not already done there needs to be a formal agreement with SUS that 5F meets the requirement for ETM ear bonding - almost certainly it does. Action to SUS to confirm that 5F is acceptable.
    c. Qualify “no inclusions within 5 mm” – what size limit?
7) Section 2.2.1.1 Shapes:
    a. Change “… optic types are summarized in Tables one and two.” To “… optic types are summarized in Table 1.”, unless by Table 2 you mean not the appendix A table, but the un-numbered Table.

b. ~~Change "… layout as described in LIGO-T010076." To "… layout (as described in LIGO-T010076, but with pending revision)."~~

c. Change "Wedges are specified by AOS, the magnitude and orientation in LIGO-T080007." To "Preliminary wedge magnitudes and orientations are defined in LIGO-T080078."

8) Section 2.2.1.2.:

a. The statement "All Test Masses will have flats polished on the OD perpendicular to gravity" is incorrect and awkwardly worded. How they are polished relative to the gravity vector is of course not relevant; the flats are aligned parallel to the gravity vector, but then this isn't particularly relevant to COC either. The flats can't be polished on the OD (outer diameter) by the very nature of a diameter. I know this is just semantics, but a better wording is "All Test Masses will have two opposing flats polished into the barrel."

b. Include a reference citation for the design details of the CP grooves and collision stops. If the precise details are not known, then cite representative grooves used for example in the LASTI prototype.

c. "SUS has indicated, in supplying the drawing for the LASTI TM, that these marks should be located within 1°0' parallel and perpendicular to the wedge axis." This is awkwardly worded; How can the marks be both parallel and perpendicular to the wedge axis? The wedge is a plane and angle – how is the axis defined?
Add the drawing number.
Also make clear that it is intended that all COC optics are similarly marked (not just the LASTI optic).

d. Add a note to the effect that the SUS group may soon request some additional alignment references on the TMs for the purpose of setting the ETM reaction mass and the ITM compensation plate parallel to the TM and at a desired standoff (gap) distance.
Answer: We respectfully submit that this is premature. We have not included gold coating requirements, we suggest this be left for final design.
Agreed – no change.

e. There is an interface issue around the preparation of spares. Although suspensions can be adjusted to accommodate a spread in the ITM/ETM mass of order 100g, the most rapid replacement by a spare will be achieved if major re-balancing can be avoided. This requires order of 30g matching of core optics (and incidentally their penultimate masses). A 100g spread in mass corresponds to a tolerance on diameter and thickness of ± 0.0043 inches (±110 microns), whereas a 30g spread corresponds to ± 0.0014 (± 35 microns). The associated tolerance on wedge angle for a 30g mass spread is 0.35' (103 microrad). SUS tolerance definition needs to be set in collaboration with COC, based on knowledge of what manufacturers can deliver within our budget constraints. (For comparison tolerances on initial LIGO TMs were ±0.25 mm on thickness, ±0.5 mm on diameter and ±5' on wedge angle.) SYS may need to decide if the additional cost for tighter tolerances is needed given the

infrequency of spare replacement. SUS also needs to define acceptable limits on absolute mass variation for initial assembly (not spare replacement), which also includes absolute density knowledge.

We are aware of, and actively working with SUS on this issue. We suggest that tight tolerance on the TM is –not- the ideal answer. If a TM needs repolish, it will come in under size. Allow ~0.25mm removal for each repolish.
We accept this answer and agree that tight mass (or dimensional) tolerances on the TM should not be imposed. SUS has an action to incorporate provision to adjust for variation in the TM mass.

9) Section 2.2.2 Final Polishing:
   a. In this section the results to date of the polishing pathfinder (prototyping) efforts should be summarized and references provided to pathfinder documentation.
   b. Explain that for the transmission optics (ITM, BS, CP) it is expected that the surface 2 ROC will need to be polished to compensate for the transmission inhomogeneity – correct?

      Corect except: BS homogeneity will not be compensated, it is thin enough that homogeneity is not an issue. OK

10) Section 2.3 Coatings: In this section the results to date of the coating pathfinder (prototyping) efforts should be summarized and references provided to pathfinder documentation.

11) Sections 2.3.1, 2.3.2 and 2.3.2.1 (shouldn't this be 2.3.3?):
   a. Please include the coating design details such as coating layer materials and material parameters, number of layers, estimated thermal noise, key data from the LASTI coating, etc. Make clear what design information is for reference and not delivered design performance (e.g. we do not require a certain number of layers in the dielectric coatings, but instead specify reflectance value).
   b. What tolerance on R, or BS R/T = 50/50, will be given to the vendor, to meet the requirements given in the DRD?

12) Section 2.3.2.1: How large of a coating stress induced ROC is expected without compensation (i.e. is it really a problem)? What experience (if any) do we (or industry) have that says either approach for compensating will work to the ROC tolerance given in the DRD? How will a decision on the two approaches be made?

    Please clarify: Should we add this description to the PDD? Yes, or in a separate document referenced in the PDD.

13) Section 2.3.4.2.
   a. Change title from "Suspension Coating" to "Electro-Static Drive (ESD)" coating.
   b. Should note, in the way of a brief description, something like the following: "The ESD pattern is a segmented (currently in quadrants) pattern in an annular region between the edge of the optic and an inner clear aperture. (See

D060189-A1 for a drawing of the evaporative mask for the ETM reaction mask for the suspension noise prototype, which is representative of the intended design.) The minimum inner aperture diameter is defined by COC in the DRD based on optical considerations. The ESD pattern, thickness and material (nominally gold) is defined by SUS. COC has the responsibility to implement the coating."

14) Section 2.4, Figure 2: Replace the figure with a current Adv. LIGO quadruple pendulum suspension (magnets, flats, ERM mounting all changed) and the figure caption should state that this is a TM suspension.

15) Section 2.4.1. Replace with the following, or similar statement:
"The SUS group will add appendages to the optics for the purpose of suspending them. The most sensitive optics, the test masses, have 'ears' that are bonded to the flats on the sides of the optic. Analysis was used to set the maximum bond area so that the resulting increase to the thermal noise was less than 10% of the overall intrinsic thermal noise of the interferometer (T050216-00), as required."

16) Section 2.5::

    a. Text says 100% spares for the TMs, but Table 1 lists 6 ITMs and 6 ETMs in the row "Number in IFOs". Since only 3 ITMs are required (1 per IFO), this implies that the spares are shown in the "Number in IFO" row. However an additional 4 ITMs and 4 ETMs are shown in the "Total Spares" row. Please clarify and insure that the text and Table 1 agree.

    b. Text says there are two 2 BSs, but the table 1 shows 3 spare BSs (1 per IFO). Correct the disagreement and call out spares as total or per IFO to be clear.

    c. Some further comment on the basis for the number of planned in-process and delivered spares would be helpful. Perhaps citing spares used for initial LIGO and how that compares/contrasts to plans for Adv. LIGO would help motivate the basis for the spares selection. For example, at LHO after initial installation 3 ITM delivered spares were used. One due to glass being pulled from an earth quake and two due to coating losses probably due to early cleaning techniques.

17) It is worth noting in the text (perhaps as a new section 2.6 on "scatter loss"), with reference to table, the < 15 ppm is difficult to achieve on large optics, but needed to meet the loss budget goal set in the DRD. We have some hope of meeting these values based on scatter loss from pristine small optics which have had similar processing as planned for the large optics. If we fail to achieve this goal, the loss will be compensated by a change in the RM transmission resulting in "graceful" (not catastrophic) degradation in overall interferometer sensitivity.

18) Table 1.

    a. There are some inconsistencies between these numbers and those in the DRD that need to be sorted out.

    b. Where do the absolute ROC numbers for the TMs come from?

    Clarification: Do we need to add a descriptive paragraph in the text?
    In general if the design parameter values are not verbatim those from the DRD,

then yes some descriptive text indicating how these values are derived is needed. If they are identical, then there shouldn't be a need to add descriptive text.

c. Change "SUS coating" to "ESD Coating"

d. Remove columns for PRM, PR2, SRM, SR2

e. The PR3 and SR3 ROC tolerances are listed as 0.10, but are intended to be 0.1 %. However these values are the needed uncertainty in the measurement of the delivered optics, not the absolute accuracy needed for the ROC. Please add a "Measured ROC uncertainty" row in the table.

f. Change the row label "optic size (mm)" to "dia. x thickness (mm)"

g. What steps are needed to define the flatness specifications for the BS, FM and CP?

Good question. Please outline these steps in the PDD, or resolve.

19) Section 3.1 Verification Metrology: Amplify on the statement "Technical development through the Pathfinder mechanism should allow all production COC to be specified and measured to a level satisfying the optical performance requirements of the DRD." What has been accomplished? What remains to be accomplished?

20) Section 3.1.1: Describe the scanning instrument, show results, define required performance and provide references. Is any further development needed to meet Adv. LIGO verification requirements?

21) Section 3.1.2: State that the plan is for LIGO to procure an interferometer capable of performing full aperture phase map measurements at 1064 microns. Also state the performance characteristics to be specified for this instrument (with values TBD until final design phase), e.g. spatial resolution, repeatability, precision, etc. Also compare/contrast to initial LIGO phase map metrology, e.g. is it proposed that Adv. LIGO phase map metrology performance be comparable to initial LIGO, just over a larger aperture, or is the performance better in some aspects?

22) Section 3.1.4 Birefringence: When are birefringence measurements required?

23) Section 3.1.5 Bulk Absorption/OH Content: Statistical correlation of absorption to OH level on delivered optics is late for verification. Can we make absorption measurements on boule samples as blanks are delivered?

Answer: No, we need a polished surface. The plan should be sufficient as is.
OK.

24) Section 3.1.7:

a. Add that the mass will also be measured (by the vendor or LIGO?).

b. The statement that there is no plan for LIGO to verify dimensions which are measured/certified by the vendor seems to be in conflict with Appendix A, Table 2 which indicates 100% inspection of optic sizes by LIGO. Make consistent or clarify.

25) Section 3.2: Will (can) we have witness plates representing each optic for evaluation? If so, state so. This would permit sampled or 100% testing as the coatings are produced.

26) Section 3.3.1.

    a. The design of the storage containers should be shown and described in this document.

    b. State that the storage container for the LASTI test mass (procedure for its use documented in E070070) will be used without modification for AdLIGO (except to accommodate wedge angle variations).

    c. Cite the drawings for the storage container.

27) Section 3.3.2.

    a. The design of the handling devices should be shown and described briefly in this section, including citing references for procedures for their use and the drawings used to produce the prototypes. Note any intended design changes based on the use of the prototypes.

    b. It is unclear when the ergonomic arm is used versus the high friction band tool; please clarify.

       Answer: Based on availability. The ERGO arm should be the first choice. If there is no objection, we will add this information to the document.
       For the final design phase, indicate the processing steps and define the handling tools and procedures for each processing step.

    c. State the intention to perform a failure effects and modes analysis, in the final design phase, to determine what measures (design or procedural) need to be made to insure with high confidence that neither optics nor operators are damaged/injured.

    d. State our intention with regard to contractors handling our optics, i.e. do we provide ergonomic arms or high friction bands, or does the contractor use or develop their own tooling (subject to our review and approval)?

    e. Call out use of the “buddy-system” when transporting optics, including into, and out of, containers.

       I respectfully disagree. Transporting optics should easily be a one-man job given the tooling we have in place. I don’t see the necessity to have two people present when using tooling that is designed for easy lift/move. I am happy to discuss.
       A hazard analysis will need to be written in the final design phase and the proposed use of the ERGO arm by a single person will need to be justified and approved via the hazard analysis report.

28) Section 3.4.

    a. Section 3.4.2, change “silicon” to “silicone”

b. Section 3.4.3 states that in situ cleaning for optics suspended by wires is to be done by drag wiping and FirstContact™ is also an option. What about optics suspended by silica ribbons? Have any tests of FirstContact™ been performed for an optic with its surface vertical?

c. From this section, it is not clear to me what the cleaning/contamination plan is through the optics 'life cycle', starting from receipt of coated optic to end of installation. Please amplify.

d. We think that the intent is that for as long as practically possible, COC optics will have First Contact sealing the HR and AR surfaces; the document should state this. Also reference
E070292-00, "Specification: Optics Cleaning Specification - First Contact™"
T070280-00, "Technical Information on First Contact™"
T070002-01, "Absorption measurements on MMT4K04-1 before and after applying First Contact"
T060161-00, "Test of First Contact™ Strippable Material"

e. Work has been done on characterizing the potential optical contamination issue, and should be briefly summarized here with references to documents, such as T070051-00, "Initial LIGO COC Loss investigation Summary"

f. .Perhaps equally concerning, has any thought gone into considering the effects of residual charge left on the optic after the First Contact™ film is removed? What are the plans for characterizing and de-charging the optic after removing the film?

g. Before First Contact is applied, We'd like to explicitly recommend that for storage and times when the optic is on the flow bench but processing is not taking place, the business (HR) side of COC components be placed facing down.

Never ever on its face. Either in it's protective carrier, or on tooling. Reminder that during metrology the optic remains upright for days, not under a flow hood. It –must- be cleaned prior to first contact being applied. We will add this to the document.

29) Section 4.1.4.2, Data:

a. Put the current text under a subsection 4.1.4.2.1 Vendor Data. Add that vendor supplied data need to have LIGO (customer) review and approval prior to shipment of the optics.

b. Add a subsection 4.1.4.2.2 LIGO Data. Note that a traveler and data package are developed and maintained for every optic by COC, up to the point of delivery of the optics to SUS (for assembly) or INS (spares). It becomes the responsibility of the SUS team (in assembly) and the INS team (in installation) to maintain the travelers and data packages.

30) COC has elected to cover the last sections of the requirements guidelines (defined in T950065-A) in the PDD rather than the DRD (specifically the sections starting with "Documentation"). This is acceptable. However, the sections entitled "Logistics",

"Precedence" and "Qualification" should not be subsections of the section "Documentation" (see T950065-A).

31) Section 4.2, Logistics: Why ship every time back to LIGO (Caltech specifically?), rather than performing the inspection at the vendor's shop prior to shipment to the next vendor? Should cite a requirement for the vendor to perform a post-shipment inspection to accept.

32) Section 4.3 Listing the relative importance of requirements or goals (as suggested for this section by T950065-A) does not seem to be useful and would be difficult to apply in practice should trade-offs in achieving requirements be confronted during implementation, We advise that the intent of this "precedence" section be changed. One should list here other documentation which in the event of a conflict takes precedence, e.g. Tighter DRD values take precedence over the PDD, RODAs which might conflict with the PDD statements take precedence, the System Design Document has precedence, etc.

33) Section 4.4 Qualification: Change "… will assure that the requirements of section 4.2.1 …" to "… will assure that the requirements of Table 1 …"

34) Section 5, QA Provisions: There should be some explanation of the tests and inspections listed and the acceptance criteria for these tests and inspections. Cite reference documents or standards for descriptions, as appropriate, of the tests/inspections which should include the test configurations and a call out for calibration requirements (e.g. frequency and standard).

35) Section 5.1.1 Responsibility for Tests, frequency and method: Test and inspection throughout the fabrication phase is not clear. Appendix A does not distinguish between processing steps. For example, section 2.2.1 states that we perform inspections and tests on the blanks before shipping, but it is not clear which inspections and tests.

36) Section 5.1.2, Special Tests: There should be an explanation of why these tests are called out as "special", e.g. performed at 1064 micron wavelength, or exceptionally large aperture, etc. Also some statement about the plan and capability to perform these measurements, e.g. plan to procure an instrument (phase map metrology), or instrument already developed and in operation (absorption scanner). For each test include references to the documentation which defines the test and its requirements (as available).

37) Section 6.1 Preparation: What about requirements on vendors regarding preparation?

38) Section 6.2 Packaging: The containers only work for substrates and optics (I think). What about blanks?

39) Section 7:

    a. The title "Notes" seems inadequate. How about "Material Specification Notes"

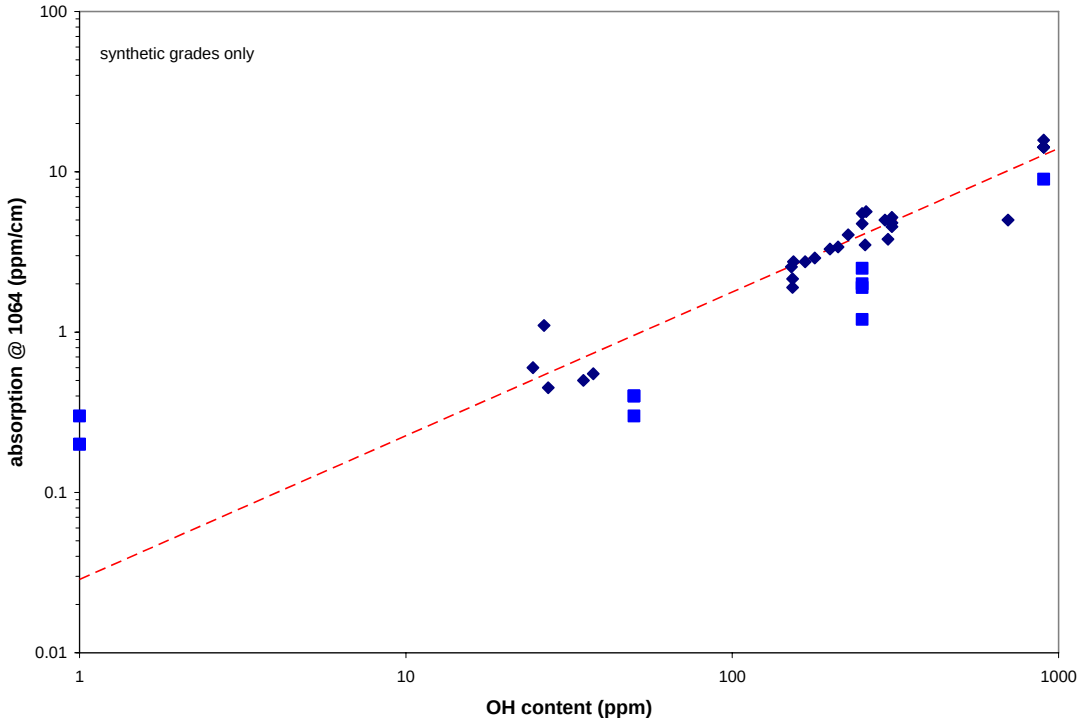
    b. Is the index of refraction homogeneity good enough that a compensating polish on the AR side is not required?

       Answer: it is close enough that it is not guaranteed. We must have the polisher certify. Unless we can budget the BS/FM flatness to provide a total phase change in the recycling cavity that would allow relaxing our current requirement

on the ITM transmission (± 15 m through surface 2 and the bulk).

Note: There is an identified need to specify the transmitted OPD requirements for the ETM and ETM reaction mass. See L080029-00 item (27)

40) Cite a reference for the absorption vs OH content data that supports the claim that 3001 material will have an absorption of < 0.02 ppm/cm. (Also either state the units of the slope and explain how it is relevant, or omit.) The only data that I'm aware (a collection provided by Heraeus; see figure below) requires an extrapolation of over an order of magnitude in OH level. Is there any data on absorption for Heraeus 3001?
No one can measure the expected absorption at the 0.02 ppm/cm. More importantly we only need absorption of < ~0.2 ppm/cm. These two points should be mentioned in the PDD text.



41) Un-numbered & un-labeled Table on page 19:

a. Largely redundant with Table 1 – can it be combined with Table 1?

OR

b. Include a reference to the table in section 7.

c. Give it a number and caption

~~d. Remove columns RM1 and RM2~~

e. Change column label "RM3" to "PR3 & SR3"

f. Change the PR3 & SR3 material from BK7 to FS. Also call out specific grade of FS for each optic (as in Table 1).

42) Section 8 PDR checklist M050220-05 (not -02):
    a. Replace T080026 references with T000127
    b. Design approach & justification that design can meet requirements should be E080033 (not the DRD)
    c. Add C070214 and E080033 to “material considerations and selection”
    d. Resolution to action items from DRR: change “closed via email August 2004” to “closed per L080032-00”
43) Appendix A: Please explain the difference between Measurement, Inspection, Certification and Certification inspection. Also explain measurements less than 100%, i.e. does this mean sampling optics for test or less than full area measurement on each optic.