LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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LIGO Vacuum Compatible Materials List

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LIGO Science Collaboration

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NOMENCLATURE AND ACRONYMS

ADP	Ammonium Di-hydrogen Phosphate [$(NH_4)H_2PO_4$]
AES	Auger Electron Spectroscopy
AMU	Atomic Mass Unit
BT	Beam Tube
FTIR	Fourier Transform Infrared Spectroscopy
HC	Hydrocarbons
HF	Hydrofluoric acid
KDP	Potassium Di-hydrogen Phosphate [KH_2PO_4]
LIGO	Laser Interferometer Gravitational Wave Observatory
OFHC	Oxygen Free High-Conductivity Copper
NEO	Neodymium Iron Boron
PFA	Perfluoroalkoxy fluoropolymer (Du Pont)
PTFE	Polytetrafluorethylene (Du Pont)
PZT	Lead-Zirconate-Titanate
RTV	Room Temperature Vulconizing Silicone elastomer
SIMS	Stimulated Ion Mass Spectroscopy
TBD	To Be Determine
UHV	Ultra High Vacuum

XPS X-ray Photoelectric Spectroscopy

1 INTRODUCTION

All items to be installed inside LIGO vacuum vessels or tubes must be on the "approved materials" list (components and materials). Items on the "provisional materials" list have been installed into the prototype/R&D interferometers (i.e., the 40-meter interferometer) and may be considered for LIGO designs.

2 APPLICATION

Materials can only be added to either the "approved" or "provisional" lists by the LIGO Vacuum Standards Board. The procedures to be followed, and the data required, for submitting a material for consideration by the Board for inclusion on either list are documented in the "LIGO Vacuum Compatibility, Cleaning Methods and Procedures", E960022.

For commercially produced components with potentially many materials used in the construction, a detailed accounting of all of the materials and the amounts used must be submitted for review. It may be necessary for some components to get certifications (per article or serial number) of the materials employed in their manufacture, so that material substitutions by the manufacturer are visible to LIGO. The specific requirements/procedures to ensure that approved components do not have material substitutions by the manufacturers are discussed in LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, LIGO-E960022.

Designers should not assume that materials on the "presently used" or "provisional" list will be approved, or even tested, for LIGO use. Only materials for which a request has been of the LIGO Vacuum Standards Board, to test for compliance with LIGO vacuum requirements will be acted upon. This request must be accompanied with justification why an alternate material can not be used for the intended application.

Despite the fact that some polymer materials are approved for use, these materials should be avoided if possible and used sparingly (since they do outgass and their quantities must be limited), especially if used in proximity to LIGO optics.

Some materials have been approved for use in the initial LIGO detector. The requirements for the advanced LIGO detector are more stringent. Consequently, for each material an indication is noted as to whether it is approved for use in initial LIGO, advanced LIGO or both.

The materials listed herein are those which are intended for use in vacuum. Materials used for items which are temporarily inside a LIGO vacuum system, but do not reside in vacuum (e.g. alignment fixtures, installation tooling, etc.) are not restricted to this material list. These items (referred to as "Class B" as opposed to "Class A" items which remain in the vacuum system) must comply with LIGO cleanliness standards and must not leave residues of non-vacuum compatible materials (e.g. hydrocarbon lubricants).

3 APPLICABLE DOCUMENTS

1) LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, LIGO-E960022-00-E.

2) LIGO Contamination Control Plan, M990034-00

4 PROBLEMS ASSOCIATED WITH MATERIAL IN THE VACUUM SYSTEM

The outgassing of the material in the vacuum vessels or tubes raise concerns in the LIGO detection system. There are two concerns that are associated with material in the vacuum system:

a) Outgassing that increases the gas load (and column density) in the system and through this either compromises the Interferometer phase noise budget or forces higher pumping capacity. Reduction with time, whether 1/t (range of adsorption energies) or 1/sqrt(t) (diffusion followed by desorption) is important and the particular gas species (whether condensable or non-condensable) is critical. The literature is most useful in providing total and water outgassing rates. Since in LIGO, there is a special problem of larger phase noise sensitivity to heavy hydrocarbons (and fear of optical contamination from them), where possible, the hydrocarbon outgassing or surface contamination information should be provided.

b) Outgassing as a source of contamination on the optics with the result of increased optical losses and ultimately failure due to heating. The amount of outgassing is less important than the molecular species that is outgassed. Little is known of the most important contamination sources or the mechanisms that lead to the optical loss (e.g., UV from second harmonic generation, double photon absorption photoeffect, simple molecular decomposition in the optical fields leaving an absorbing residue, etc.).

In the following sections of Approved Materials and Other Materials, a column is provided in the tables to identify whether the listed material has the potential for (is suspected of) being a problem as regards a) or b) or both.

5 APPROVED MATERIALS

The following Table 1 materials list is approved for use in all LIGO vacuum systems. The outgassing rate entries in the table are representative of material sample measurements and provided as a design guideline for working up a gas budget in the vacuum vessels or tubes.

Table 1: Approved construction materials (all outgassing rates are in torr liter/sec cm2)

Material	Approval		Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*	*outgassing concern(s)*	*references*
	Adv.LIGO	Initial LIGO								
Metals										
Aluminum and alloys (e.g. 6061, 2024)	✓	✓	unbaked	7.6E-9	7.6E-9	----	----	----	----	1
Beryllium copper*	✓	✓	----	----	----	----	----	----	----	----
Copper-nickel alloys*	✓	✓	----	----	----	----	----	----	----	----
Copper (OFHC)	✓	✓	unbaked	4.2E-9	4.2E-9	----	----	----	----	2
Electroless nickel*	✓	✓	----	----	----	----	----	----	----	----
Gold*	✓	✓	----	----	----	----	----	----	----	----
Indium*	✓	✓	----	----	----	----	----	----	----	----
Molybdenum	✓	✓	unbaked	6.8E-7	6.8E-7	----	----	----	----	3
Niobium*	✓	✓	----	----	----	----	----	----	----	----
Phosphor bronze*	✓	✓	----	----	----	----	----	----	----	----
Platinum*	✓	✓	----	----	----	----	----	----	----	----
Silver	✓	✓	unbaked	6E-7	6E-7	----	----	----	----	3
Silver solder*	✓	✓	----	----	----	----	----	----	----	----
Maraging Steel (300)*	✓	✓								
Stainless Steels (304)	✓	✓	unbaked	1.8E-8	1.8E-8	----	----	----	----	1
Stainless Steel (316, 303, 18-8, 17-4PH)*	✓	✓	----	----	----	----	----	----	----	----
Titanium*	✓	✓	----	----	----	----	----	----	----	----
Tungsten	✓	✓	unbaked	1.95E-7	1.95E-7	----	----	----	----	3

Material	Approval		Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*	*outgassing concern(s)*	*references*
	Adv.LIGO	**Initial LIGO**								
Ceramics										
Fired nonpermeable ceramics (e.g. alumina, beryllia)*	✓	✓	----	----	----	----	----	----	----	----
Boron Nitride (machinable)*	✓	✓	----	----	----	----	----	----	----	----
Macor (machinable)[3]*	✓	✓	----	----	----	----	----	----	----	----
BT Baffle Clayless Black Enamel, Ferro Corp. L.O., 34792	✓	✓	Stressed & baked[4]	5.2E-12	----	5.2E-12	----	< 0.1 monolayer carbon by XPS assay	----	----
Glazed Ceramics (e.g., Porcelain)	✓	✓	Unbaked	1E-8	1E-8	----	----	----	----	1,4
Aremco Ceramabond 571 [used for bonding wire and alumina circuit boards into the suspension OSEM]		✓								
Crystalline Materials										
ADP*	✓	✓	----	----	----	----	----	----	----	----
Calcite*	✓	✓	----	----	----	----	----	----	----	----
Diamond	✓	✓	----	----	----	----	----	----	----	----
Germanium*	✓	✓	----	----	----	----	----	----	----	----
KDP*	✓	✓	----	----	----	----	----	----	----	----
Quartz*	✓	✓	----	----	----	----	----	----	----	----
Sapphire*	✓	✓	----	----	----	----	----	----	----	----
Silicon Dioxide*	✓	✓	----	----	----	----	----	----	----	----
Tantalum Pentoxide (hard optical coating)*	✓	✓	----	----	----	----	----	----	----	----

Material	Approval		Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*	*outgassing concern(s)*	*references*
	Adv.LIGO	**Initial LIGO**								
Glasses										
Fused quartz*	✓	✓	----	----	----	----	----	----	----	----
Pyrex glass	✓	✓	unbaked	1.6E-10	1.6E-10	----	----	----	----	2
Glass	✓	✓	unbaked	1E-8	1E-8	----	----	----	----	4
Black Glass, shade 12/14 Welders [used for beam dumps]	✓	✓								
Polymers										
Teflon PFA-440HP (Dupont) [used for the custom connector bodies on the suspension cable and on the OSEM head]		✓								
Teflon insulated wire, Cooner Wire, P/N CZ1104 [used for OSEM cabling, e.g. LIGO-D990676-C]		✓								
Kapton wire insulation: 1) Kapton film (spiral wrapped around conductor, 50% overlap): DuPont film, FM616 2) Overcoat (conformal coating): polyimide dispersant (liquid resin): Imitec P/N 201A, with additives (additives aid drying, etc., and are proprietary; they will not identify them); this material is in compliance with mil spec MIL-W-81381 [used in the Acu-Glass in-vacuum ribbon cabling procured through MDC Vacuum Products Corp. as P/N 680535-1000. KAP-R25-300SC2]		✓								

Material	Approval		Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*	*outgassing concern(s)*	*references*
	Adv.LIGO	**Initial LIGO**								
Kapton wire insulation: MWS Wire Industries 32HML, which is 32 gauge copper with a thick coating of polyimide-ML [used in the OSEM coil winding]		✓								
PEEK connectors and thread [woven into the ribbon cabling in the Acu-Glass in-vacuum cabling, procured through MDC Vacuum Products Corp. as P/N 680535-1000. KAP-R25-300SC2]]		✓								
3M/Dyneon Fluorel FC2180 (or FE5641) as processed per LIGO-E970130 [used for seismic isolation system coil spring seats; see also T970168-00, C972528-B]		✓	unbaked baked				8.8E-13 1.9E-13			5
3M Fluorel V747-75 as specified in LIGO-C990061-00 [used for LLO mid-point gate valve o-rings]	✓	✓								
Dupont Viton E-60C as specified per LIGO-E960085-06-V Dupont Viton A500 as specified per LIGO-C961792-06 (also known as E960085-06) [used for vacuum equipment o-ring seals]	✓	✓								
Vac-Seal epoxy [for use in bonding to optics]		✓								

Material	Approval		Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*	*outgassing concern(s)*	*references*
	Adv.LIGO	Initial LIGO								
Electronics Components										
Surface Mount LED, Honeywell P/N SME-2470-001 [used in the suspension OSEM]		✓								
Surface Mount PD, Honeywell P/N SMD-2420-001 [used in the suspension OSEM]		✓								

1. The amount of carbon bearing molecules on the surface. The surface measurement is in units of monolayers of carbon as determined by one of the following methods:

a) X-ray Photoelectric Spectroscopy (XPS) - note if carbon or carbon combined with hydrogen or oxygen.

b) Auger Electron Spectroscopy (AES) - can only give elemental abundances.

c) Stimulated Ion Mass Spectroscopy (SIMS) - note the more abundant AMU values.

d) Fourier Transform Infrared Spectroscopy (FTIR) - note the strongest absorption bands.

2. In sufficient quantity and conductance a material may present one or both of the following problems:

a) Gas Load - material outgassing increases the gas load (and column density) and as a consequence either compromises the phase noise budget or forces higher pumping capacity.

b) Contamination - material outgassing is a source of optics contamination and as a consequence increases optical losses and ultimately failure due to heating.

3. Macor is a machinable ceramic made by Corning.

4. Stressed and baked under Beam Tube bakeout conditions (i.e., 150°C, 30 days)

Glass Unbaked 1E-8 1E-8 ---- ---- ---- ---- 4

* Denotes materials which, although not tested by LIGO, are intrinsically Ultra High Vacuum (UHV) compatible and are used in UHV practices. Many of these items, if used at all, will be used in “trace” quantities.

6 PROVISIONAL MATERIALS

The following list of materials (Table 2) are, or have been, used in the 40m experiment facility. At present, they are not approved for use on the LIGO observatory vacuum systems. Outgassing properties of these materials have been assessed in the past; however documented values are not available at present in usable format. Before any of these materials are used in LIGO, their vacuum properties, and compatibility with the LIGO optics, must be determined.

Table 2: Provisional Materials

Material	Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement1*	*outgassing concern(s)*	*references*
Metals								
Carbon steel suspension wire	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Carbon steel balls	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Carbon steel race ways	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Sm-Co permanent magnets (Remco-18™)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
NEO-35 magnet material	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Active Components								
PZT piezoelectric ceramics (e.g. Vernitron PZT-5H or Channel Industries 5500 materials)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Adhesives								
Vac-Seal3 epoxy	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Torr-Seal™ epoxy	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Conductors								
Non-OFHC copper4	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Standard tin/lead solder (e.g. Sn 63)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Elastomers								
Molded castings [Flouroelastomer (e.g. Viton)]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Seals and O-rings [Flouroelastomer (e.g. Viton)]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Springs (e.g. Fluorel 2176)5 [Flouroelastomer (e.g. Viton)]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----

Material	Condition	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement1*	*outgassing concern(s)*	*references*
Electronics Components								
Glass and ceramic type vacuum connectors (made by ISI or Ceramaseal)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
LED TLN107A (Toshiba)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Photo diode TPS703A (Toshiba)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Ceramic connector head P/N 14444-02-W (Ceramaseal)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Ceramic connector plug P/N 14449-02-A (Ceramaseal)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Lubricants								
DuPont Krytox™ high vacuum grease	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Molybdenum Disulphide dry lubricant	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Plastic Insulators								
Kapton wire insulation	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Teflon PFA 440 HP (DuPont)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----

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b) Contamination - material outgassing is a source of optics contamination and as a consequence increases optical losses and ultimately failure due to heating.

3. Vac-Seal is an epoxy resin made by Perkin Elmer.

4. For electrical conductors only, not for structural members.

5. Spring, Fluorel 2176 (70 durometer), made by 3M.

7 EXPLICITLY REJECTED MATERIALS

Alkali metals

Cadmium and zinc plating on metal parts

Cadmium and zinc have prohibitively high vapour pressures. Crystalline whiskers grow on cadmium, can cause short circuits.

Delrin™ or similar polyacetal resin plastics

Outgassing products known to contaminate mirrors.

Oilite™ or other lubricant-impregnated bearings

Oriel MotorMike™ actuators filled with hydrocarbon oil, not cleanable

Palladium

RTV Type 615

Soldering flux

Tellurium

8 REFERENCES

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