



LIGO Laboratory / LIGO Scientific Collaboration

LIGO-E960050-v7
see DCC record for approval

Advanced LIGO

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LIGO Vacuum Compatible Materials List

D. Coyne (ed.)

Distribution of this document:
LIGO Science Collaboration

This is an internal working note
of the LIGO Project.

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CHANGE RECORD

Revision	Date	Authority	Description
A	30 Jul 1996	Initial Release	Initial Release
B/v1	5 Apr 2004	DCN E030570-01	Added approved materials for initial LIGO, clarified the designation "presently used", or "provisional" materials, added independent approval for Initial LIGO and Advanced LIGO approval.
v2	9 Sep 2009	See DCC record	<ul style="list-style-type: none"> Removed distinction between initial and advanced LIGO for approval Made an explicit notation in the materials list if the use of a material is restricted (or not) Moved a number of materials from the provisionally approved to the approved list, although in some cases with restrictions (e.g. carbon steel, Sm-Co, Nd-Fe-B, Vac-Seal, copper, Tin-Lead solder, etc.) and removed the provisional list from the document Added a number of materials to the approved list, although in some cases with restrictions (e.g. adhesives, aluminum bronze, etc.) Added a few materials to the explicitly excluded list, e.g. aluminum alloy 7000 series, brass (aka manganese bronze), free-machining grades of stainless steel (303, 303S, 303Se) except as small fasteners, etc. Added a number of references Added a section on general restrictions on materials (e.g. no castings, material certifications are always required, only the grades and sources called out for the polymers are permitted, etc.) Most outgassing rate values remain blank in the materials list (pending)
v3	16 Sep 2009	See DCC record	<ul style="list-style-type: none"> Added SEI-ISI actuators to approved list Clarified that no castings refers to metals only Added exception for the use of grinding to prepare the leads for in-vacuum photodiodes Added numbers to the rows of the approved materials list for easier reference Added the grade and source for PEEK and carbon-loaded PEEK
v4	12 Nov 2009	See DCC record	<ul style="list-style-type: none"> Explicitly added the Ferritic Stainless Steels (400 series) to the approved materials list. Of high vapor pressure elements, these alloys have 0.06% P max and 0.15% S max, which is well under the 0.5% max allowed in LIGO-L080072-00 [Ref. b7]

CHANGE RECORD

<i>Revision</i>	<i>Date</i>	<i>Authority</i>	<i>Description</i>
v5	13 May 2010	See DCC record	<ul style="list-style-type: none"> • Added permalloy MuMetals (i.e. nickel-iron-molybdenum alloys) which is an inherently vacuum compatible material if wrought (not cast) • Clarified that 450G, 450GL, 450CA and 450U grades of PEEK are all allowable, but restricted (all polymers are restricted) • Added PEEK ESD 480 (for use as the A-OSEM head)
v6	17 Jun 2010	See DCC record	<ul style="list-style-type: none"> • Added as an allowable material: Ferro Corporation porcelain/enamel frit, PE RTU GC Gloss Blk RM108
v7	7 Sep 2010	See DCC record	<ul style="list-style-type: none"> • Added Tungsten Carbide cermet (aka cemented carbide; WC-Co or WC-Ni) as an inherently vacuum compatible material

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1 Introduction

All items to be installed inside LIGO Observatory vacuum systems must be on the "approved materials" list (components and materials).

2 Scope

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"¹ 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 Nomenclature and Acronyms

AdL	Advanced LIGO
ADP	Ammonium Di-hydrogen Phosphate [(NH ₄)H ₂ PO ₄]
AES	Auger Electron Spectroscopy
AMU	Atomic Mass Unit
FTIR	Fourier Transform Infrared Spectroscopy
HC	Hydrocarbons
InL	Initial LIGO
KDP	Potassium Di-hydrogen Phosphate [KH ₂ PO 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 Vulcanizing Silicone elastomer
SIMS	Stimulated Ion Mass Spectroscopy
UHV	Ultra High Vacuum
VRB	LIGO Vacuum Review Board
XPS	X-ray Photoelectric Spectroscopy

¹ Betsy Bland (ed.), LIGO Contamination Control Plan, [LIGO-E0900047](#)

4 Ultra-High Vacuum Material Concerns

There are two principal concerns associated with outgassing of materials in the LIGO vacuum system:

- a) Outgassing increases the gas load (and column density) in the system and consequently may either compromise the interferometer phase noise budget or require 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. Even inherently compatible, low outgassing materials (e.g. 6061 aluminum alloy) will contribute to the gas load (especially if not properly cleaned and/or copious amounts are installed into the vacuum system). However, the most significant risk is likely to be from materials which have inherently high outgassing rates (e.g. water outgassing from fluoroelastomers such as Viton® and Flourel®).

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 (and concern of optical contamination from) heavy hydrocarbons, where possible, the hydrocarbon outgassing or surface contamination information should be provided.

- b) Outgassing is a potential source of contamination on the optics with the result of increased optical losses (scatter and absorption) 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 approved materials list, one column entry indicates whether the listed material has the potential for (is suspected of) being a significant contributor as regards a) or b) or both.

5 Vacuum Requirements

An allocation of high molecular weight hydrocarbon outgassing budget to assemblies within the AdL UHV is given in LIGO-T040001². However, this document is in need of revision (a) to reflect the pumping capacity of the beam tube (which reduces the requirements considerably), and (b) to more accurately reflect the evolved AdL configuration.

An allocation of total gas load for AdL has not been made as yet. With the elimination of the significant amount of Flourel® fluoroelastomer in InL (spring seats, parts of the InL seismic isolation system), the water load will decrease dramatically. However, recent calculations³ of test mass damping due to residual gas suggest that this may not be sufficient. We will need to achieve a total pressure of 10^{-9} torr or less in proximity to each test mass. A total gas load budget/estimate will be created.

The limits on optical loss due contamination are < 1 ppm/yr absorption and < 4 ppm/yr scatter loss

² D. Coyne, Vacuum Hydrocarbon Outgassing Requirements, [LIGO-T040001](#)

³ N. Robertson, J. Hough, Gas Damping in Advanced LIGO Suspensions, [LIGO-T0900416-v1](#)

for any test mass (TM), high reflectance (HR), surface⁴.

6 Procedure for Qualifying New Materials

A request to qualify a new material or component/assembly should be addressed to the LIGO Chief Engineer or the LIGO Vacuum Review Board with a justification regarding the need for the new material and an estimate of the amount of material required. Materials can only be added to the "approved" list after extensive testing in accordance with the document "LIGO Vacuum Compatibility, Cleaning Methods and Procedures"⁵.

7 VRB wiki Log

This revision captures all relevant LIGO Vacuum Review Board (VRB) decisions as of the date of this release. For more recent direction not yet captured in a revision of this document, see the [LIGO VRB wiki log](#) (access restricted to LSC members).

8 General Restrictions

- 1) Material certifications are required in every case.
- 2) Only the grades called out
- 3) Only the grades and sources called out for the polymers (unless otherwise noted).
- 4) All polymers are restricted (even if approved). The use of an approved polymer in a new application must be approved. Despite the fact that some polymer materials are approved for use, these materials should be avoided if possible and used sparingly, especially if used in proximity to LIGO optics.
- 5) Special precautions must be taken for adhesives. Often the shelf life for adhesives is limited. All adhesives should be degassed as part of the preparation procedure. Extreme care must be taken when mixing multi-part adhesives, to insure that the proper ratio is used and accurately controlled.
- 6) No metal castings, including no aluminum tooling plate.
- 7) All surfaces are to be smooth (preferably ≤ 32 micro inches Ra). All metal surfaces are ideally machined.
- 8) All machining fluids must be fully synthetic (water soluble, not simply water miscible) and free of sulfur, chlorine, and silicone.
- 9) No bead or sand blasting is permitted.

⁴ G. Billingsley et. al., Core Optics Components Design Requirements Document, section 4.2.2.6 of [LIGO-T080026-00](#). The timescale for accumulation (i.e. the time span between in situ re-cleaning of the test mass optics) has been chosen here to be 1 year. It is possible that a somewhat shorter time span could be accommodated.

⁵ D. Coyne (ed.), LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, [LIGO-E960022](#)

- 10) No grinding is permitted (due to potential contamination from the grinding wheel matrix), except for (a) grinding maraging steel blades to thickness⁶ and (b) photodiode lead end preparation for pin sockets.
- 11) Parts should be designed and fabricated to provide venting for enclosed volumes
- 12) For design applications where dimensional control is extremely important or tolerances are exceedingly tight, it is the responsibility of the design engineer to (a) establish a basis for baking parts at temperatures lower than the default temperatures (defined in [LIGO-E960022](#)), and (b) get a waiver for a lower temperature bake from the LIGO Vacuum Review Board.
- 13) All materials must be cleaned with appropriate chemicals and procedures (defined in [LIGO-E960022](#)) and subsequently baked at “high temperature”. The appropriate temperature is defined in [LIGO-E960022](#). Typical hold duration at temperature is 24 hours. The preferred bake is in a vacuum oven so that the outgassing rate can be shown to be acceptable by Residual Gas Assay (RGA) measurement with a mass spectrometer. If the part is too large to be placed in a vacuum oven, then it is air baked (or dry nitrogen baked) and then its surface cleanliness is established by FTIR measurement.
- 14) Welding, brazing, soldering have special restrictions and requirements⁷ defined in LIGO-E0900048.
- 15) 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.

9 Approved Materials

The following Table lists materials which are approved for use in all LIGO vacuum systems. In many cases the materials are restricted to a particular application. Use of the material for another application must be approved by either the LIGO Chief Engineer or the LIGO Vacuum Review Board. References for the approved materials list table are given in the last section.

⁶ C. Torrie et. al., Manufacturing Process for Cantilever Spring Blades for Advanced LIGO, [LIGO-E0900023](#)

⁷ C. Torrie, D. Coyne, Welding Specification for Weldments used within the Advanced LIGO Vacuum System, [LIGO-E0900048](#)

Table 1: Approved Construction Materials

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)					references
					Condition	J _{Total}	J _{water}	J _{H2}	J _{HC}	
	Adhesives									
1	hydroxy-catalysis, silicate bonding* for bonding highly flat, fused silica components together	✓								
2	<u>Obsolete</u> : Vac-Seal epoxy Manufactured by Tra-Con ⁹ and distributed by Physical Electronics and later Gamma Vacuum.		✓	for use in bonding to optics						a, b
3	Epoxy Tra-Bond #2151 (thermally conductive, electrically insulating, low outgassing), from Tra-Con, Inc.		✓	ADE capacitive position sensors for the seismic system only						a, b
4	<u>Obsolete</u> : Epoxy Tra-Bond #2254, from Tra-Con, Inc. No longer manufactured		✓	Used for prototype ADE capacitive sensors (~2004)						a, b
5	Epoxy Tra-Duct #2902 Epoxy (electrically conductive, silver epoxy, low outgassing), from Tra-Con, Inc.		✓	ADE capacitive position sensors for the seismic system only						a, b
6	<u>Obsolete</u> : Epoxy Tra-Duct #2903 (conducting), from Tra-Con, Inc. No longer manufactured		✓	Used for prototype ADE capacitive sensors (~2004)						a, b

⁸ 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 system.

⁹ Apparently as of March 2008, the Vac-Seal product is no longer available. In previous versions of this document it was (erroneously?) reported that VacSeal was manufactured by Perkin Elmer. It appears to have been manufactured by Tra-Con, now part of Emerson & Cuming, a division of Henkel. There is another product called Vaseal from SPI, which we have not qualified for use.

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references	
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{H2C}	a) gas b) contam.		
7	Obsolete: Epoxy Tra-Bond 2103 (a medium viscosity, low outgassing, general purpose epoxy). No longer manufactured.		✓	Used for prototype ADE capacitive sensors (~2004)							a, b	
8	Polyimide Dupont PI-2525 (Can only be used in thin films, e.g. for potting coils.)		✓	PSI actuator coils for the seismic isolation system only							a, b	
9	Polyimide Cycom 3001 and 3002, manufactured by Cytec Engineered Materials Inc. (Can only be used in thin films, e.g. for potting coils.) [N.B.: apparently no longer manufactured.]		✓	Used in prototype PSI actuator coils for the seismic isolation system only							a, b	
10	Ceramabond #835M & 571 (inorganic, ceramic cements)	✓		used for bonding wire and alumina circuit boards into the Initial LIGO suspension OSEM assembly								
11	Electronic Materials Inc.'s Optocast 3553LV-UTF-HM (A Low Viscosity, Ultra Thin Film epoxy with Heat Mechanism. The assembly/cure procedure includes both a UV binding step and a 120 degree cure for 24 hours.)		✓	Bonding fused silica optical elements to a fused silica base plate for a semi-monolithic assembly, for use in the Output Mode Cleaner (OMC)							a, b	
Ceramics & Cermets												
12	Fired nonpermeable ceramics (e.g. alumina, beryllia)*	✓			----		----	----	----			----
13	Boron Nitride (machinable)*	✓			----		----	----	----			----
14	Macor (a machinable ceramic made by Corning)*	✓			----		----	----	----			----

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}	a) gas b) contam.	
15	Clayless Black Enamel, Ferro Corp. L.O., 34792	✓		Fired onto prototype stainless steel baffles for the Beam Tube (not used in installation)	Stressed & baked		5.2E-12	----	5.2E-12		21
16	Glazed Ceramics (e.g., Porcelain)	✓			Unbaked		1E-8	1E-8	----		1,4
17	Tungsten Carbide cermet (aka cemented carbide)* (WC-Co or WC-Ni)	✓									22
Coatings/Platings											
18	flame-sprayed Aluminum-oxide (white)	✓		Used as a high emissivity coating for in-vacuum thermal management of the ISC photodiode pre-amp assembly							
19	flame-sprayed 80% Aluminum Nitride, 20% Aluminum Oxide (grey)	✓		Used as a high emissivity coating for in-vacuum thermal management of the ISC photodiode pre-amp assembly							
20	Electroless nickel plating		✓	Low phosphorous plating; see specification in reference 11	----		----	----	----	a, b	10,11
21	Silver*	✓		Used on fasteners in stainless steel						a, b	
22	Titanium-Nitride Magnaplate Corp., PVD TiN coating, Magnagold	✓		Used on several of the InL seismic isolation system parts							
Crystalline Materials											
23	ADP (Ammonium Di-hydrogen Phosphate [(NH ₄)H ₂ PO ₄])*	✓			----		----	----	----		----
24	Calcite*	✓			----		----	----	----		----
25	Diamond*	✓			----		----	----	----		----
26	Germanium*	✓			----		----	----	----		----

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}	a) gas b) contam.	
27	KDP (Potassium Di-hydrogen Phosphate [KH ₂ PO ₄])*	✓			----		----	----	----		----
28	Quartz*	✓			----		----	----	----		----
29	Sapphire*	✓			----		----	----	----		----
30	Silicon Dioxide*	✓			----		----	----	----		----
31	Tantalum Pentoxide (hard optical coating) (including Titanium dopes Ta ₂ O ₅)*	✓			----		----	----	----		----
32	Zinc Selenide, ZnSe*	✓		Used in viewports for 10.6 micron wavelength transmission							
Electronic Components											
33	OSEM Assembly (Adv. LIGO Optical Sensor and Electro-Magnetic actuator), D#? Material composition list is given in REF?		✓	Used in the InL suspension systems						a, b	
34	AOSEM Assembly (Adv. LIGO Optical Sensor and Electro-Magnetic actuator), D#pending; see T0900286 and related documents Material composition list is given in REF# pending		✓	Used in the AdL suspension systems						a, b	
35	BOSEM Assembly (Birmingham Optical Sensor and Electro-Magnetic actuator), D#? Material composition list is given in E040373-00		✓	Used in AdL suspension systems						a, b	

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{H2C}	a) gas b) contam.	
36	Electro-Magnetic Actuators, SEI-ISI, manufactured by PSI, model nos. ? and ? comprised of: SmCo magnets stainless steel housing PEEK terminal block (Accu-Glass Products Inc. part # PEEK-TB-2P) Coil wire ? Coil potting adhesive: Polyimide Dupont PI-2525		✓	For use in the SEI-ISI subsystems only							
37	Connector: Glenair Micro-D (no interfacial seal with nickel or gold plating): 9-pin micro-D PCB (Right Angled) connector 9-pin micro-D Solder (Straight) connector [materials composition list]		✓	Used in the suspension BOSEM assembly (OSEM coilformer and mating connector)						a, b	
38	Cable: Acu-Glass ribbon cabling procured through MDC Vacuum Products Corp. as P/N 680535-1000. KAP-R25-300SC2 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 (proprietary additives to aid drying, etc.); this material is in compliance with mil spec MIL-W-81381 Connector: Accu-Glass Part #, PEEK		✓	Used for power and signal cabling for the seismic isolation system and its active payload elements						a, b	

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references	
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{H2C}	a) gas b) contam.		
39	Emitter: Optek OP232		✓	Used in the BOSEM assembly, D060218-C							a, b	
40	Emitter: Surface Mount LED, Honeywell P/N SME-2470-001		✓	used in the second (surface mount) versions of the Initial LIGO OSEM assembly, D000180-A (short) and D000069-A (long)							a, b	
41	Emitter: LED TLN107A, Toshiba			Used in the first version of the Initial LIGO OSEM, D960138-02							a, b	
42	Receiver: Centronics BPX65		✓	Used in the BOSEM assembly, D060218-C							a, b	
43	Receiver: Surface Mount Photodiode, Honeywell P/N SMD-2420-001		✓	used in the second (surface mount) versions of the Initial LIGO OSEM assembly, D000180-A (short) and D000069-A (long)							a, b	
44	Receiver: Photodiode TPS703A, Toshiba		✓	Used in the first version of the Initial LIGO OSEM, D960138-02							a, b	
45	Flexible Circuit: DuPont Pyralux® Flexible Circuit , comprised of: (a) Pyralux® LF Copper-Clad Laminate , which is a Kapton® (polyimide) film bonded to a copper foil with a C-staged modified acrylic adhesive, and (b) Pyralux® coverlay composite are constructed of Kapton® polyimide film, coated on one side with a proprietary B-staged modified acrylic adhesive		✓	Used in the suspension BOSEM assembly, D050435-C							a, b	
46	Capacitive Position Sensor, ADE Technologies Inc., Model Nos. 2820-V, 2821-V, 2822-V Vacuum Prepared Probe [material composition list is proprietary]		✓	Used in the seismic isolation systems for HAM and BSC chambers							a, b	

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)					references	
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{H2C}		a) gas b) contam.
47	MWS Wire Industries 32HML (heavy), or 32QML (quad-build) Kapton insulated copper wire (32 gauge) with a thick coating of polyimide-ML		✓	Used for OSEM, AOSEM and BOSEM voice coil actuators.						a, b	
48	Teflon (FEP) insulated, coaxial, shielded, silver-plated copper wire, Cooner Wire Inc., Part# CW2040-3650 F		✓	For the Electro-Static Driver (ESD) assembly of the Input and End Test Mass suspensions						a, b	
49	Teflon insulated wire, Cooner Wire, P/N CZ1104 and P/N CZ1105		✓	used for OSEM cabling, e.g. LIGO-D990676-C						a, b	
50	Vacuum Feedthroughs, Glass & Ceramic, manufactured by ISI or Ceramaseal with Kovar glass to metal seals	✓									
Glasses											
51	Corning 7056 or Kodial glass	✓		Used in viewport assemblies							
52	Fused quartz* Fused silica*	✓			----		----	----	----		----
53	Pyrex glass*	✓			unbaked		1.6E-10	1.6E-10	----		2
54	Glass (non-leaded)*	✓			unbaked		1E-8	1E-8	----		4
55	Black Glass, shade 12/14 Welders*	✓		used for beam dumps							
Lubricants											
56	Molybdenum disulfide (MoS ₂)*		✓	Limited to applications where generated particulates can't migrate							

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}	a) gas b) contam.	
	Metals										
57	Aluminum and Aluminum alloys: 2000 series 4000 series 5000 series 6000 series (e.g. 6061, 4043, 5052, 2024) [N.B.: Not the 7000 series]	✓		Wrought form (not a casting). Cast tooling plate is not acceptable.	unbaked		7.6E-9	7.6E-9	----		1,8
58	Aluminum bronze		✓	Some aluminum bronze alloys include high vapor pressure elements such as zinc (Zn), phosphorous (P) and lead (Pb). These alloys must comply with the limits established in L080072-00; Most alloys should comply						a	6,7
59	Beryllium copper*	✓		Wrought form (not a casting)	----		----	----	----		6
60	Carbon Steel		✓	Minimize carbon steel use due to concerns regarding particulate contamination from oxidation. Approved use is for: (a) high tensile strength suspension wire (per ASTM A 228/A 228M), (b) hardened small steel balls and contact plates in quasi-kinematic mounts, (c) small disc for magnet attachment for voice coil actuator on suspension assemblies							18
61	Copper-nickel alloys*	✓			----		----	----	----		6
62	Copper (elemental and OFHC)*	✓			unbaked		4.2E-9	4.2E-9	----		2,6
63	Gold*	✓			----		----	----	----		----
64	Indium*	✓			----		----	----	----		----

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}	a) gas b) contam.	
65	Invar™ 36*, Nickel-Iron alloys	✓									
66	Maraging Steel (c-250, Marval 18, c-300)*		✓	Should be electroless nickel plated (see restrictions on plating in this table) to minimize corrosion. Limited to spring and flexure applications in seismic and suspension systems.							20
67	Molybdenum*	✓			unbaked		6.8E-7	6.8E-7	----		3
68	MuMetal if a permalloy, i.e. a nickel-iron-molybdenum alloy	✓		Must comply with ASTM A-753							
69	Neodymium-Iron-Boron (Nd-Fe-B) Magnets (NEO-35)	✓									
70	Nichrome (Nickel-Chromium) wire*	✓									
71	Niobium*	✓			----		----	----	----		----
72	Phosphor bronze		✓	Phosphor-Bronze alloys with P ≤ 0.35 %, Pb ≤ 1%, Zn ≤ 1% are acceptable for UHV service at 1 m or more from any optics, when the surface area is limited to ~1000 cm ² with sufficient justification (i.e. no reasonable alternate materials/parts). However these parts must be air baked (not vacuum baked) and require FTIR (not RGA) qualification.	----		----	----	----	a	6
73	Platinum*	✓			----		----	----	----		----
74	Samarium-Cobalt (Sm-Co) permanent magnets	✓									19
75	Silver*	✓			unbaked		6E-7	6E-7	----		3
76	Silver solder*	✓			----		----	----	----		----

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)						references
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}	a) gas b) contam.	
77	Stainless Steels:* 18-8 17-4PH 302 304, 304L, 304LN 316, 316L, 316LN 317, 317L 400 series (ferritic stainless steel) A286 (iron-based "super alloy", similar in composition to Stainless Steels) Nitronic 60	✓			unbaked		1.8E-8 (304, 304L)	1.8E-8 (304, 304L)	----		1
78	Stainless Steels, free machining grades: 303, 303S, 303Se		✓	Only acceptable for small hardware items (e.g. nuts, bolts, washers)						a	9
79	Tin-Lead Solder grade Sn63Pb37, Kester 6337		✓	Restricted to electrical conductor applications and with minimal amount due to lead content. Crimped pin connections are preferred. Rosinless core only.						a, b	
80	Titanium*	✓			----		----	----	----		----
81	Tungsten*	✓			unbaked		1.95E-7	1.95E-7	----		3

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)					references	
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}		a) gas b) contam.
	Polymers										
82	PEEK (grade unknown), cable & connector parts		✓	(1) Adv. LIGO: Electro-Static Drive (ESD) coaxial cable assembly (cable adaptor sleeve, part of Accu-Glass coaxial connector part #100909) (2) Adv. LIGO: Power and Signal cables for SEI and payload elements on Optics Tables (Accu-Glass D-25 connectors, part #?) (3) In Initial LIGO, threads used for tying together the Accu-Glass Kapton-insulated ribbon cabling (part #?) (4) PEEK thread woven into the ribbon cabling in the Acu-Glass in-vacuum cabling for InL, procured through MDC Vacuum Products Corp. as P/N 680535-1000. KAP-R25-300SC2						a, b	
83	PEEK: Victrex grade TDS-450CA30, Carbon Fiber Loaded.		✓	This material is used to form the abrasion and dielectric covering used on in-vacuum cables for AdL							
84	PEEK: Victrex grade TDS-450G.		✓	This is a general purpose, machinable or moldable, version of basic PEEK used to make connector bodies and cable clamps, e.g. Adv. LIGO: cable clamps, D0900004-v1							
85	PEEK: Victrex grade 450G, 450GL, 450CA and 450U		✓	Used for adjuster mechanism on the BOSEM assembly						a, b	
86	PEEK: Grade 450CA30 from Boedeker Plastics, 30% Carbon Loaded, virgin PEEK resin, no other additives		✓	Restricted to use for the body of the AOSEM assembly, D0901048						a, b	

#	Material	Unrestrict	Restrict	Specific Restrictions	Reference Outgassing Data ⁸ (torr-liter/s/cm ²)					references	
					Condition	<i>J</i> _{Total}	<i>J</i> _{water}	<i>J</i> _{H2}	<i>J</i> _{HC}		a) gas b) contam.
87	PEEK: Semitron ESd 480 from Boedeker Plastics, a static dissipative reinforced PEEK		✓	A-OSEM head							
88	Teflon PFA-440HP (Dupont)		✓	In initial LIGO used for the custom connector pin-plates on the suspension cable and on the OSEM head. For Adv. LIGO used for AOSEM and BOSEM assemblies.						a, b	
89	Viton or Fluorel o-rings, commercial off the shelf, manufactured by Dupont, 3M, Parker or Parco		✓	Restricted to o-ring cross sections ≤ 0.275 inch diameter.. For O-rings of less than 8 inches in diameter processing shall be as called out in E960022. The large diameter o-rings used for vacuum chamber seals and large quantities of smaller o-rings may be processed according to E960159-01.						a, b	12,13, 14
90	3M/Dyneon Fluorel FC2180 (or FE5641) as processed per LIGO-E970130-A		✓	Used for Initial LIGO seismic isolation system coil spring seats; Initial LIGO cable clamp liners; Initial LIGO earthquake stops	unbaked baked				8.8E-13 1.9E-13	a, b	5,15
91	3M Fluorel V747-75 as specified in LIGO-C990061-00		✓	[used for LLO mid-point gate valve o-rings]						a, b	16
92	Dupont Viton E-60C as specified per LIGO-E960085-06		✓	[used for vacuum equipment o-ring seals]						a, b	17
93	Dupont Viton A500 as specified per LIGO-C961792-06 (also known as E960085-06)		✓	[used for vacuum equipment o-ring seals]						a, b	17

* 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.

10 Explicitly Rejected Materials

- 1) Alkali metals
- 2) Aluminum alloy 7000 series: due to the high zinc content
- 3) Brass (aka manganese bronze): due to high zinc content
- 4) Cadmium or zinc plating on metal parts: Cadmium and zinc have prohibitively high vapour pressures. Crystalline whiskers grow on cadmium, can cause short circuits.
- 5) Delrin™ or similar polyacetal resin plastics: Outgassing products known to contaminate mirrors.
- 6) Dyes
- 7) Epoxy Tra-Bond 2101: outgassing was measured by LIGO to be too high (note that this is not a low outgassing epoxy formulation)
- 8) Inks
- 9) Manganese bronze (aka brass): due to high zinc content
- 10) Oils and greases for lubrication
- 11) Oilite™ or other lubricant-impregnated bearings
- 12) Oriel MotorMike™ actuators filled with hydrocarbon oil, not cleanable
- 13) Palladium
- 14) Soldering flux
- 15) Stainless Steel, free-machining grades (303, 303S, 303Se): allowable only as small hardware components (nuts, bolts, washers), due to high sulfur or selenium content
- 16) RTV Type 615
- 17) Tellurium

11 References for the approved materials table

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