LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Specification	**LIGO-E960050-A -**	**E**	7-30-96

LIGO Vacuum Compatible Materials List

W. Young

Distribution of this draft:

LIGO

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (818) 395-2129
Fax (818) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

WWW: http://www.ligo.caltech.edu/

CHANGE RECORD				
Revision	*Date*	*Authority*	*Pages Affected*	*Item(s) Affected*
A	7/30/96	Initial Release	All	All

Organization/Group	*Name*	*Signature*	*Date*
Systems Engineering	Albert Lazzarini		
Detector System	Stan Whitcomb		
Detector System	Mike Zucker		
Facilities/Vacuum Equipment	Mark Coles		
Project Manager	Gary Sanders		

TABLE OF CONTENTS

List of Tables

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 "presently used materials" list have been installed into the prototype/R&D interferometers (i.e., the 40-meter interferometer at CIT and the 5-meter interferometer at MIT) and maybe used for LIGO preliminary designs. Presently used materials are deemed as “provisionally approved”.

2. APPLICATION

Materials can only be added to either the "approved" or "presently used" 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".

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.

With improved specifications and qualification procedures, and time (to be documented in the "LIGO Vacuum Compatibility, Cleaning Methods and Procedures" document), it is anticipated that provisionally approved materials will be transferred to the approved list. Provisionally approved materials shall be used sparingly and only as necessary, to minimize the impact of unforeseen contamination problems. At the same time, an effort shall be made to change the status of these materials to "approved" or to find replacement approved materials.

3. APPLICABLE DOCUMENTS

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

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 condensible or non-condensible) 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 the LIGO vacuum vessels or tubes, in the 40 meter prototype interferometer at CIT, and in the 5 meter research and development interferometer laboratory at MIT. 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 cm^2)

Materials	*conditions*	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*[1]	*outgassing concern(s)*[2]	*references*
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*	----	----	----	----	----	----	----	----
Stainless Steels (304)	unbaked	1.8E-8	1.8E-8	----	----	----	----	1
Stainless Steel (316)*	----	----	----	----	----	----	----	----
Titanium*	----	----	----	----	----	----	----	----
Tungsten	unbaked	1.95E-7	1.95E-7	----	----	----	----	3
Ceramics								

Table 1: Approved construction materials (all outgassing rates are in torr liter/sec cm^2)

Materials	***conditions***	J_{Total}	J_{water}	J_{H2}	J_{HC}	***applicable surface measurement[1]***	***outgassing concern(s)[2]***	***references***
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 mono-layer carbon by XPS assay	----	----
Glazed Ceramics (e.g., Porcelain)	Unbaked	1E-8	1E-8	----	----	----	----	1,4
<u>Crystalline materials</u>								
ADP*	----	----	----	----	----	----	----	----
Calcite*	----	----	----	----	----	----	----	----
Diamond*	----	----	----	----	----	----	----	----
Germanium*	----	----	----	----	----	----	----	----
KDP*	----	----	----	----	----	----	----	----
Quartz*	----	----	----	----	----	----	----	----
Sapphire*	----	----	----	----	----	----	----	----
Silicon Dioxide*	----	----	----	----	----	----	----	----
Tantalum Pentoxide (hard optical coating)*	----	----	----	----	----	----	----	----
<u>Glasses</u>								
Fused quartz*	----	----	----	----	----	----	----	----
Pyrex glass	unbaked	1.6E-10	1.6E-10	----	----	----	----	2

Table 1: Approved construction materials (all outgassing rates are in torr liter/sec cm^2)

Materials	*conditions*	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*[1]	*outgassing concern(s)*[2]	*references*
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.

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)

6. PRESENTLY USED MATERIALS

The following list of materials (Table 2) used in the 40m and the 5m Facilities presently used in the LIGO Project prototypes. At present, they are not approved for use on LIGO. 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 must be determined.

Table 2: Materials presently used in 40m and 5m laboratories.

Materials	*conditions*	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*[1]	*outgassing concern(s)*[2]	*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-Seal[3] epoxy	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Torr-Seal™ epoxy	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Conductors								
Non-OFHC copper[4]	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	----

Table 2: Materials presently used in 40m and 5m laboratories.

Materials	***conditions***	J_{Total}	J_{water}	J_{H2}	J_{HC}	***applicable surface measurement***[1]	***outgassing concern(s)***[2]	***references***
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	----
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	----

Table 2: Materials presently used in 40m and 5m laboratories.

Materials	*conditions*	J_{Total}	J_{water}	J_{H2}	J_{HC}	*applicable surface measurement*[1]	*outgassing concern(s)*[2]	*references*
Plastic insulators								
Kapton wire insulation	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----
Teflon PFA 440 HP (DuPont)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	----

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. 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

1. Dayton, B.B. (1960) Trans. 6th Nat. Vacuum Congress; p 101
2. Schram, A. (1963) Le Vide, No 103, p 55
3. Holland, Steckelmacher, Yarwood (1974) Vacuum Manual
4. Lewin, G. (1965) Fundamentals of Vacuum Science and Technology, p 72