***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S146**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **05/10/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled and submitted for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials. The analysis followed the ACL-120 procedure that complies with Mil-STD-1246C Notice 3 and is sensitive to the most stringent level (A/100).

Results and Discussion

The swabs removed *very low levels* of oily residue. A level of 1 microgram per square centimeter (μg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	**Chemical Functional Group**	**Amount** μg/cm^2
Air Bake1	Trace AHC	~ 0.02
Air Bake 2	AHC	0.03
Air Bake 3	Trace AHC	~0.02
Vacuum Bake 1	Trace AHC	~0.02
Vacuum Bake 2	Trace AHC	~0.02

AHC = Aliphatic hydrocarbon, base oil of common lubricants
Silicone = polydimethyl siloxane, typically from silicone based polymers.
Silica dust is common small grain dust.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S158**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **06/05/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled and submitted for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The swabs removed *very low levels* of oily residue (see ref. 2). A level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount µg/cm^2*
#1.	Trace AHC-amide	~0.02
#2	Trace AHC-amide	~0.02
#3	Trace AHC-amide	~0.02
#4	Trace AHC	~0.02
#5	Trace AHC-amide	~0.02
#6	Trace AHC-Ester	~0.02
#7	Trace AHC	~0.02
#8	Trace AHC	~0.02
#9	Trace AHC	~0.02
#10	Trace AHC-Ester	~0.02
Blank (ref 3)	-	-

** This is based on a 6"by 6" swab area*
AHC: Aliphatic hydrocarbon, base oil of common lubricants
AHC-amides: common antistatic agents
AHC-ester: common plasticizers, fingerprints

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and

Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or ~0.02 to 0.1 $\mu g/cm^2$ (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 $\mu g/cm^2$) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 $\mu g/cm^2$ of removed residue from a $100cm^2$ sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S182**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **07/12/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled and submitted (7/10/07) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The swabs removed *very low levels* of oily residue (see reference 2). Note a level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of $\rho = 1.0$).

Sample	Chemical Functional Group	Amount µg/cm^2
ISI-BSC Keel Weight DWS#047867-A S/N 26758-001 (area ½-13thrd hole)	Trace AHC	2.0 ug total (no area given)
ISI-BSC Keel Weight DWS#047867-A, S/N26758-002 (area ½-13thrd hole)	Trace AHC	0.7 ug total (no area given)
ISI BCS Keel Weight DWS#047867-A, S/N 26758-001 (flat end 6x6”)	Trace AHC	~0.02 µg/cm^2
ISI BCS Keel Weight DWS#047867-A, S/N 26758-002 (flat end 6x6”)	Trace AHC	~0.02 µg/cm^2
1 Frame Plate	Trace AHC	~0.5 ug total (no area given)
2 Frame Plate	Trace AHC	~0.5 ug total (no area given)
3 Frame Plate	Trace AHC	0.8 ug total (no area given)
4 Frame Plate	Trace AHC	~0.5 ug

		total (no area given)
Blank (reference 3)	-	-

AHC: Aliphatic hydrocarbon, base oil of common lubricants

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or ~0.02 to 0.1 μg/cm^2 (for ρ = 1). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 μg/cm^2) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 μg/cm^2 of removed residue from a 100cm^2 sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S183**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **07/13/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis: Part#20007846

Purpose

Part surfaces were swab-sampled and submitted (by Fedex 7/12/07 from Stephany Foley, MIT) for chemical analysis from part #20007846 Al-6061. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The swabs removed *very low levels* of oily residue (see ref. 2). A level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount
A	Trace AHC	~0.02 µg/cm^2
B	Trace AHC	~0.02 µg/cm^2
C	Trace AHC, Carbonate*	~0.02 µg/cm^2
D	AHC, Ester	2 µg total
E	AHC, Ester	53 µg total
F	AHC	1.5 µg total
G	AHC	1.3 µg total
H	**AHC**	**0.2 µg/cm^2**
I	Trace AHC	<0.01 µg/cm^2
J	Trace AHC	<0.01 µg/cm^2
K	AHC, Carbonate*	0.07 µg/cm^2 (AHC)
L	AHC, Carbonate *	0.07 µg/cm^2 (AHC)
M	Trace AHC	<0.01 µg/cm^2
N	Trace AHC	~0.02 µg/cm^2
Blank (ref 3)	-	-

AHC: Aliphatic hydrocarbon, base oil of common lubricants
Esters: commonly from plasticizers, fingerprints

µg/cm^2- micrograms per square centimeter
*Carbonates – commonly from water spots, this is not quantified in this test
References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 µg/cm^2 (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 µg/cm^2) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 µg/cm^2 of removed residue from a 100cm^2 sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S262**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **11/13/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted (11/12/07) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The sample #4 had a moderate level of aliphatic hydrocarbon oil. The other samples had relatively low levels of oily residue (2). A level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount * µg/cm^2
1	AHC	0.05
2	AHC	0.06
3	Trace AHC	~0.03
4	AHC, Trace Ester	**0.9**
5	Trace AHC	~0.02

AHC: Aliphatic hydrocarbon, base oil of common lubricants
Esters: commonly from plasticizers, fingerprints
µg/cm^2- micrograms per square centimeter
* Results based on 4in^2 (26cm^2)

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 $\mu g/cm^2$ (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 $\mu g/cm^2$) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 $\mu g/cm^2$ of removed residue from a $100cm^2$ sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S262**
Analytical Chemistry and Materials Development Group 3531

To: **Rusyl Wooley, Robert Taylor** **11/14/07**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The surfaces were all very clean with only trace levels of aliphatic hydrocarbon oil (2, 3). A level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount µg/cm^2
1	AHC	0.03
2	Trace AHC	~0.02
3	Trace AHC	~0.02
4	Trace AHC	~0.02
5	Trace AHC	~0.02
6	Trace AHC	~0.02
7	Trace AHC	~0.02
8. Outer O-ring Grove	Trace AHC	~0.02
9. Inner O-ring Grove	Trace AHC	~0.02
10. Surface O-ring Side	Trace AHC	~0.02
11. Center Conflat	Trace AHC	~0.02
12. Surface Conflat Side	Trace AHC	~0.02

AHC: Aliphatic hydrocarbon, base oil of common lubricants
µg/cm^2- micrograms per square centimeter

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and

Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 $\mu g/cm^2$ (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 $\mu g/cm^2$) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 $\mu g/cm^2$ of removed residue from a $100cm^2$ sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S269**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **12/3/2007**

From: Mark S. Anderson

Subject: LIGO Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted (12/3/07 via UPS urgent) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The samples had very low levels of oily residue (2). Note a level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount µg/cm^2
1	Trace AHC	~0.02
2	Trace AHC	~0.02

AHC: Aliphatic hydrocarbon, base oil of common lubricants
µg/cm^2- micrograms per square centimeter

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This “adventitious” carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 µg/cm^2 (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a “corrosion” layer. Therefore solvent based sampling methods may not remove these corrosion

fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 μg/cm^2) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 μg/cm^2 of removed residue from a 100cm^2 sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S270**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **12/5/2007**

From: Mark S. Anderson

Subject: LIGO Hanford: Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted (received 12/4/07 via Fed-Ex) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the JPL ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The samples all had very low levels of oily residue (2, 3). Note a level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount µg/cm^2*
1	AHC, Bray	0.08
2	Trace AHC	~0.02
3	Trace AHC	~0.03
4	Trace AHC	~0.02
5	Trace AHC	~0.02
6	Trace AHC	~0.02
7	Trace AHC	~0.02
8	Trace AHC	~0.02
9	Aliphatic Ester	0.09
10	Trace AHC	~0.02

* The results are based on a 6in^2 swab area.

AHC: Aliphatic hydrocarbon, base oil of common lubricants
Bray: perfluorniated polyether, base of braycote type lubricants
Aliphatic Ester: fingerprint residue
µg/cm^2: micrograms per square centimeter

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 $\mu g/cm^2$ (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 $\mu g/cm^2$) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 $\mu g/cm^2$ of removed residue from a $100cm^2$ sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S278**
Analytical Chemistry and Materials Development Group 3531

To: **Rusly Wooley, Robert Taylor, Helena Armandula** **12/13/2007**

From: Mark S. Anderson

Subject: LIGO: Molecular Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted (received 12/12/07 via Fed-Ex) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the JPL ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The samples all had very low levels of oily residue (2, 3). Note a level of 1 microgram per square centimeter (µg/cm^2) corresponds to an average film thickness of 100 angstroms (assuming a density of 1.0).

Sample	Chemical Functional Group	Amount µg/cm^2
Vial 3	AHC, Ester	~0.02 µg/cm^2
Vial 4	AHC, Ester	~0.02 µg/cm^2
Vial 5	AHC, Ester	~0.02 µg/cm^2
Vial 6	AHC, Ester	~0.02 µg/cm^2
Vial 7	AHC, Ester, OAS	~0.6 µg total
Vial 8	AHC, Ester, OAS	1.2 µg total
Vial 9	AHC, Ester, OAS	2 µg total
Vial 10	AHC, Ester, OAS	~0.6 µg total
Vial 11	AHC, Ester, OAS	~0.6 µg total
Vial 12	AHC	~0.5 µg total
Vial 13	AHC, OAS	~1.0 µg total
Vial 14	AHC, Ester, OAS	~0.5 µg total
Vial 15	AHC, Ester, OAS	~0.5 µg total
Vial 16	AHC	3 µg total
Vial 17	AHC, Ester, OAS	1.5 µg total
Vial 18	AHC	2.5 µg total

AHC: Aliphatic hydrocarbon, base oil of common lubricants
Bray: perfluorniated polyether, base of braycote type lubricants
Aliphatic Ester: fingerprint residue

OAS: Organic Acid Salt, soap cleaner residue
µg/cm^2: micrograms per square centimeter

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

2. The last mono-molecular layers are more complex to describe when cleaning or analyzing. Carbon/hydrocarbon based substances are known to rapidly (~1 hour) accumulate on most, if not all, freshly exposed surfaces. This "adventitious" carbon is well documented in clean rooms and vacuum systems and compositionally varies by environment. Adventitious carbon is a discontinuous layer of approximately ~0.2-1 nanometers thick or **~0.02** to 0.1 µg/cm^2 (for $\rho = 1$). The last mono-layer fractions may in some cases be strongly adsorbed to the surface as a "corrosion" layer. Therefore solvent based sampling methods may not remove these corrosion fractions. This is further complicated if the surface is porous. When specifying cleanliness level to less than level A/10 IEST-STD-CC1246D (0.1 µg/cm^2) these monolayer effects become more significant. See also: H. Piao and N. S. McIntyre, "Adventitious carbon growth on aluminum and gold–aluminum alloy surfaces", Surface and Interface Analysis, *Surf. Interface Anal.* 2002; 33: 591–594.

3. A typical solvent wipe has a detection limit of ~0.005 µg/cm^2 of removed residue from a 100cm^2 sample. Note this limit is well below the adventitious carbon level. Lower limits are possible using modified methods. The wipe blanks are at levels less than 10% the amount removed from the sample and this is subtracted from the reported sample amount. High blanks (greater than 10%) are noted in the report.

***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S279**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **12/14/2007**

From: Mark S. Anderson

Subject: LIGO Contamination Analysis

Purpose

Part surfaces were swab-sampled on site and submitted (12/13/07) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100). The powder elemental analysis was performed using an X-Ray Fluorescence Microscope (μXRF). This technique non-destructively excites the sample with high energy X-Rays and measures the energies and intensities of Fluorescence X-Rays emitted by the sample. This is sensitive to elements with the atomic number range from Na to U.

Results and Discussion

The samples 1 and 2 had relatively low levels of oily residue (2). Sample 3 (with dark powder) had AHC, mixed silicate dust residue and possible reduced carbon. No significant amount of aluminum was detected in the dark powdery sample.

Sample	Chemical Functional Group	Amount μg
SL 1	AHC	0.05
SL 2	AHC	0.06
3. with dark powder	AHC, Mixed silicate	~7 (AHC)

AHC: Aliphatic hydrocarbon, base oil of common lubricants
Mixed silicate: a mixture of silicates, a component of common dust
μg: micrograms

References

1. M. S. Anderson et al "Analysis of Semi-Volatile Residues Using Diffuse Reflectance Infrared Fourier Transform Spectroscopy" in Optical System Contamination: Effects, Measurements, and Control VII; July 2002, edited by Phillip T. C. Chen and O. Manuel Lee; Proceedings of the SPIE, Vol. 4774, pp. 251-261, (2002).

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***JPL* ANALYTICAL CHEMISTRY LABORATORY** **S285**
Analytical Chemistry and Materials Development Group 3531

To: **Robert Taylor, Helena Armandula** **12/20/2007**

From: Mark S. Anderson

Subject: LIGO Contamination Analysis: IST Tables and Risers

Purpose

Part surfaces were swab-sampled on site and submitted (12/19/07) for chemical analysis. This was to determine the level and identity of molecular (oily) contamination on the surface of parts.

Method

The analytical swabs consisted of extracted fiber-free lens tissue using Freon-TF solvent. The low volatility residue (LVR) was analyzed using Diffuse Reflectance/ Fourier Transform Infrared (DRIFT/FTIR) spectroscopy. FTIR provides chemical functional group information for quantitative analysis and qualitative identification of materials (1). The analysis followed the ACL-120 procedure that complies with IEST-STD-CC1246D and is sensitive to the most stringent level (A/100).

Results and Discussion

The areas are relatively clean in terms of oily molecular residue.

Sample	Chemical Functional Group	Amount
Vial 19 top center D071001 Stage 0 Base	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 21 bottom center D071001 Stage 0 Base	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 22 threaded hole D071001 Stage 0 Base	Aliphatic hydrocarbon	2.0 Total µg
Vial 23 helicoil D071001 Stage 0 Base	Aliphatic hydrocarbon	2.2 Total µg
Vial 24 top center D071051 Stage 1 Floor	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 25 bottom center D071051 Stage 1 Floor	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 26 threaded hole D071051 Stage 1 Floor	Aliphatic hydrocarbon	1.8 Total µg
Vial 27 helicoil D071051 Stage 1 Floor	Aliphatic hydrocarbon	14 Total µg
Vial 28 top center D071050 Table	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 29 bottom center D071050 Table	Aliphatic hydrocarbon	~0.02 µg/cm^2
Vial 30 threaded hole D071050 Table	Aliphatic hydrocarbon	1.0 Total µg

Aliphatic hydrocarbon: base oil of common lubricants
µg/cm^2: micrograms/square centimeter

References

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