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Effects of Spacecraft Material Outgassing on Optical Systems in the Vacuum Ultraviolet

W. T. Bertrand
Micro Craft Technology/AEDC Operations

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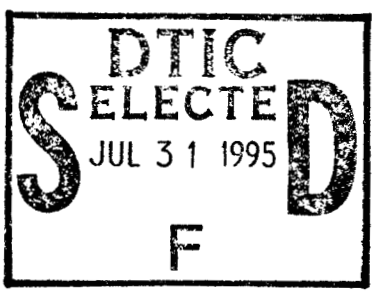

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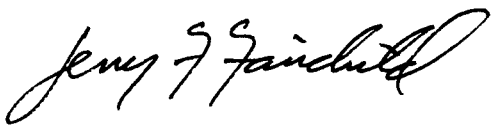

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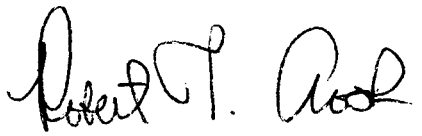

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A new facility for measurement of transmittance as a function of contaminant thickness in the vacuum ultraviolet spectral region is described in this report. A series of tests were completed to validate the operation of the chamber and the spectral diagnostic systems. Transmittance of contaminant films deposited on a window were measured for five typical spacecraft materials. System performance met design specifications, with the exception of the signal to noise in the short wavenumber spectral range (115-130 nm). This problem resulted from the degradation of the deuterium source lamp output. The reduced output was caused by the accumulation of contaminants on the lamp window. Periodic cleaning of the lamp window can eliminate this problem.

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PREFACE

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Materiel Command (AFMC) under Program Element 62102F. The results were obtained by Micro Craft Technology, support and technical service contractor of Flight Dynamics Test Facilities, Air Force Materiel Command, Arnold Engineering Development Center, Arnold Air Force Base, TN 37389-4300, under AEDC Project No. 0107. The AEDC Project Manager was Capt. F. Fairchild. This report was submitted for publication on June 14, 1995.

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ILLUSTRATIONS

1.0 INTRODUCTION

Contamination of optical surfaces is a major factor in determining the operation lifetime of spacecraft. The primary source of contaminants is the outgassing products of spacecraft materials on critical optical surfaces including mirrors, windows, solar cells, and thermal control surfaces. A surface effects facility has been established at Arnold Engineering Development Center (AEDC) to provide the spacecraft designer with optical property data for spacecraft material outgassing products.

Measurement capabilities have been developed to provide (1) solar absorptance changes on thermal control surfaces as a function of contaminant thickness and solar radiation exposure (Refs. 1-2); (2) contaminant film effects on solar cell efficiency (Ref. 1); (3) refractive and absorptive indices for contaminant films condensed on cryogenic optical surfaces (Refs. 3-5); and (4) bidirectional reflectance distribution function (BRDF) measurements for determining contaminant effects on mirror scatter (Ref. 6).

A new facility for measurement of transmittance as a function of contaminant thickness in the vacuum ultraviolet (VUV) spectral region is described in this report. Validation of chamber operation included the following items:

1. Operate chamber vacuum system and verify that chamber pressure can be maintained in the 10^{-5} torr range.

2. Operate the VUV spectrometer control and data acquisition system. Verify computer control of spectrometer spectral scan (speed and range) and slit setting; verify data acquisition specifications (signal levels, noise, repeatability); and determine stability of spectral source lamp.

3. Verify operation of sample positioning system and sample temperature control.

4. Develop and verify procedures for chamber operation and material testing.

5. Identify and procure five spacecraft materials for validation testing.

6. Test each material with sufficient measurements to determine optical effect as a function of contaminant thickness.

7. Develop and validate data reduction computer code with graphical output capability.

8. Reduce data and verify that results meet analysis requirements in terms of data quality and support to spacecraft design.

2.0 EXPERIMENTAL TEST APPARATUS

2.1 VACUUM ULTRAVIOLET TRANSMITTANCE MEASUREMENTS CHAMBER

The vacuum ultraviolet measurements chamber provides a capability for measuring changes in the transmittance of optical surfaces contaminated by outgassing products at vacuum conditions. The equipment also allows generation of the outgassing products within the chamber and the determination of the amount of material deposited on the sample surface using a QCM. The chamber and associated contamination equipment are shown in Fig. 1. The details of each of these systems are discussed separately in the following sections.

The VUV Chamber is 88 cm in diameter and 62 cm high. Vacuum is maintained by a 250 l/sec turbomolecular pump, and chamber pressure is measured with a Bayard-Alpert type ion gauge. The test apparatus can be maintained below 2×10^{-5} torr.

2.2 EFFUSION CELL

The outgassing products for contaminating the sample surface are generated by an effusion cell comprised of a 5.08-cm-long cylindrical aluminum body with a 6.99-cm-diam internal bore. One end is closed, while the other end has a replaceable orifice plate. The material used to produce the outgassing flux is loaded into the open end of the effusion cell, and heating elements around the outside of the cylinder are used to heat the effusion cell to the desired temperature, usually 125°C. A platinum resistance temperature detector (RTD) mounted in the effusion cell housing senses the effusion cell temperature. Output of the RTD feeds a proportional temperature controller which varies the power applied to the heaters, maintaining the effusion cell temperature within 1°C of the setpoint. The controller has an analog output from which the effusion cell temperature is recorded. The effusion cell is capable of maintaining temperatures from ambient to 200°C.

The effusion cell is lined with disposable aluminum foil liners. The liners and aluminum foil sample boat are baked at 125°C for 24 hours prior to each material test to ensure that the deposited contaminants come from the material being tested, and not the peripheral components. New aluminum foil liners and boats are installed after each material test.

The effusion cell can be retracted into an antechamber through a load lock in order to reload the cell while maintaining vacuum in the main chamber.

2.3 QUARTZ CRYSTAL MICROBALANCE (QCM)

A water-cooled QCM is used to measure the mass deposition on the sample surface. The QCM and the sample collecting surface are located equidistant from the effusion cell exit and symmetrically about the effusion cell axis.

A QCM is based on the principle that the oscillation frequency of a quartz crystal varies proportionally to its mass or any mass adhering to the crystal surface. The oscillation frequency is also dependent upon other things such as temperature. To compensate for temperature effects, the QCMs selected are made up of two quartz crystal oscillators in a single housing. The oscillator outputs are mixed, and their difference frequency is monitored. One crystal oscillator (the reference oscillator) is enclosed and shielded from contaminants, sensing temperature effects but not contaminants. One surface of the remaining quartz crystal oscillator is polished to an optical finish and overcoated with aluminum. This surface is exposed to the contaminant flow and is used as the mass sensing oscillator. The contaminant's accumulated mass is determined by the change in the two oscillator frequencies (i.e., the change in the difference frequency).

The relation between the difference frequency change (Δf) and the deposited mass (Δm) can be expressed as (Ref. 2)

$$\Delta m = 1.4 \times 10^{-9} \Delta f \ \text{gm/Hz} \tag{1}$$

or

$$\Delta m/S = 4.43 \times 10^{-9} \Delta f \ \text{gm/cm}^2\text{*Hz} \tag{2}$$

where S = surface area of the sensing crystal electrode, 0.316 cm^2. If a density of 1.0 gm/cm^3 is assumed for the film, then the change in film thickness (Δt) can be calculated from the frequency change (Δf) using the equation

$$\Delta t = 4.43 \times 10^{-9} \Delta f \tag{3}$$

where Δt is given in centimeters and f is given in Hertz. For the results presented, a density of 1.0 was assumed. Previous density measurements of DC6-1104, RTV-566, and Uralane films collected on an 80K surface varied from 0.8 to 0.96. No density measurements were obtained during this test.

Both quartz crystals have crystal cuts selected to minimize temperature effects at the selected operating temperature. In this case, the crystal cut is optimized for 25°C operation by using crystals with a cut of 35.2 deg. Temperature of the QCM is stabilized by flowing water through the QCM housing.

The QCM has a platinum RTD placed between the sensing and reference crystals that functions as both a temperature sensor and a low-power (2-W) heater through a time-sharing electronic circuit. In this way, the temperature of the crystals may be monitored, and small temperature changes may be made.

The QCM electronic controller has three analog outputs proportional to mass, temperature, and mass rate. In addition, the frequency can be sent to a counter or a frequency-to-voltage converter. The mass deposited on the sensing crystal is determined by recording the change in mass directly or by monitoring the difference frequency between the sensing crystal and the reference crystal.

2.4 CONTAMINATION DEPOSITION SURFACES

The 7.09-cm-diam, 6-mm-thick magnesium fluoride (MgF_2) window assembly can be remotely positioned perpendicular to the effusion cell or perpendicular to the optic axis. The window temperature (25°C for this test) is maintained by flowing water from a temperature-controlled bath through the mounting assembly.

2.5 TRANSMITTANCE MEASURING APPARATUS

A deuterium light source is used to illuminate the entrance slit of a McPherson 0.2-m vacuum ultraviolet monochrometer. The source radiation in the spectral region from 115 to 400 nm is shown in Fig. 2. As seen in Fig. 2, the output of the source lamp degraded with time. This effect is caused by the accumulation of contaminants on the lamp window. The output (7/14/94 curve) when system checkout began is compared to the output (10/11/94 curve) during the first material measurement and the output (1/10/95) during the last material measurement. Low signal to noise in the short wavelength region limited the usable data acquisition range from 130 to 400 nm. The radiation is modulated by a vacuum-compatible chopper to permit synchronization of the detector signal with a lock-in amplifier. Radiation is dispersed by a concave holographic grating and imaged on the monochrometer exit slit. An optical assembly attached to the exit slit is used to collimate or reimage the radiation inside the test chamber. After passing through the test window, the radiation is detected by a vacuum-rated photomultiplier. The detector signal is coupled to a lock-in amplifier by a current preamplifier.

2.6 DATA ACQUISITION AND CONTROL SYSTEM

A microcomputer with a hard disk and a floppy disk was used to control the monochrometer and to acquire and store the data from the measurements. The scan controller, slit controller, lock-in amplifier, and the computer are connected by RS232 communications. Software drivers permit on-screen control of all functions. Data manipulation subroutines are available for smoothing, subtraction of spectra, mathematical interpolation, and conversion to various formats.

3.0 EXPERIMENTAL TEST PROCEDURE

3.1 INTRODUCTION

Measurements of transmittance change with contaminant thickness were obtained for five spacecraft materials. The contaminating samples were prepared, installed in the VUV Chamber, heated to 125°C, and contaminants were condensed on the MgF_2 window. Contaminant thickness was monitored with the QCM measurements. When the thickness reached a predetermined value, the spectral transmittance of the contaminant film and window was measured and recorded. This procedure was repeated from two to four times for each material.

3.2 SAMPLE PREPARATION

Two types of spacecraft materials were tested. Materials prepared by mixing a base compound with a curing agent were RTV-566, Solithane, and Uralane. RTV-142 and DC6-1104 were one-part materials. The two-component samples were prepared as specified by the manufacturer and weighed to the specified mixing ratios. One component was added to a disposable aluminum mixing container, weighed, then the other component was added until the correct mixing ratio by weight was obtained. Measurements were made on an analytical balance capable of 0.1-mg precision. After preparation, the sample material was transferred to a previously outgassed and weighed aluminum foil boat. The material sample was cured according to manufacturer recommendations.

3.3 EFFUSION CELL PREPARATION

Prior to the first test of each type of material, the effusion cell interior was cleaned and a new foil liner was installed. The effusion cell was then outgassed under vacuum at 125°C for 24 hours.

3.4 QCM PREPARATION

The QCM was cleaned with ethyl alcohol and dried under vacuum. The QCM was mounted at a symmetric location with the same distance horizontally from the effusion cell aperture and vertically from the effusion cell centerline as the test surface.

3.5 WINDOW PREPARATION

Prior to the first test of each type of material the MgF_2 window was cleaned with a soap solution and rinsed with alcohol.

3.6 TRANSMITTANCE MEASUREMENT

The transmittance degradation test proceeded as follows:

1. Cooling water to the QCM and the window sample was turned on.

2. The material sample was installed in the effusion cell.

3. The VUV Chamber was closed and pumped down.

4. The sample window was positioned perpendicular to the radiation beam. A spectral scan of the clean window was completed.

5. The sample window was positioned to face the effusion cell.

6. The effusion cell temperature was increased to 125°C.

7. The contaminant buildup was monitored by observing the QCM frequency change. At the desired thickness, the window was positioned perpendicular to the radiation beam and a spectral scan of the window was completed. The sample window was positioned to face the effusion cell and the contamination of the window was resumed.

8. Repeat spectral measurements were made as desired.

4.0 MEASUREMENT RESULTS

To demonstrate operation of the new system, transmittance values of contaminant films deposited on the test window were measured for five typical spacecraft materials in the 130- to 400-nm spectral range. Data analysis was limited to comparison of the change in transmittance as a function of contaminant thickness for each material.

4.1 DOW CORNING 6-1104 SEALANT

Spectral transmittance scans for DC6-1104 sealant are shown in Fig. 3. Data were obtained for the clean window and for film thicknesses of 59, 236, 410, and 553 angstroms. Change in transmittance as a function of contaminant thickness is limited to the spectral range below 190 nm.

4.2 MORTON-THIOKOL SOLITHANE 113

Spectral transmittance scans for Solithane adhesive are shown in Fig. 4. Data were obtained for the clean window and for film thicknesses of 79, 114, 286, and 401 angstroms. Change in transmittance as a function of contaminant thickness is seen across the full spectral range.

4.3 GENERAL ELECTRIC RTV-142

Spectral transmittance scans for RTV-142 silicon rubber are shown in Fig. 5. Data were obtained for the clean window and for film thicknesses of 80 and 262 angstroms. Change in transmittance as a function of contaminant thickness is seen across the full spectral range.

4.4 FURANE PRODUCTS URALANE® 5753-A/B(LV)

Spectral transmittance scans for Uralane casting compound are shown in Fig. 6. Data were obtained for the clean window and for film thicknesses of 93, 227, and 640 angstroms. Change in transmittance as a function of contaminant thickness is seen across the full spectral range.

4.5 GENERAL ELECTRIC RTV-566

Spectral transmittance scans for RTV-566 silicon rubber are shown in Fig. 7. Data were obtained for the clean window and for film thicknesses of 80 and 262 angstroms. Change in transmittance as a function of contaminant thickness is limited to the spectral range below 230 nm.

5.0 CONCLUDING REMARKS

A new facility for measurement of transmittance as a function of contaminant thickness in the vacuum ultraviolet spectral region is described in this report. A series of tests were completed to validate the operation of the chamber and the spectral diagnostic systems. Transmittance of contaminant films deposited on a window were measured for five typical spacecraft materials. System performance met design specifications with the exception of the signal to noise in the short wavenumber spectral range (115–130 nm). This problem resulted from the degradation of the deuterium source lamp output. The reduced output was caused by the accumulation of contaminants on the lamp window. Periodic cleaning of the lamp window can eliminate this problem.

Future improvements to this system will include the addition of the capability to make bidirectional reflectance distribution function (BRDF) measurements as a function of contaminant thickness.

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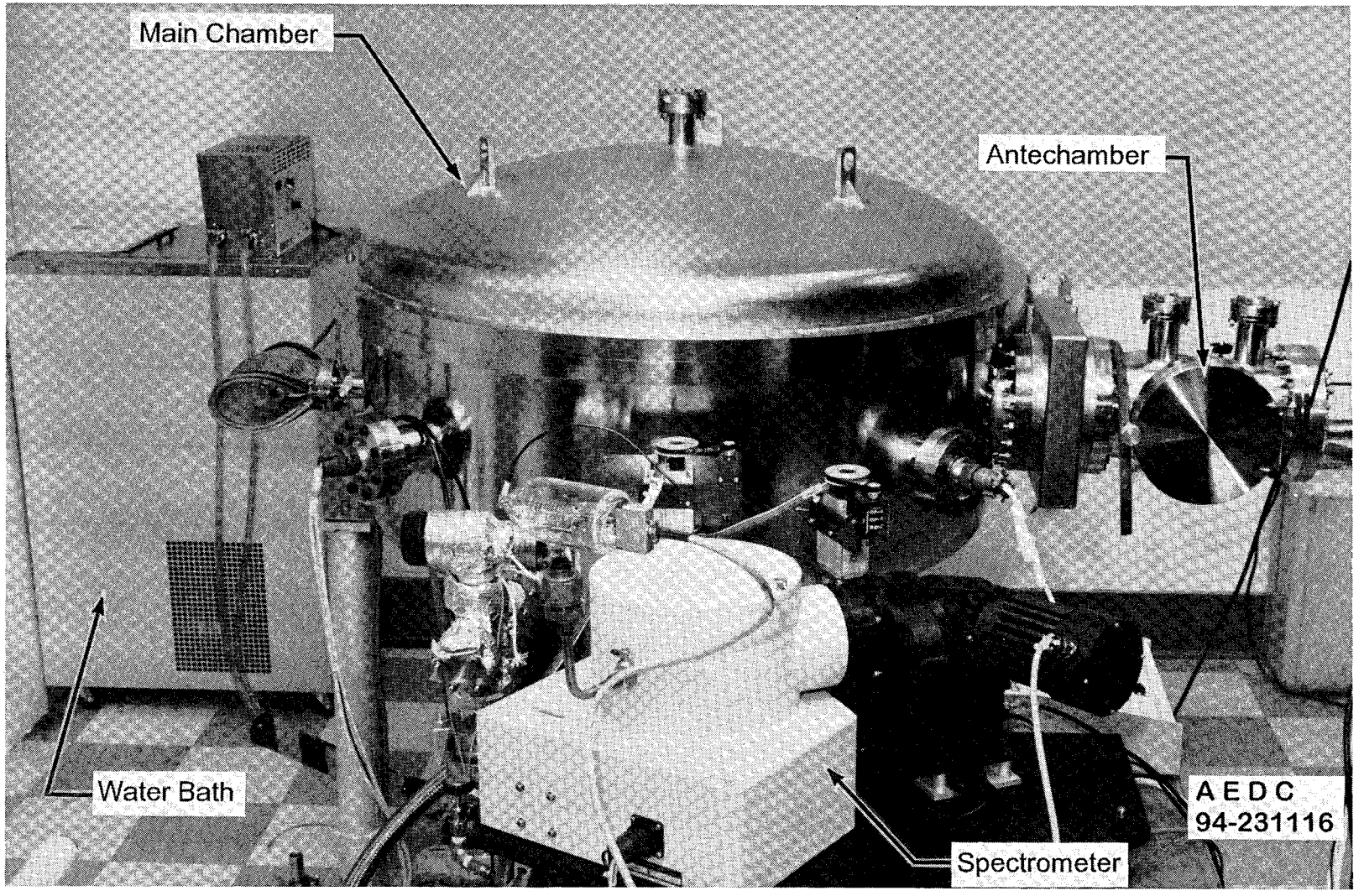

Figure 1. Vacuum Ultraviolet Measurements Chamber.

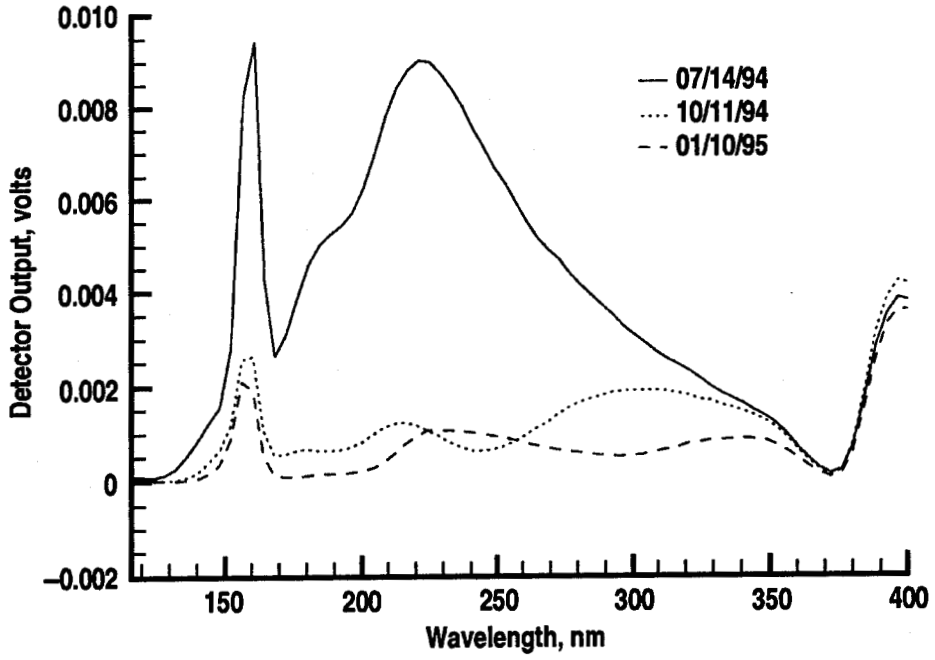

Figure 2. Deuterium lamp spectra.

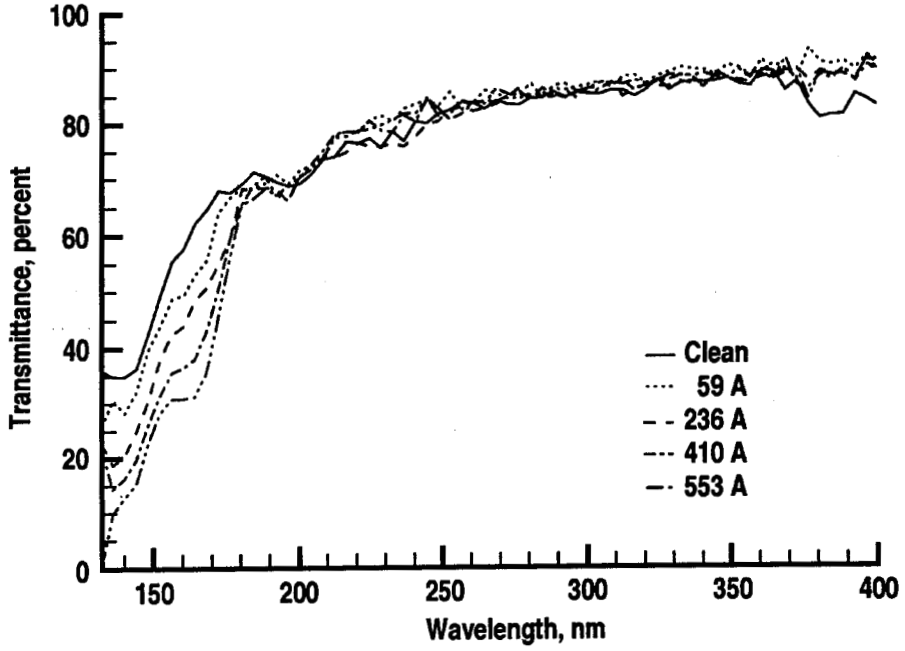

Figure 3. Transmittance as function of DC6-1104 film thickness.

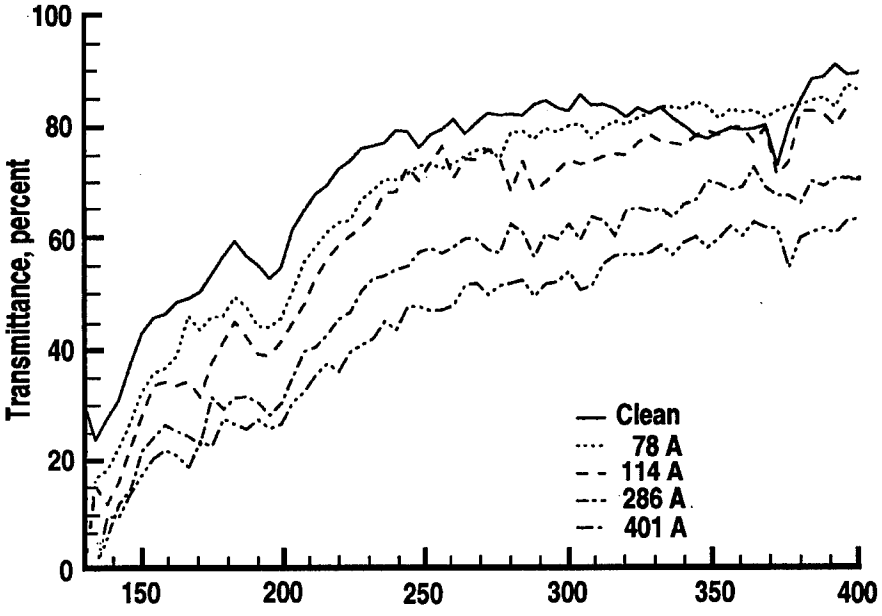

Figure 4. Transmittance as function of Solithane film thickness.

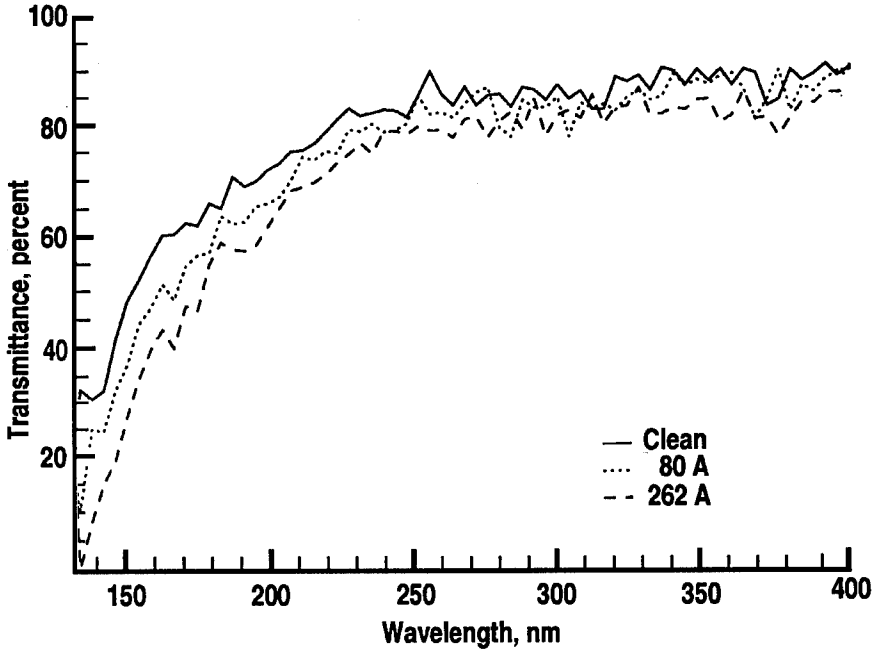

Figure 5. Transmittance as function of RTV-142 film thickness.

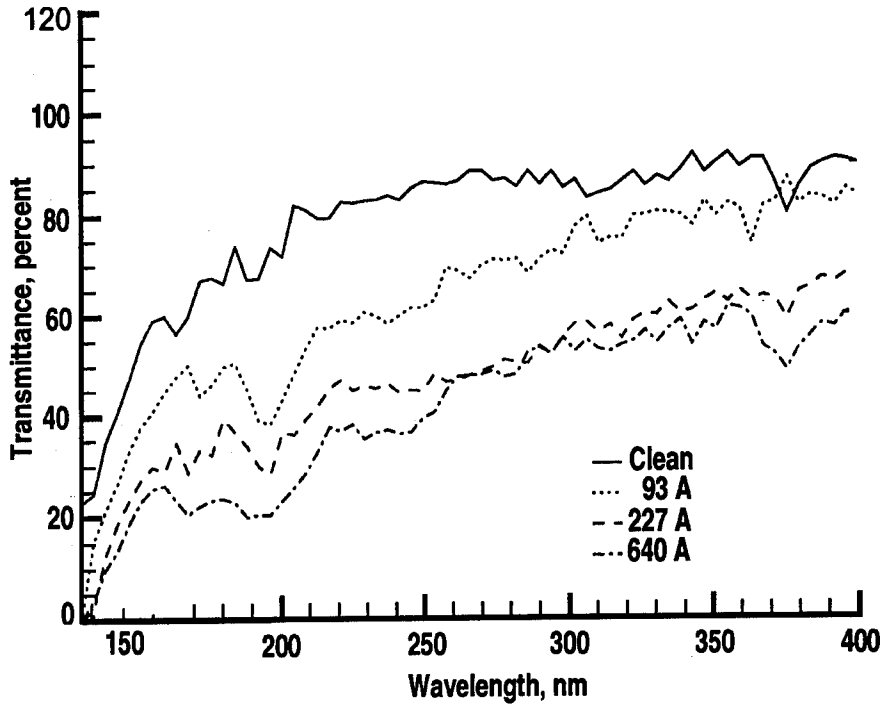

Figure 6. Transmittance as function of Uralane® film thickness.

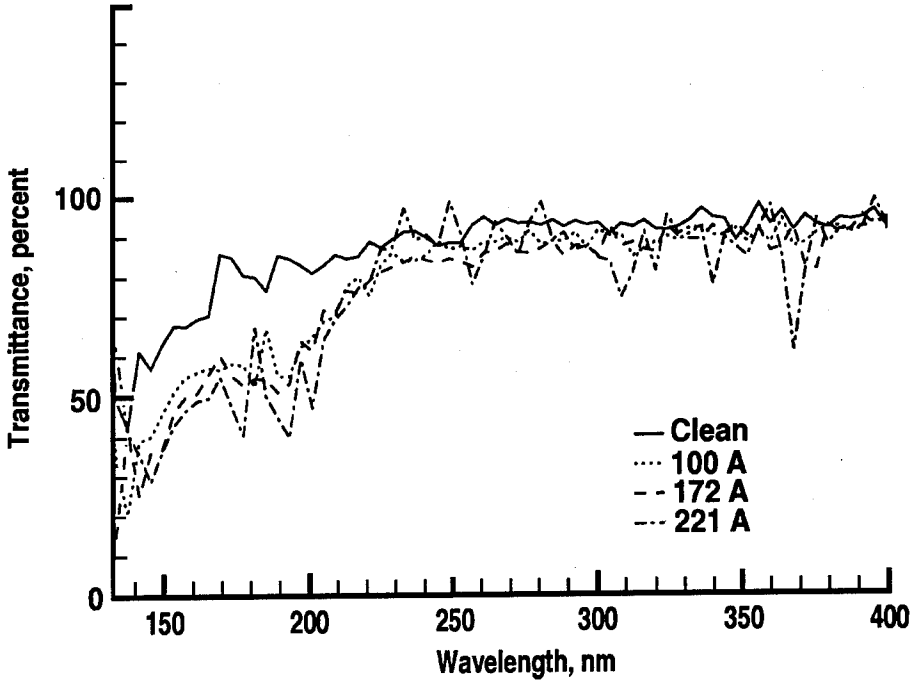

Figure 7. Transmittance as function of RTV-566 film thickness.