Topical Meeting on

Optics in Adverse Environments

TOPICAL MEETING ON

OPTICS IN ADVERSE ENVIRONMENTS

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WEDNESDAY, FEBRUARY 11, 1987

BALLROOM LOBBY

7:30 AM–4:00 PM REGISTRATION

BALLROOM B

8:30–9:45 AM
WA, SESSION 1
W. Howard Lowdermilk, *Lawrence Livermore National Laboratory, Presider*

8:30 AM (Invited Paper)
WA1 Environmental Impacts on the Hubble Space Telescope, Terence A. Facey, *Perkin-Elmer Corporation.* This paper reviews the more significant environment factors that influence the observatory's performance, and the precautions taken during assembly operations to minimize their effects. (p. 2)

9:00 AM (Invited Paper)
WA2 Ultralightweight Optics in a Cryogenic Environment, David A. Crowe, *Eastman Kodak Company.* This paper addresses the mount attachment and mount issues related to optical design to minimize degradation of the ultralightweight mirror at 100 K with and without a kinematic mount support and mirror attachments. Key issues demonstrated by this task are: mirror optical performance room temperature to 100 K, strain-free mirror mount attachment (glass/metal), and flexured kinematic mount design. (p. 6)

9:30 AM
WA3 Learjet Observatory Operations in The Tropics, Paul H. Hagen, *Teledyne Brown Engineering;* M. G. Dix, *NASA Ames Research Center;* R. W. Russell, G. S. Rossano, D. K. Lynch, J. A. Hackwell, R. J. Rudy, D. A. Retig, *Aerospace Corporation;* P. Alvarez, Jr., *Northrop Services, Inc.* Tropical operation of an airborne sealed open-port infrared telescope presents problems related to salt corrosion, freezing/thawing, vacuum window degradation, and elevated mirror emissivity. (p. 7)

BALLROOM LOBBY

9:45 AM–10:30 AM COFFEE BREAK

BALLROOM B

10:30 AM–12:00 M
WB, SESSION 2
Joseph H. Apfel, *Optical Coating Laboratory, Inc., Presider*

10:30 AM (Invited Paper)
WB1 Advanced Optics Fabrication Trends, William J. Kaveney, *RADC/OCSE (p. 10)*

11:00 AM (Invited Paper)
WB2 Materials for Space Optics, Bruce Pierce, *Strategic Defense Initiative. (p. 11)*

11:30 AM
WB3 Optical Fabrication Using Ion-Beam Figuring, S. R. Wilson, A. C. Barron, J. R. McNeil, *U. New Mexico.* Ion-beam figuring is a practical, efficient technique for figuring large optical components. Practical issues and performance data for a 30-cm figuring system are discussed. (p. 12)

WEDNESDAY, FEBRUARY 11, 1987—*Continued*

11:45 AM
WB4 Holography in Adverse Environments, J. Surget, *Office National d'Etudes et de Recherches Aerospatiales, France.* Holography is used for both recording an unapproachable phenomenon and restoring the 3-D real image ultimately allowed to any classical image data treatment. (p. 16)

BALLROOM B

1:30–3:00 PM
WC, SESSION 3
Benjamin Snavely, *Eastman Kodak Company, Presider*

1:30 PM (Invited Paper)
WC1 Optics for the Free Electron Laser, Thomas J. Karr, *Lawrence Livermore National Laboratory. (p. 20)*

2:00 PM
WC2 All-Metal Resonator Design for Visible/Near IR Free-Electron Laser Oscillators, Brian Newnam, *Los Alamos National Laboratory. (p. 21)*

2:15 PM (Invited Paper)
WC3 Cooled Optics for High Powered Laser Applications, Patrick J. Pomphrey, *TRW. (p. 23)*

2:45 PM
WC4 Impinged Droplet Evaporative Cooling for Optical Mirrors Subjected to High Thermal Flux Loads, John A. Wellman, John J. Meyers, *Eastman Kodak Company.* Utilization of evaporative cooling for optical mirrors subjected to high thermal flux loads has been investigated. Analytical and experimental results show advantages over convective cooling. (p. 24)

BALLROOM LOBBY

3:00–3:30 PM COFFEE BREAK

BALLROOM B

3:30–5:00 PM
WD, SESSION 4
Patrick Pomphrey, *TRW, Presider*

3:30 PM
WD1 Radiation Effects in Optical Components, E. J. Friebele, *U.S. Naval Research Laboratory.* The performance of optical components is often severely degraded by exposure to radiation, usually due to the formation of defect centers. This paper reviews the effects of radiation on thin film coatings, transmissive optics, and mirror substrate materials. (p. 26)

4:00 PM
WD2 Gamma Radiation-Induced Absorptions in Calcium Fluoride, C. W. King, O. H. Nestor, *Harshaw/Filtrol Partnership.* Changes in the transmission characteristics of calcium fluoride are investigated while varying the exposure to gamma radiation. Experimental results are presented and discussed. (p. 30)

WEDNESDAY, FEBRUARY 11, 1987—*Continued*

4:15 PM
WD3 Variation of the Index of Refraction in Glasses Exposed to Ionizing Radiation, Thad J. Englert, Mark C. Flohr, *U. Wyoming.* The index of refraction of optical quality glasses has been found to increase slightly with very moderate gamma-ray exposures. (p. 33)

4:30 PM
WD4 Radiation Damage to Dielectric Mirrors, Francis B. Harrison, *Los Alamos National Laboratory.* Multilayer dielectric mirrors showed no significant degradation under 120 MW/cm^2 of KrF light simultaneous with 10^{13} rads/s of ionizing radiation. (p. 37)

4:45 PM
WD5 Effect of Surface Pitting on Scattered Light in Transparent Domes, Douglas W. Ricks, *U.S. Naval Weapons Center.* The transmittance, total integrated scatter, and near-angle scatter from several environmentally pitted glass domes have been measured and are compared. (p. 41)

BALLROOM C

6:30 PM CONFERENCE BANQUET
Colonel Lawrence L. Gooch, *Kirtland Air Force Base, Speaker*

THURSDAY, FEBRUARY 12, 1987

BALLROOM LOBBY

7:30 AM–4:00 PM REGISTRATION

BALLROOM B

8:30–10:00 AM ThA, SESSION 5
Alan F. Stewart, *U.S. Air Force Weapons Laboratory, Presider*

8:30 AM (Invited Paper)
ThA1 High Damage Threshold Optical Coatings, D. Milam, *Lawrence Livermore National Laboratory.* Damage experiments with 20-ns pulses at rates up to 100 Hz indicate that some coatings survive fluences to 20 J/cm^2 at both 351 and 1064 nm. (p. 40)

9:00 AM
ThA2 Fluorine Resistance of Dielectric Coatings for Excimer Laser Optics, S. Foltyn, J. Boyer, G. Lindholm, K. Padgett, *Los Alamos National Laboratory. (p. 48)*

9:15 AM
ThA3 Porous Halide Antireflective Coatings for Adverse Environments, Ian M. Thomas, *Lawrence Livermore National Laboratory.* Porous magnesium and calcium fluoride coatings have been prepared from colloidal suspensions in methanol. These have excellent optical performance and high laser damage thresholds. (p. 49)

9:30 AM
ThA4 Auger Analysis of Elemental Depth Profiles Correlated with Multipulse Laser Damage of GaAs Surfaces, Dhiraj K. Sardar, Michael F. Becker, Rodger M. Walser, *U. Texas at Austin.* We study multipulse laser (10 ns, 10 Hz and 1064 nm) damage of GaAs. Damage morphologies, dependence on accumulated energy, and Auger analysis of elemental depth profiles are presented. (p. 52)

9:45 AM
ThA5 Compressive Coatings on Optical Components for Improving Mechanical Durability and Increasing Strength, J. E. Marion, *Lawrence Livermore National Laboratory.* Based on our theoretical and experimental studies, we have developed compressive coatings for slab laser components. The coatings significantly increase mechanical durability and give moderate strengthening. (p. 56)

BALLROOM LOBBY

10:00–10:30 AM COFFEE BREAK

BALLROOM B

10:30 AM–12:00 M
ThB, SESSION 6
Brian E. Newnam, *Los Alamos National Laboratory, Presider*

10:30 AM (Invited Paper)
ThB1 Natural and Induced Space Radiation Effects on Coated Laser Optics, T. M. Donovan, *U.S. Naval Weapons Center.* The results of pulsed x-ray experiments are compared with calculations of predicted melt and thermomechanical damage and discussed in the light of pulsed laser experiments. (p. 62)

11:00 AM
ThB2 Increased Visible Absorptance of Visible Reflectors due to Ultraviolet Radiation, Stephen Browning, Robert Young, *Optical Coating Laboratory, Inc.* Laser reflectors experience reversible performance degradation when exposed to ultraviolet light. Cavity ring-down lossmeter measurements show this to depend on ambient humidity, deposition conditions, and wavelength. (p. 63)

11:15 AM
ThB3 Ultraviolet Degradation of Ring Laser Gyroscope Mirrors, Austin Kalb. (p. 67)

11:30 AM
ThB4 Damage Threshold and Environmental Durability of Oxide Coatings Deposited Using Ion-Assisted Deposition, James J. McNally, *U.S. Air Force Academy;* J. R. McNeil, *U. New Mexico.* The effects of ion bombardment during deposition of Ta_2O_5, Al_2O_3 and SiO_2 thin films are presented. Laser damage, environmental durability, abrasion resistance, and fluorine gas durability results are reported. (p. 68)

11:45 AM
ThB5 Ion-Assisted Deposition of Optical Coatings at Low Temperature and Effects of Ar^+ Bombardment and Temperature on Heavy Metal Fluoride Glass, Forrest L. Williams, D. W. Reicher, J. R. McNeil, *U. New Mexico;* J. J. McNally, *U.S. Air Force Academy;* G. A. Al-Jumaily, *Barr Associates, Inc.* Ion-assisted deposition of optical coatings at low temperature and effects of Ar^+ bombardment and temperature on the crystalline phase of heavy metal fluoride glass are reported. (p. 72)

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BALLROOM B
8:30 A.M.–9:45 A.M.

WA1–3

SESSION 1

W. Howard Lowdermilk, Lawrence Livermore National Laboratory, *Presider*

Environmental Impacts on the Hubble Space Telescope

Terence A. Facey
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Danbury, Connecticut.

Introduction

The Hubble Space Telescope represents the largest single advance in astronomical instrumentation since the Hale 5 metre telescope at Mt Palomar. Its extreme sensitivity and resolution, however, are susceptible to degradation from a number of environmental effects. This is particularly true for observations in the ultra-violet spectrum.

Environmental factors range from dust, humidity and aerosols in the atmosphere on the ground, through the stresses and acoustic fields of the launch phase, to the thermal-vacuum rigors of the space environment itself.

Given reasonable thermal control, the near Earth orbital environment is quite benign. Essentially contamination free, and with no light pollution, space provides an almost ideal base from which to conduct astronomical observations.

The stresses of launch, too, can be overcome by reasonable design. Once the system has been designed and verified to withstand the acceleration, vibration and acoustic loads of the launch vehicle, the launch environment poses no real threat to observatory performance.

On the ground, however, during manufacture and assembly operations, there are a number of environmental factors which can significantly impact the future performance of the observatory. The two most important of these, in terms of their potential damaging impact, are dust and humidity in the atmosphere.

Atmospheric dust.

Dust particles, settling out from the atmosphere and accumulating on the surface of the mirrors will degrade performance in a number of ways. The obscuration of the primary mirror is a direct reduction in optical throughput. The small apertures have a diffraction pattern many times the full aperture diffraction limit, so light is scattered from a bright source into neighboring faint images. The particles scatter over wide angles to illuminate the telescope baffles from bright sources adding more photons to the focal plane background.

Inevitably, in the construction of a large telescope, a lengthy period of time elapses between coating the mirrors and final completion of the telescope assembly. Of course, all operations subsequent to the coating are performed in a well controlled clean room. However, no clean room is perfectly clean, and the long duration of the assembly process makes some accumulation of dust on the optics unavoidable. In the case of Space Telescope, the primary mirror was coated in December 1981. The Optical Telescope Assembly (OTA) was completed in October 1984. During the intervening three years the mirror surface could not possibly improve - it could only deteriorate by the accumulation of contaminants.

Besides doing all assembly work in a class 10k clean room - and much subassembly work in class 1k or class 100 areas - all items of flight hardware were surface cleaned prior to their integration into the OTA.

The large light baffles, in particular, were cleaned by repeated acoustic exposure and vacuum cleaning. Their large size and close proximity to the optics make them the dominant contamination source in subsequent environmental testing, unless special care is taken in their cleaning.

Use of clean rooms, rigorous procedural control of operations and careful cleaning of hardware were all necessary - but they were not sufficient. The need for long labor intensive assembly operations in the immediate vicinity of the primary mirror, and the need to have the mirror resting face up for long periods of time made some accumulation of dust on its surface inevitable, even though it was covered most of the time.

Measurements made a year or so after the coating showed the beginning of a particulate layer which might eventually adversely affect ultra-violet sensitivity of the observatory.

A cleaning plan was developed, which would allow us to "vacuum clean" the mirror surface at the latest possible time in the assembly cycle. Thereafter, the mirror would be kept covered right up to integration with the space shuttle at Kennedy Space Center.

The special cleaning tool involved the combination of nitrogen gas jets to dislodge the particles, and a vacuum hose to suck away the debris. For the cleaning operation, the mirror was suspended face down. The cleaning head was mounted to a special carriage, which allowed the whole mirror surface to be cleaned from underneath. The cleaning was conducted during June of 1984, just prior to completion and delivery of the OTA in October. Subsequent measurements of surface particulates showed the cleaning operation to have been highly successful.

Later in the Space Telescope assembly sequence, and after the environmental tests, particulate measurements by LMSC in May of 1986 still showed very little particle contamination.

Humidity

High levels of humidity could damage the Magnesium Fluoride coatings on the mirrors. However, this was protected against by the clean room environment, in which the Relative Humidity is controlled to be below 50% at all times.

In addition to the mirrors, though, the large telescope structures are also susceptible to moisture. The major structures, and all of the optical benches, are made of graphite-epoxy. This material, chosen for its light weight, high stiffness and low expansion coefficient, is hygroscopic.

The behavior of graphite epoxy is a little like another, more common, composite material: wood. As it absorbs moisture, the material swells, and as it dries out, it shrinks again. This effect is bad enough in the floor boards of your house, but in the alignment critical structures of an astronomical telescope, it could be a disaster!

Metering Truss

The metering truss is an all graphite structure, 5 metres long by 2.5 metres in diameter. Its function is to support the secondary mirror and keep it properly aligned on the optical axis of the telescope and 4.9 metres in front of the primary mirror vertex within +/- 0.000002 metres (2 micrometres).

On the ground, in a 50% RH environment, the graphite absorbs water equal to about 0.4% of its weight. Once in space, this water will slowly evaporate from the graphite, causing the truss to shrink a total of about 350 micrometres.

In such a large structure, it is virtually impossible to prevent the absorption of water. It would take a long time to dry it out prior to launch, and would be impossible to keep dry right up to launch - especially in the high humidity of the KSC area.

Rather than prevention, in this case we opt in favor of symptomatic relief. The telescope can be refocused from the ground, by using on board wavefront sensors to determine optical image quality, and secondary mirror position actuators to realign the system. Test data and analyses have yielded a fairly good model of water desorption from the truss as a function of time and temperature. This model can be further refined early in the mission, by measuring focus errors as a function of time in orbit. Thereafter, it will be possible to make open-loop focus adjustments periodically. More accurate measurements of focus error and appropriate corrections can be made less frequently.
,cp4
Fine Guidance Sensor Optical Bench

Similar expansion and contraction occurs in the FGS optical bench. This bench is the precision support for the more than 30 elements in the FGS optical train. The purpose of the FGS is to measure telescope pointing errors on the order of 15 nanoradians, and to do this repeatably over long periods of time. Clearly, structural distortions of its optical bench could compromise that ability.

The design of the FGS takes advantage of symmetry wherever possible to minimize the effects of mechanical growth - whether from moisture or thermal effects. Some residual moisture sensitivity remains, however. This is ameliorated by performing the final alignment in as dry an environment as possible (RH <25%) and checking the performance in a thermal vacuum chamber after it has had time to dry out. Afterward, the graphite may re-absorb water from the atmosphere, but when launched into space it will again dry out and become realigned in the process.

Management of graphite absorption and desorption is made easier in the case of the optical bench, by the shorter time constants involved. Since the graphite epoxy section thicknesses are small, the material absorbs and desorbs more rapidly than the metering truss, which can take weeks to dry out completely.

Conclusion

Environmental impacts on the Hubble Space Telescope are dominated by ground environment factors. The most important of these are associated with the atmosphere. Air-borne particulates and atmospheric humidity both present significant challenges to the assembly of a large high quality astronomical observatory. It is possible to meet these challenges, however; often not by preventing the environmental impact, but by learning to live with it.

ULTRA LIGHTWEIGHT OPTICS IN A CRYOGENIC ENVIRONMENT

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A high performance infrared spaceborne telescope such as the Space Infra-Red Telescope Facility (SIRTF) will require aspheric optical forms with smooth, low-scatter surface, high performance coatings, and an ultra-lightweight design approach that can perform from room temperature to cryogenic temperature. The design approach must not only be rugged, low risk, and reliable, but also capable of surviving a launch environment and enduring in space for many years. A design approach, which meets performance requirements at cryogenic temperatures employing passive mirrors (without figure control actuators, sensors, electronics, etc.), offers significant advantage in weight, performance, and reliability.

For several years, Kodak has been engaged in developing passive fused silica mirrors which meet stringent weight budgets and optical figure quality requirements from room temperature to cryogenic temperature. This capability has been successfully demonstrated with ultra-lightweight fused silica, frit bonded mirrors with and without broadband multilayer high reflectance coating up to diameters of 0.5 meters. Technical issues addressed and resolved include the design and manufacture of ultra-lightweight frit mirrors, CTE match, bond strength, CTE homogeneity, polishing to diffraction limited quality, optical stability, optical performance at cryogenic temperature and coating performance.

The next logical step in this technology evolution is to demonstrate the optical performance of these new generation ultra-lightweight mirrors kinematically mounted and subjected to cryogenic environment. This paper addresses the mount attachment and mount issues related to optical design to minimize degradation of the ultra-lightweight mirror at 100° Kelvin with and without a kinematic mount support and mirror attachments. Key issues demonstrated by this task are: (1) mirror optical performance room temperature to 100° Kelvin, (2) strain-free mirror mount attachment (glass/metal), and (3) flexured kinematic mount design.

Learjet Observatory Operations in The Tropics

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Tropical operation of an airborne sealed open-port infrared telescope presents problems related to salt corrosion, freezing/thawing, vacuum window degradation, and elevated mirror emissivity.

NOTES

WEDNESDAY, FEBRUARY 11, 1987

BALLROOM B
10:30 A.M.–12:00 M

WB1–4

SESSION 2

Joseph H. Apfel, Optical Coating Laboratory, Inc.,
Presider

WB1

Advanced Optics Fabrication Trends

William J. Kaveney
RADC/OCSE