The Cleanliness Control Program for SUMER/SOHO

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ABSTRACT

An overview of the cleanliness control activities is given for the solar EUV instrument SUMER/SOHO. Results of contamination effects studies, both theoretical and experimental, are summerized, and from these, cleanliness requirements for the instrument and the EUV mirrors in particular are derived. Specific design characteristics implemented to comply with these requirements, aiming at prolonged performance under irradiation by solar photon and particle flux, are highlighted. Monitoring the contamination of flight hardware and facilities make use of advanced techniques. For verification of mirror efficiencies and reflection characteristics of materials an EUV reflectometer has been built. Unique feature if this apparatus is a high photon flux light source in a UHV environment.

1 INTRODUCTION

SUMER is a high-resolution far-ultraviolet spectrometer which is designed to operate as part of the Solar and Heliospheric Observatory (SOHO) in the wavelength range of 50 to 160 nm. The joint ESA/NASA mission is to be launched in 1995 with a baselined observation period of 2 years. The instrument combines good image quality and high spectral resolution using the optical scheme depicted in Fig. 1 (see also Wilhelm et al. 1989). A single mirror telescope images the Sun onto the entrance slit of the spectrometer. Light from the slit is collimated and directed to a scan mirror and a spherical concave grating which produces a stigmatic image of the slit in the detector plane. Mirrors are made from SiC substrates with SiC/CVD surface cladding for best reflectivity at normal incidence in the far ultraviolet range. The two-dimensional imaging detector (Multi Anode Microchannel Array Detector) has a pixel size corresponding to 1 arcsec in spatial direction and 4 pm spectral resolution in first order (2 pm in second order) of the grating.

Many solar ultraviolet instruments developed during the last 15 years have suffered significant performance degradation after deployment in space due to contamination. Once an instrument is in orbit, it is not easily possible with current technology to reclean the optics or to take any measures to recover the instruments performance.

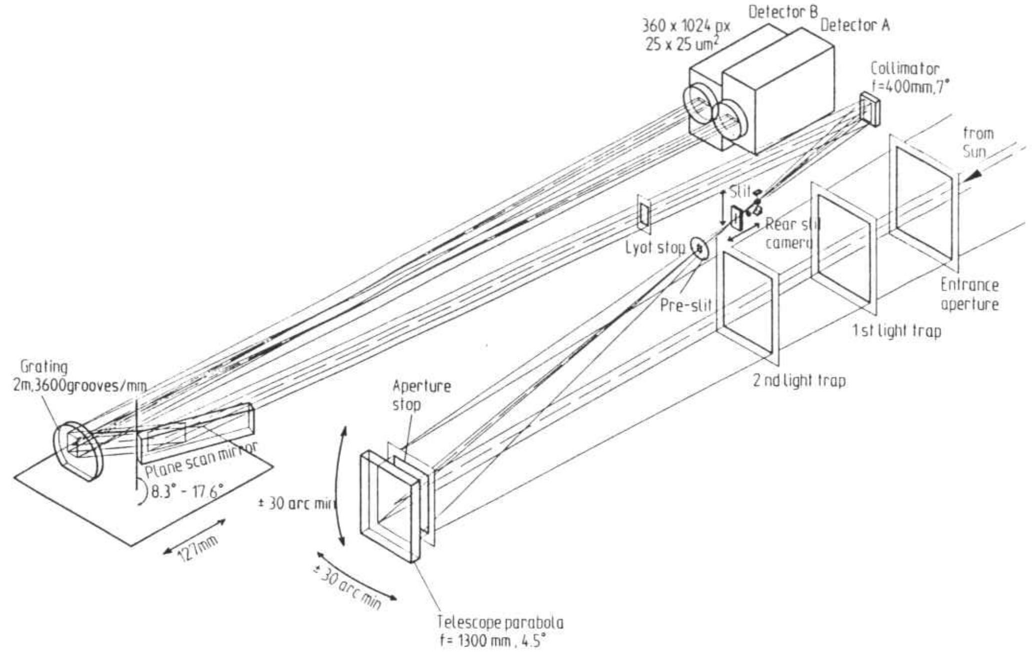


Fig. 1 – Schematic optical layout of the SUMER instrument.

The optical design of SUMER, using two normal-incidence mirrors, one grazing-incidence mirror and a concave grating, renders this instrument very sensitive to contamination of particulate or molecular nature. In addition, the combined effects of organic species and high flux of solar radiation is known to produce irreversible deposition of contaminants on sunlit surfaces by photochemical activation and subsequent polymerization (Steward 1989). The telescope mirror, therefore, is in general the most sensitive part of a solar EUV instrument, and the strong degradation of previous solar ultraviolet instruments can be attributed to this effect (Lemaire 1991).

Prevention and control of contamination is thus a major effort, which has to be carried through the entire program, yet different program phases require specific strategies: Most importantly, at the design phase preventive design considerations can still be implemented that avoid or at least reduce contamination that mainly occures at the last phase, when the instrument is delivered to the space environment. Here, cleanliness oriented operation can significantly reduce contamination by, e.g., closing an aperture door during inactive periods, thereby reducing the total time of UV irradiation while venting can still proceed.

The contamination control program carried out for SUMER included several studies to assess the effects on the optical performance imparted by contamination expected during exposure to solar EUV flux and solar wind particles, self-contamination by dust particles and outgassing organic condensables, as well as combined effects of the above. The results led to the implementation of preventive measures in the design of the instrument and stringent contamination control activities. Here we present the results of contamination studies, and we outline specific measures to prevent and control the contamination of the EUV instrument.

2 CONTAMINATION EFFECTS STUDIES

In a first, theoretical, study all possible sources of contaminants have been considered and their expected degrading effect on the instrument performance been estimated. According to these results cleanliness requirements were established. The components most sensitive to degradation by contaminants are the mirrors, and the expected degrading effects set the limit to the acceptable amount of contaminants. The most severe degrading effect on the instruments performance is change of reflectance of the mirrors by absorption, obscuration, and increase of scatter. Absorption and obscuration simply reduce the instruments throughput, while scattering degrades the point spread function and reduces the contrast. Both, sensitivity and image quality of the instrument can be acutely affected by various kinds of contamination. The following possible contaminants have been identified (Krueger 1989):

- dust particles
- organic condensables
- organic condensables and UV radiation
- solar wind
- organic condensables and solar wind

Spectral and angular resolution may be degraded by roughening of the optical surfaces by impact of particles from space environment, e.g., solar wind, micrometeoroids, but also by dust particles, increasing scattering from surfaces, thus degrading image quality and contrast. Sensitivity and contrast are also suffering from molecular contamination, especially condensable organic species, building a strongly absorbing overlayer on optical surfaces. This is more severe for normal incidence than for grazing incidence optics, as a contamination layer may still have good reflectivity at grazing angles. Gratings used near normal incidence, however, may be doubly effected as the contaminant layer may change the diffraction efficiency as well (Koide 1987).

The deposition of organic contaminants may be dramatically enhanced when the contaminated surface is exposed to ultraviolet radiation of solar intensity by photochemical reactions leading to polymerization of deposited material. This is expected to be the prime degradation process of space optical UV instruments. In addition, the irradiation by solar wind particles, i.e. protons and alpha particles, may, although at a much smaller rate, contribute to this polymerization process (Gillette 1971; Shimizu 1979). However, the radiation damage, physical alteration of the surface profile, roughening of the surface profile, is probably more deteriorating.

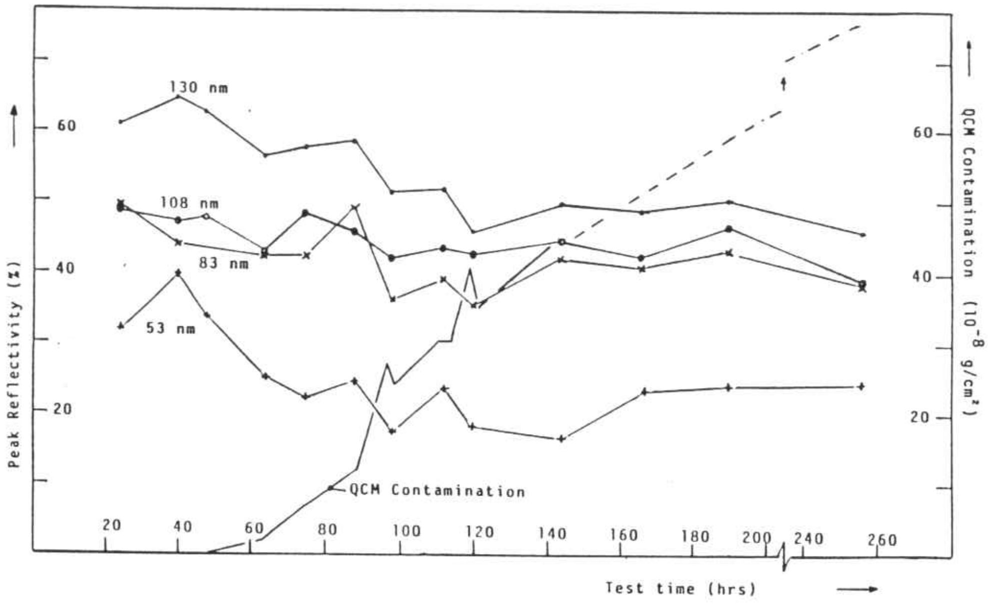


Fig. 2 - Peak reflectivity versus exposure time at the four wavelengths 53 nm, 83 nm, 108 nm, 130 nm. This is related to the mass accumulation on the QCM.

Experimental studies have been performed simultaniously in an attempt to quantitatively confirm theoretical predictions. Samples of SiC/CVD mirrors were exposed under vacuum to organic contaminants while they were irradiated by far ultraviolet light, the intensity being close to solar intensity at 160 nm. Intermittent measurements of reflectivity at different wavelengths in the EUV have shown only weak, but steady reduction of mirror efficiency correlating with the amount of collected contaminants (see Fig. 2), yet the amount of reduction of reflectivity was less than predicted. A microscopic investigation of the contaminated mirror surface was undertaken which showed that contaminants do polymerize under the UV exposure while agglomerating to island like spots (see Fig. 3). Thus, reflectance loss was not as high as expected, because no homogenious,absorbing film has been built, but increase of scattering must be considered.

Other samples of SiC/CVD mirrors have been exposed to an ion beam source run with H_2^+ and He^+ in order to simulate the effect of solar wind proton and alpha particles. The irradiated dose was varied to represent a total exposure of a 1 to 4 years mission time. Specifically, the H_2^+ dose was chosen to be between 2 and 8×10^{16} cm^{-2} @ 1 keV, the He^+ dose was between 0.5 and 2×10^{15} cm^{-2} @ 4 keV. Reflectivity was measured after each exposure. Inspection of the samples showed that the exposure has, even at the lowest dose, visibly changed the reflection properties. The EUV-reflectivity was found to be reduced by 20 % to 50 % proportional to the dose of primary particles at every wavelength measured (Dornier 1989).

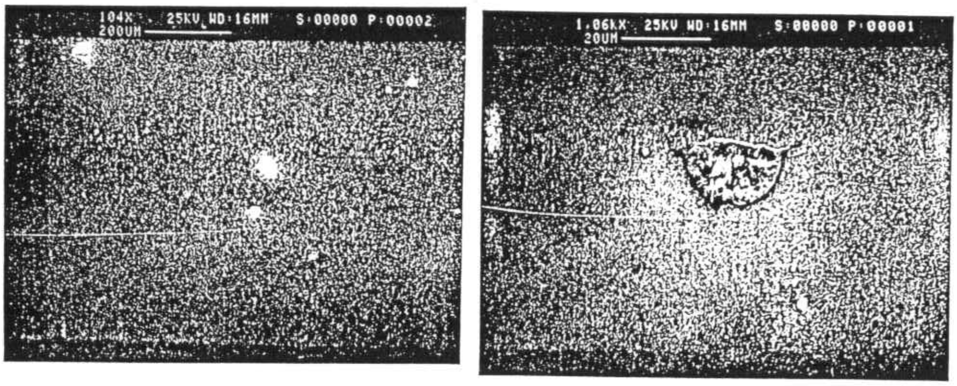


Fig. 3 – Microscopic photograph of the contaminated surface: The contaminants polymerize with UV light in islands (rather than a homogenious film).

3 CLEANLINESS REQUIREMENTS

The development of cleanliness requirements must be accomplished, using different methods for particulate and molecular contamination, by assessment of the degrading effects. The least tolerable degradation is dictated by the scientific objectives, and from these the requirements must be inferred.

Observations very close above the solar limb require a very low scatter telescope mirror to suppress the much brighter solar disk, while high image quality requires a very narrow piont spread function. For the SUMER telescope mirror we require scatter properties such that the diameter of 80 % encircled energy is less than 1 arcsec, and no more than 2×10^{-5} of the solar brightness is scattered outside a 2 arcmin radius. Using the particle size distribution of MIL-STD-1246B the angular distribution of scattered light from dust particles can be calculated (Ray 1990). For the SUMER telescope and spectrometer compartments we derive required particle cleanliness of Level 200 and Level 300, respectively, at the end of the integration phase, assuming that thereafter no more particles can be introduced to the optical housing (Schühle 1990).

Molecular contamination on mirrors have been assumed to be highly absorbing in the EUV, whether they were UV polymerized or not. In fact, it has been shown for some substances commonly used, that the produced contamination film becomes opaque already at a thickness of 15 nm (Muscari 1981). For SUMER, a 15 % loss of reflectivity at each of the four mirrors at end-of-life is the maximum degradation that could be accepted. Accordingly, this only allowes a contaminant layer of 1.0 nm thickness, or as much as 0.1 $\mu g/cm^2$ (of material with density 1 g/cm^3). This is the end-of-life requirement for the optical housing of the instrument. While this requirement is very hard to accomplish, it is clear that before launch the contamination level must be considerably lower since outgassing is an ongoing, though declining, process. Evidently, without special measures that prevent molecular outgassing and deposition the requirement for molecular cleanliness cannot be fulfilled.

4 PREVENTION OF CONTAMINATION

According to the results of the contamination studies some significant measures to reduce contamination below the required level have been implemented, most important among others are design changes and selection of proper materials. Some design features have especially been implemented aiming at the reduction of contamination:

- Aperture Door
  The instrument has been equiped with a door which guarantees that the optical compartment is always closed except when EUV measurements are undertaken. The spring loaded door serves also as an outlet for purge gas which is continuously supplied during ground operations and storage. After launch the door is partially opened for venting and to facilitate the exhaust of outgassing material without delivering any UV light onto the mirrors. This period of time shall last a few months. During this phase, energy is transmitted through a UV blind window which is implemented inside the aperture door. This way a temperature of the primary mirror of 45° C is achieved.
- Passive Heating of Primary Mirror
  The primary mirror shall always be at the highest temperature level in order to prevent condensation of molecular contaminants and to make residence times of contaminants small and desorption rates high. A passive heating solution was chosen to accomplish this, making use of the solar radiation input in the visible and IR. The mirror will be thermally isolated from the structure and will reach 75° C. When the aperture door is closed, a UV-black window in it will result in a mirror temperature of 45° C.
- Solar Wind Deflector
  Deflection plates inside the optical entrance baffle, held at a potential of -2 kV, will prevent protons and alpha particles with energies up to 5 keV and 10 keV, respectively, from impacting the telescope mirror.
- Detector Cover
  To protect the detector photocathode coating from moisture and the microchannel plates from condensible hydrocarbons one detector tube is hermetically sealed and held under vacuum by an ion pump. The tube can be opened by an actuator mechanism that opens the ultra high vacuum valve.
- External Electrical Components
  Only the front face of the detector is connected to the optical housing. The

body of the detector head assembly, containing all electronic parts, is isolated from the optics via a seal around the rim of the detector front plate.

- Clean Optical Compartment
  Organic material has been minimized restrictively inside the optical cavity and been placed outside if possible. All electrical boards and components are kept outside, and an exeption has only been made for the motors and encoders of the various mechanisms. Electrical supply runs via feedthroughs to motors and encoders.

- Dry Lubrication of Mechanisms
  Mechanisms use lubrication-free devices like, e.g., flexural pivots or ceramic ball bearings, or make use of dry lubrication on MoS2 basis.

- Ultra High Vacuum Motors
  Stepper motors have been specially designed for ultra high vacuum use and extensively conditioned and verified for low outgassing before integration.

- Material Selection
  Organic material has been avoided whenever possible, otherwise high temperature materials or components have been chosen. The selected components, and all organic materials, inside the optical housing have been tested for outgassing using a GC/MS technique. Conditioning of the item under test consisted of oven baking under constant clean gas purging and was continued until the outgassing level was eventually found to be acceptable or the item was rejected. The conditioning procedure performed with the test specimen is then applicable to all components of this kind before integration.

- Cleaning Procedures
  Precision cleaning is mandatory for every piece of flight hardware. Ultra clean water is used for cleaning with different kind of detergent solutions, depending on the material, and ultra sonic bath is applied when possible.

- Assembly and Test Provisions
  After the cleaning procedure, piece parts are kept in a clean, laminar air flow area and assembly is taking place in a Class 100 cleanroom. The cleanroom is equiped with active charcoal filters inside the upper plenum which keep the level of organic contaminants in the air at a minimum (verified regularly by gas chromatography). Vacuum systems for conditioning, tests and EUV calibration are oil-free ultra high vacuum systems. They are integrated into the cleanroom facility such that ports can be opened for loading and unloading from the cleanroom area. Fig. 4 shows the floor plan of the SUMER Cleanroom and Test- and Calibration Facility.

- Venting and Purging
  Venting of vacuum systems and purging of the instrument is performed with clean, filtered nitrogen supplied by a central distribution system with triple filters at the point of use. After assembly, alignment and calibration the instrument will be continously purged until launch.

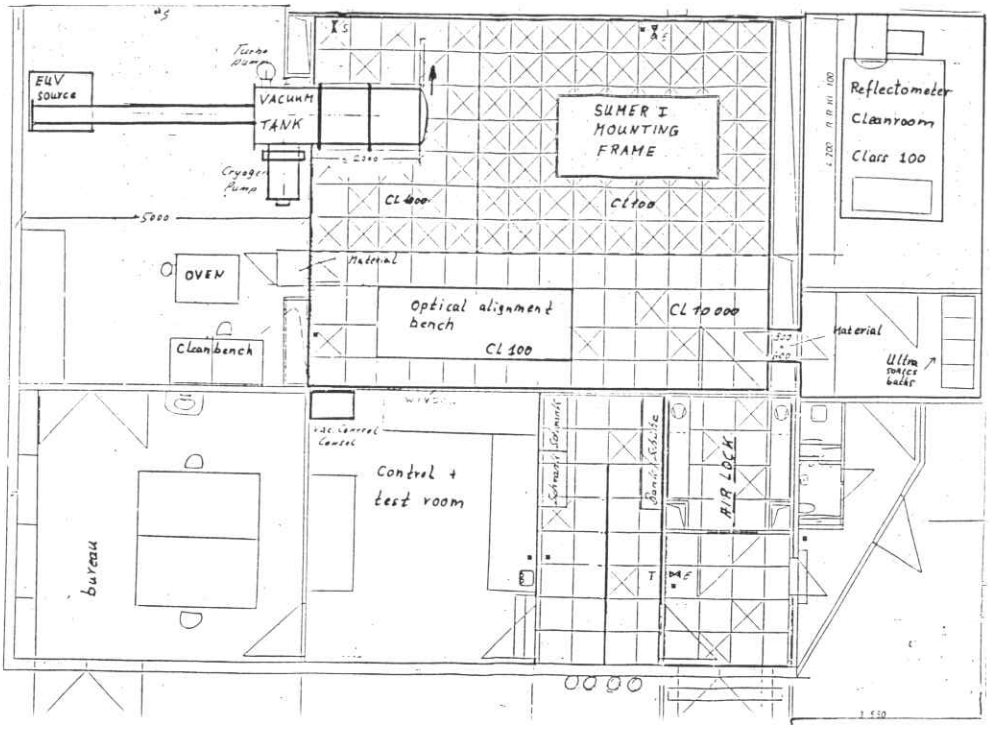
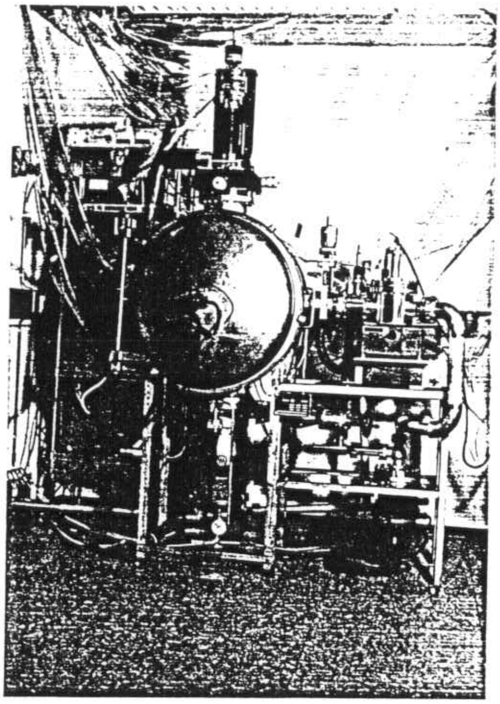


Fig. 4 – Floorplan of the SUMER cleanroom, test and calibration facility.

5 VERIFICATION OF CLEANLINESS

The cleanroom facility is being monitored continuously by particle counters and witnes plate fallout monitors. Vacuum systems, although with oil-free pumps, are known to be a source of contamination because of easier distribution of species outgassing from the internal equipment, use mass analysers and quartz cristal microbalances to monitor molecular constituents of residual gas and their condensation.

For verification of reflectivity of optical mirrors at EUV wavelengths a reflectometer has been constructed with an oil-free pumping system and commercial light source, monochromator, and sample manipulator. It will allow measurements of the bidirectional reflection distribution function at any angle of incidence as well as diffraction grating efficiencies throughout the SUMER wavelength range. It consists of a 700 mm diameter UHV vessel that can be loaded through a front door which opens into a Class 100 area. A photograph of the reflectometer is shown in Fig. 5.



The light source is a capillary discharge lamp (UPS lamp) and the monochromator is a 0.2-m concave grating with adjustable slits, both systems are UHV design. Operation of the lamp with different noble gases provides a number of roughly 30 lines distributed inside the wavelength range of SUMER with a resolution of 0.1 nm. The intensity of the system is surprisingly good: At a slit width of 0.07 mm a count rate in the Megahertz range is achieved at the principal lines. Samples of mirrors or other material to be investigated can be rotated and translated by a manipulator with 5° of freedom and 200 mm vertical motion capability.

Fig. 5 - The EUV reflectometer system.

6 Acknowledgement

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