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Contamination and Damage to Filmed Microchannel Plates on the International Space Station

J. D. Carpenter,* T. J. Stevenson,† and G. W. Fraser‡
University of Leicester, Leicester, England LE1 7RH, United Kingdom

Two microchannel plate (MCP) optic witness samples, bearing thin Al films on one face, have been exposed on the International Space Station (ISS) for 756 days. This investigation has given insight into the probable effects of exposure on the Lobster-ISS all-sky x-ray monitor, the basic optical units of which will be Al-filmed MCP optics. The samples have been examined after retrieval to investigate the extent of damage and contamination resulting from the exposure. The results of this examination are presented and reveal the effects of exposure on MCP optics, as well as offer insight into the nature of the space environment local to the ISS.

I. Introduction

MICROCHANNEL plate (MCP) optics[1] are a novel technology allowing the focusing of x rays while maintaining low mass. This low mass makes MCP optics particularly advantageous for space applications in x-ray astronomy and planetary remote sensing. These optics comprise an array of square section microchannels the width of which is of the order of tens of micrometers and the aspect ratio (length/width) of which is usually between 10 and 100. The interchannel web is made from silicon lead glass. The open area fraction of this web is typically around 0.6–0.7. The inside surface of the microchannels may be coated with a metal, for example, nickel or iridium, to maximize x-ray reflection at grazing incidence. The face of the optic may be coated with a thin Al film, which reduces the MCP's thermal absorptivity, reducing thermal expansion of the optic and the thermal load in the detector plane.

A proposed instrument utilizing this technology is the all-sky x-ray monitor Lobster,[2] whose intended platform is the International Space Station (ISS). Lobster has a wide field of view (162×22.5 deg) provided by an optical arrangement observed in the eyes of crustaceans.[3] The local-vertical–local-horizontal attitude of the ISS allows Lobster to observe the entire x-ray sky.[3]

In preparation for Lobster, two samples of MCP optic, coated on one side with a 60-nm-thick Al film, have been exposed to the external ISS environment. The aim was to investigate contamination, erosion, and particle collision damage to MCP optics in this environment and subsequently apply this to the development of the Lobster instrument. Samples returned from the ISS after 756 days were analyzed, and the results are presented here.

II. Sample Description, Location, and Duration

The samples and the sample support, to which they were attached, are shown in Fig. 1a in situ on the ISS and in Fig. 1b after return to the University of Leicester. The MCPs have a thin aluminum-film coating on one face and covering their 12.5-μm-diam, circular and hexagonally packed microchannels. The two samples differ in their orientation on the sample support. The face labeled sample 1 in Fig. 1b has the Al film on its external face (face A1), with the uncoated face (A2) attached to the Macor sample support. The orientation is reversed for sample 2 of Fig. 1b, with the Al coated face (B2) attached to the sample support. The sample support has ~12-mm-diam holes behind the samples to allow inspection of their rears. This allows investigation of Al film, which has been exposed to the ISS environment only via the channels (a possible Lobster configuration) and also provides an area that is not in contact with the support and/or adhesives. The sample support was mounted on the ISS such that the samples were outward facing.

The location of the MCP samples on the ISS docking module (Pirs) is shown in Fig. 2. Exposure began at 2204 on 25 January 2002 and ended 756 days later at 0022 on 27 February 2004.

The total atomic oxygen flux during exposure was recorded as 4×10^{20} atoms/cm (Ref. 4).

III. Analytical Techniques

Analysis of the MCP samples began on 27 July 2004. Cd–Zn–Te and Cs–I detectors were used to identify any gamma emission resulting from the presence of Be^7. An optical microscope in a clean environment was then used to observe the samples. A number of features were observed on each of the four faces and the sample support. These are described in Sec. IV.

Following this optical examination, reflection Fourier transform infrared (FTIR) analysis was used to investigate the presence of any organic contaminants on the reflective Al film. Features identified optically were then observed using a Philips XL30 scanning electron microscope (SEM), located in the Department of Engineering at the University of Leicester. The thin nature of the Al film made SEM observation problematic because a very low accelerating voltage (~1.5 keV) was required. At larger accelerating voltages, the penetration depth of the electrons was such that the Al film and any features associated with it were not observable. From the continuous slowing down approximation for electron range,[5] we calculate the penetration depth of 1.5-keV electrons in aluminum to be approximately 70 nm. Even with this low accelerating voltage, it is likely that resolution of surface features was limited.

Elemental compositions of surface features were analyzed using energy dispersive x-ray (EDX) spectroscopy. The electron energy required to allow the detection of elements of interest was such that the bulk of detected x rays came from within the MCP glass. MCP glass is primarily composed of Si, O, Pb, Bi, Na, K, and Ba (Ref. 6). C and Ca are common contaminants.[7] Based on observations of previously exposed surfaces on other platforms,[8,9] contaminants in the ISS environment are expected to be composed primarily of Si, O, and C. X-ray emission from these elements will be detected regardless of contamination because they are constituents of the MCP glass. As a result, only detection of fluorescent x rays from elements not present in MCP glass have been recorded here.

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*Research Associate, Space Research Centre, Department of Physics and Astronomy, University Road.

†Chief Engineer, Space Research Centre, Department of Physics and Astronomy, University Road.

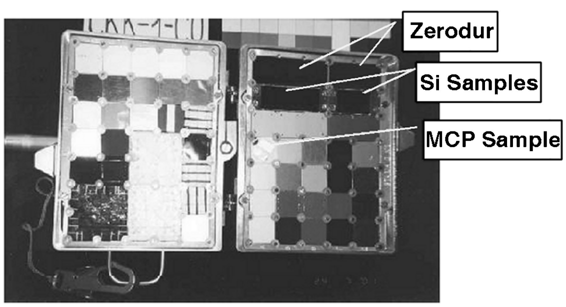
‡Director, Space Research Centre, Department of Physics and Astronomy, University Road.

IV. Observations and Contamination

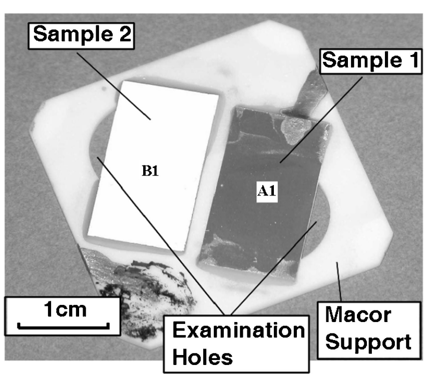
Figure 1 shows the returned samples and sample support. Analysis of these samples revealed a number of features that had appeared during exposure. These features are described next.

No gamma emission was observed from the samples, implying that no Be^7 was present.

FTIR reflection spectra of face A1 postexposure and that of a nonexposed filmed MCP of identical format are shown in Fig. 3. The bulk reflectivity of face A1 is reduced from that of nonexposed films. This may be due to the damaged film not over the examination hole reducing the reflecting area. This damage is described in the following subsections and is probably related to the process of attachment to the support structure; as such, it is unrelated to the ISS environment directly. No evidence of significant contamination was observed, although the minima at 1229 cm^{-1} indicates the presence of a carbon layer. The noise observed in the spectrum of the exposed MCP indicates the presence of a contaminating film, though any such film will be very thin and its composition cannot be quantified on the basis of such features.



a)



b)

Fig. 1 MCP samples a) in situ on ISS [image courtesy of Kayser–Threde and S. P. Korolev Rocket and Space Corporation (RKK) Energia] and b) returned filmed samples and their Macor sample support.

A. Face A1

1. Feature 1: Dark Patches; Holes in Al Film

Under an optical microscope, extended dark patches with clearly defined boundaries (Fig. 4a) were observed. The features appeared black to the naked eye but were seen to have an irregular and textured surface under the microscope with metallic and black patches. In places, the region around the rim appeared pale in comparison with the surrounding film. With the higher magnification of the SEM, the feature appeared to be made up entirely of holes in the Al film (Fig. 4b).

EDX spectra of the feature showed x-ray lines consistent with MCP glass and the Al film. No other elements were detected.

2. Feature 2: Light and Dark Patches

Two extended patches were observed optically, where the MCP film appeared slightly different in coloration to the majority of the surface (Fig. 5). Clearly defined edges were visible. Optical interference was observed with the naked eye in an oil-film effect. This implies the presence of a thin molecular film. Under the optical microscope, the areas were seen to contain light and dark patches. The shape and position of this feature corresponded with A2 feature 1 on the reverse side of the MCP.

Feature 2 was not visible with SEM imaging. EDX spectra did not indicate the presence of any elements inconsistent with MCP glass or the Al film.

3. Feature 3: Regularly Shaped Patches

Two regular shaped, approximately circular to hexagonal patches, ~12–16 microchannels across (180–240 μm), were observed under an optical microscope (Fig. 6a). In these features, the metallic

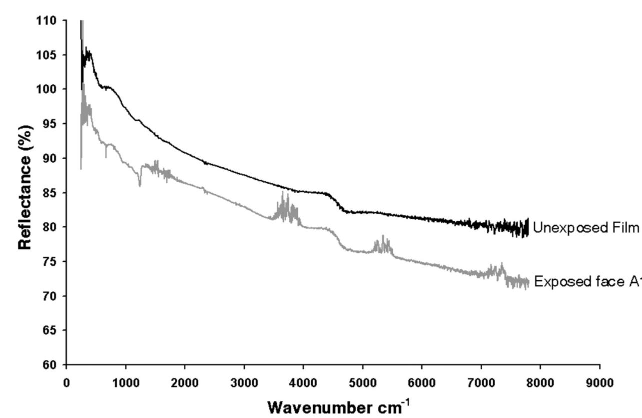


Fig. 3 FTIR spectra of faces A1 and B2.

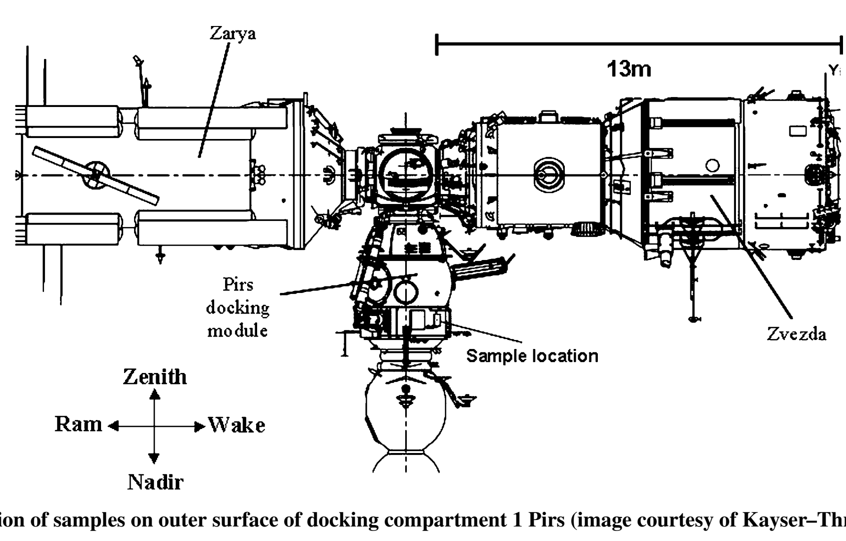


Fig. 2 Mounting location of samples on outer surface of docking compartment 1 Pirs (image courtesy of Kayser–Threde and RKK Energia).

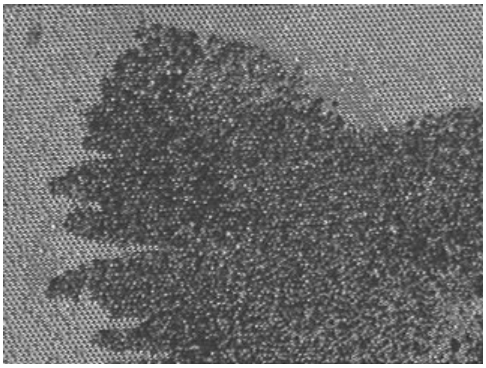


Fig. 4a Optical microscope image of face A1 feature 1.

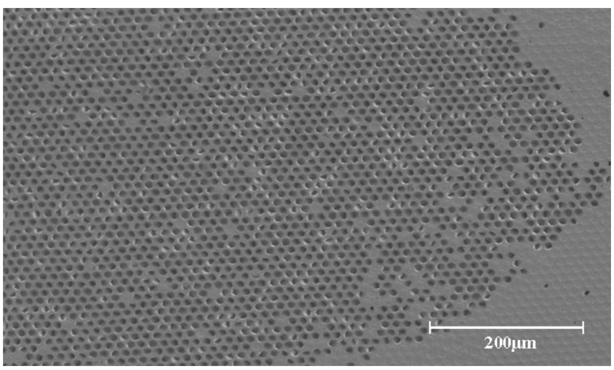


Fig. 4b SEM image of face A1 feature 1.

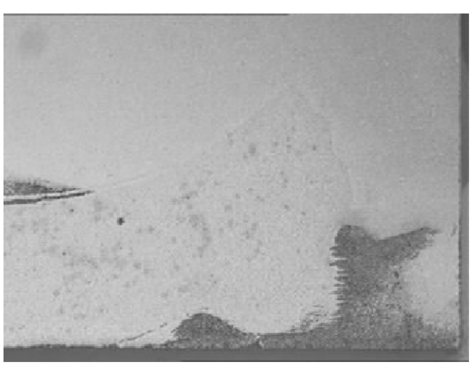


Fig. 5 Optical microscope image of one of two examples of face A1 feature 2, located at center and bottom of face A1 in Fig. 1: dark area surrounding it is face A1 feature 1.

appearance of the film was diminished. There was a clearly defined rim, which appeared brighter than the central region. This was observed in more detail with the SEM (Fig. 6b).

The shapes and structures of these features were consistent with contamination spots observed on returned samples from the Mir space station and may result from the impact of droplets during a water dump. (Mir Solar Array Returned Experiment Archive System, data available online at http://setas-www.larc.nasa.gov/sare/sare.html.) Phosphor was detected in the EDX spectra from these features, as well as traces of iron. Phosphor is an element very abundant in biological cells, suggesting that these features may contain biological waste. Other elements consistent with this were observed but are components of MCP glass and cannot, therefore, be taken into account.

4. Feature 4: Scrape

A long, thin scrape along the Al film (Fig. 7) was observed. This feature was approximately 30 microchannels diameters in length (∼450 μm).

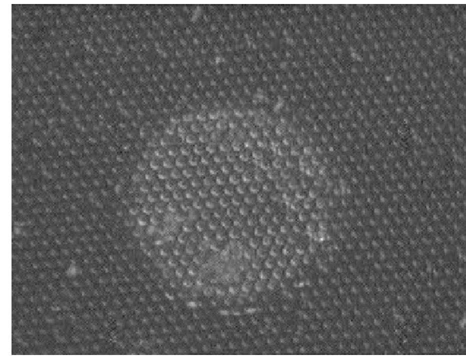


Fig. 6a Optical microscope image of one example of face A1 feature 3.

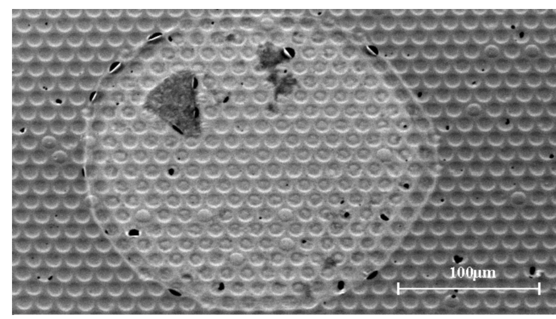


Fig. 6b SEM image of one example of face A1 feature 3.

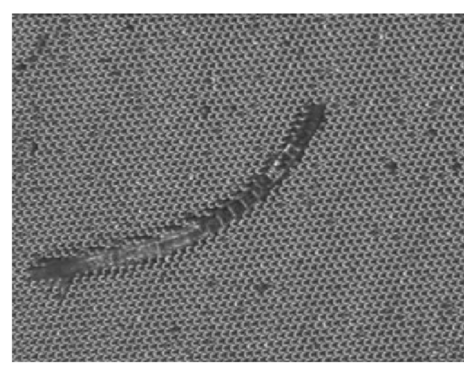


Fig. 7 Optical microscope image of face A1 feature 4, located just above bottom example of face A1 feature 1.

5. Feature 5: Close-Packed Holes

A region was observed that appeared entirely made up of closely packed (almost all microchannels) holes in the film (Fig. 8a). This region extended along the face of the MCP, arcing slightly, above the edge of the inspection hole (Fig. 1). There were visible differences in the material above and below this feature. A high-magnification SEM image of the area is also shown in Fig. 8b. These holes are likely related to the adhesion of the MCPs to the sample support, given that such features do not occur over the examination holes where the MCPs are not in contact with the sample support. Gas trapped in the microchannels during adhesion may burst the film in vacuum due to the large pressure differential across the film.

6. Feature 6: Holes from Potential Particle Impact

Two holes were seen on the in the Al film, which were resolvable with the naked eye, and ∼100 μm in diameter, enveloping several microchannels (Fig. 9a). Damage to the film around the microchannels was resolved with the optical microscope. These features are most likely the result of particle impacts.

With the SEM, further detail was resolved. A SEM image of one of these holes is presented in Fig. 9b. EDX spectra did not show

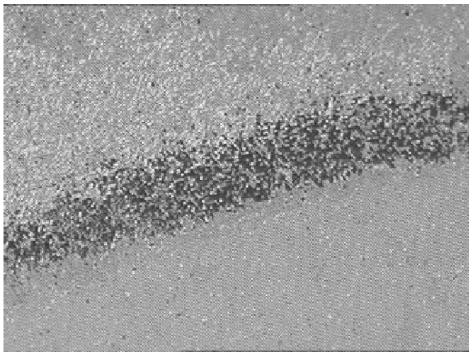


Fig. 8a Optical microscope image of face A1 feature 5.

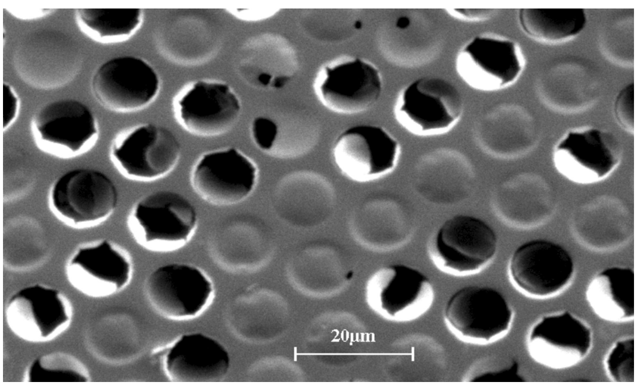


Fig. 8b SEM image of face A1 feature 5.

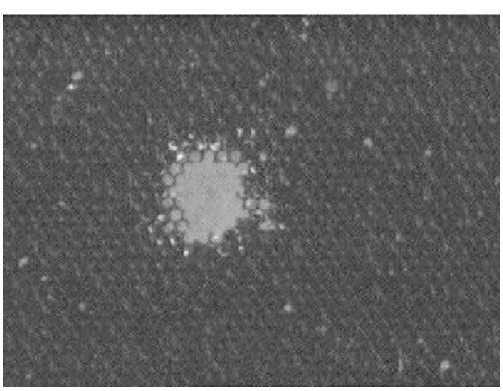


Fig. 9a Optical microscope image of one of two holes in A1 film, resolvable with naked eye.

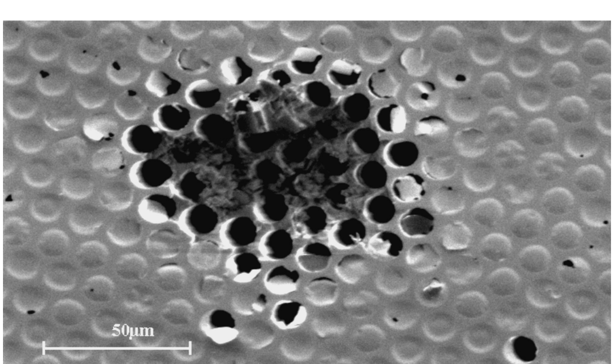


Fig. 9b SEM image of other of two holes resolvable with naked eye.

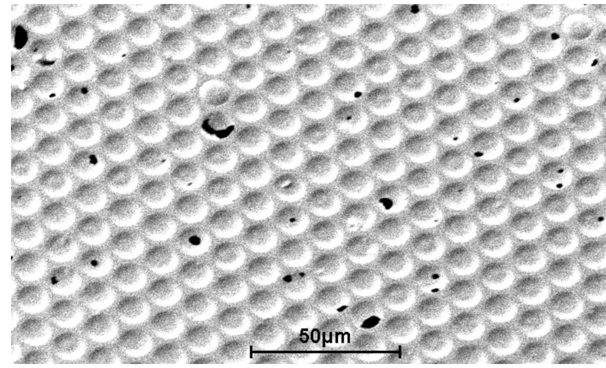


Fig. 10 SEM image of holes in A1 nanofilm.

the presence of any elements incompatible with MCP and Al film composition. As such, the impactor's origin (natural dust or man-made debris) cannot be determined.

7. Feature 7: Holes from Potential Small Particle Impacts

Over the support structure inspection hole there was a seemingly uniform distribution of small holes with less than one microchannel diameter. These may arise from a high flux of small hypervelocity dust[10] impacts and vary in size. Figure 10 shows a SEM image of these holes in the Al film. Size distribution and impactor flux have been determined though analysis of SEM images and are presented in Ref. 10. The fractional loss of Al film over the MCP open area in the region covering the inspection hole is 0.0027.

Other damage and contamination evident elsewhere on face A1 were not observed over the support structure, suggesting that such features arose through contact with adhesion to the support structure.

B. Face A2

On face A2, only the area revealed by the inspection hole was viewable, and all observations have been made in that area.

1. Feature 1: Undefined Structure

A structure extending on to face A2 from its edge was observed with optical microscopy (Fig. 11a). This was probably derived from adhesive. The shape and position of this feature correspond with face A1 feature 2 on the reverse side. SEM imaging (Fig. 11b) and EDX spectra offer no further insight into the structure or composition of the feature.

2. Feature 2: Pale Spots

Pale spots are observed in the MCP lattice across face A2. These are most likely a result of light transmission through holes in the Al film on the opposing side (Fig. 12).

3. Feature 3: Bright Patch

One bright patch was observed that was significantly larger than others on the face. This is likely to have been caused by feature 6 on the opposing face (Fig. 7).

C. Face B1

1. Feature 1: Stain

A brown stain was seen to extend around the perimeter of the MCP, where it was in contact with the support structure (Fig. 13). The stain extended in from the edge by around 5 microchannel diameters (~75 μm). The origin of this stain seems most likely to be outgassing from the underlying adhesive and subsequent exposure to solar UV radiation.[9]

EDX spectra confirmed the presence of elements expected in MCP glass with the addition of Fe and Mg.

2. Feature 2: Colored Areas

A pale feature followed the majority of the circumference of the underlying inspection hole. Within this pale region, patches of

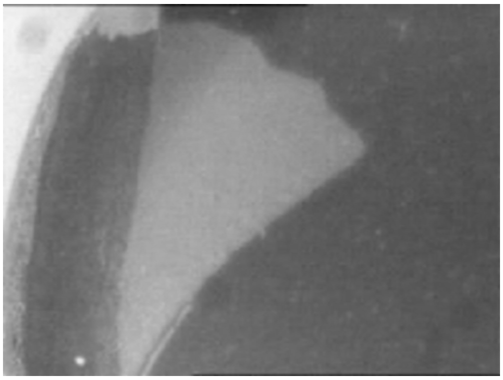


Fig. 11a Optical microscope image of face A2 feature 1.

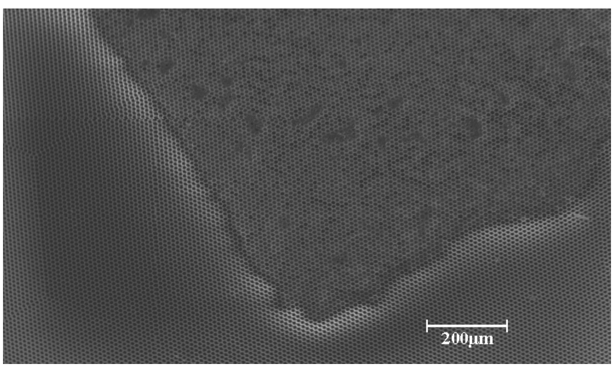


Fig. 11b SEM image of face A2 feature 1.

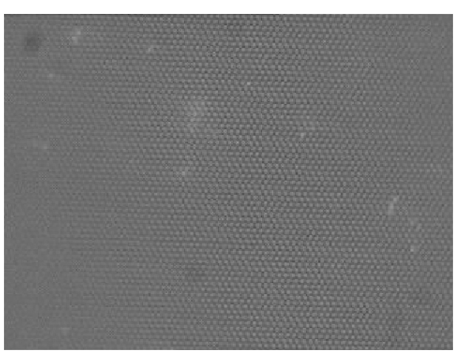


Fig. 12 Optical microscope image of face A2 feature 2.

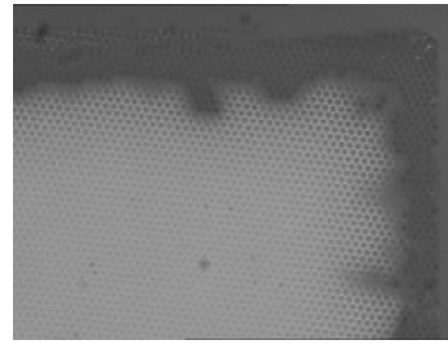


Fig. 13 Optical microscope image of face B1 feature 1 at top right corner of face B1, Fig. 1.

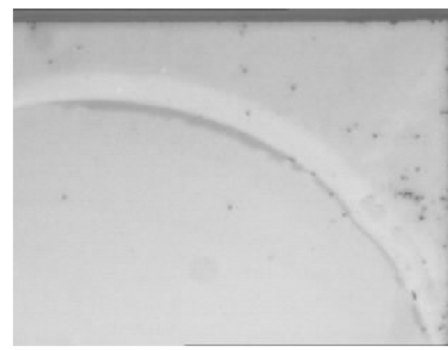


Fig. 14 Optical microscope image of face B1 feature 2 and examples of features 3 and 1.

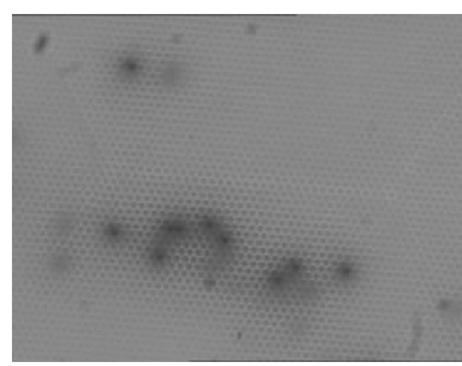


Fig. 15 Optical microscope image of examples of face B1 feature 3 located toward bottom and center of face B1.

brown staining were clearly visible, particularly in the lower edges of the feature. Along stretches of the inner edge of this region, a gray feature is visible. This corresponded with the presence of what may be adhesive on the opposing face shown in Fig. 14. The white discoloration may have been the result of a darkening of the rest of the MCP.

This feature was not observable with SEM.

3. Feature 3: Discolorations

Numerous single microchannels, or groups of a few isolated microchannels, were found to have dark brown discolorations or blockages (Fig. 15). These occurred with far lower frequency over the inspection hole.

EDX spectra showed the presence of Mg in addition to elements present in MCP glass.

4. Feature 4: Discoloration

A pale white discoloration was observed around a few isolated microchannels over the inspection hole (Fig. 16). These may have resulted from transmission through holes in Al film at the opposing face or imperfections in the MCP lattice.

D. Face B2

On this face, only the area revealed by the inspection hole is viewable, and all observations have been made in this area.

1. Feature 1: Contaminant Material

A spread of material from the inspection hole perimeter and onto the face was observed (Fig. 17). This is likely to be related to the presence of adhesive and corresponds with face B1 feature 2.

2. Feature 2: Holes

A diffuse distribution of holes was seen in the Al film (Fig. 18). However, it is less prominent than that of A1. In addition, clumps of several of these bright channels are observed together. These may result from impactors that have passed through the Al film on the front face with an angle of incidence less than the acceptance angle of the microchannels.

E. Sample Support

There was a general brown discoloration of the support structures front face (implying the presence of a molecular film), except at the

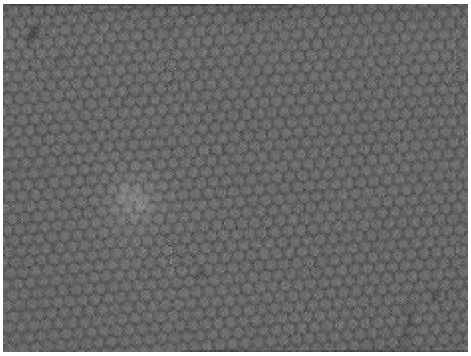


Fig. 16 Optical microscope image of face B1 feature 4.

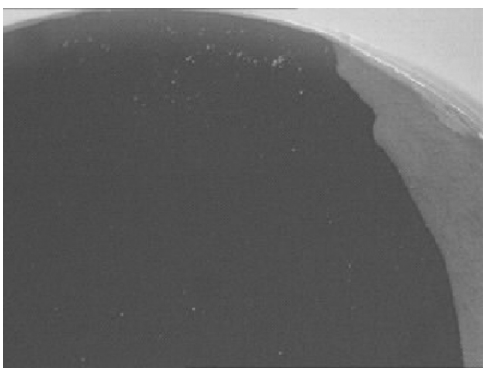


Fig. 17 Optical microscope image of face B2 feature 1.

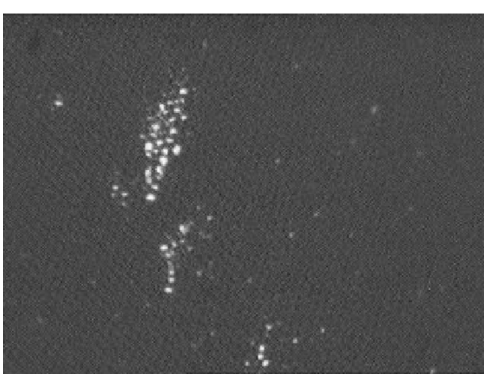


Fig. 18 Optical microscope image of clump of holes in A1 film described in face B2 feature 2.

corners where the material appears paler in color. These corners, shown in Fig. 1a, have been covered during exposure. In addition, a thick brown substance surrounded the MCP samples. This may be the adhesive used to bond the samples to the support structure altered by exposure to solar UV (Fig. 1b).

V. Conclusions

Two Al-filmed MCP samples have been exposed to the external ISS environment for 756 days. Observations have indicated contamination by a brown substance, probably a molecular film derived from the adhesive used to attach the samples to their support structure. This is indicated by the nonappearance of this contamination in areas where the sample and support are not in contact. The brown coloration of the contaminant indicates that an interaction with solar UV may have occurred.

Damage to the MCP film appears to have occurred due to both micrometeoroid impacts and by some other process. Significant damage has occurred over areas where the MCP and support are in contact via adhesive, indicating a role of the adhesion mechanism to film damage. MCP mountings using minimized quantities of adhesive are underdevelopment at Leicester for application on Lobster and other MCP optic-based instrumentation. Where there is no contact with the underlying support structure, damage appears to result exclusively from hypervelocity dust and debris collisions.

Some minor contamination is attributable to the ISS environment, although the majority of contamination observed on these samples is most likely derived from the adhesion of the samples to their support. This may have implications for the method of attaching MCP optics to the Lobster module.

The low fractional loss of the MCPs Al-film coating and the apparent low contamination to the MCP over the examination holes (the region comparable to the collecting area of Lobster), when applied to the Lobster telescope, result in negligible changes to the thermal properties of the instrument.

Acknowledgments

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I. Boyd
Associate Editor