THE DEGRADATION OF ALZAK BY SHORT WAVELENGTH ULTRAVIOLET RADIATION*

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There has recently been increasing interest in the damage to thermal control coatings caused by short wavelength ultraviolet radiation. This interest has occurred, in part, as a result of an apparent discrepancy in data returned from a coatings experiment aboard ATS 1 (Reference 1). In addition, certain other findings indicate that, at least for some coatings, degradation appears to be inversely proportional to the wavelength of irradiation (Reference 2). Since the solar spectrum is rich in the vacuum and extreme ultraviolet regions, some experimenters have postulated that this could be a matter of great importance (Reference 3). If such a hypothesis could be demonstrated, it would mean that one more factor should be added to the growing list of requirements for synergistic ground-based testing of spacecraft coatings.

At Goddard Space Flight Center, work has been underway for some time in an attempt to fully characterize the ultraviolet degradation of one of the important thermal coatings, Alzak. Alzak is the designation given to a particular type of anodized and chemically polished aluminum sheet. This material was chosen for the outer skin of the OAO spacecraft because it can be easily worked by ordinary sheet metal techniques and because it has an attractively low ratio of solar absorptance (α_S) to hemispherical emittance (ϵ_A)—approximately 0.22. Work has been reported previously which showed that the degradation of Alzak was strongly dependent upon the wavelength of irradiation, at least down to $\simeq$220 nm (Reference 4). The experiments which are described here were designed to provide data down to the solar Lyman-α region (121.6 nm).

The experimental apparatus used in this study is shown in Figure 1. It consists of an irradiation cell and three UV sources with wavelengths at

*Paper delivered by Martin J. Donohoe.

123.6 nm, 185 nm, 206.2 nm, and 240 nm. Not shown is a DK-2 spectroreflectometer with an Edwards-type integrating sphere used for in-air reflectance measurements on the sample. A 1½ liter stainless steel vacuum chamber with a side port forms the irradiation cell. The cell is ion pumped with a trapped mechanical roughing pump. All vacuum seals are the copper gasket type, and the valves have Viton elastomer seats. Irradiations take place in the 10^{-7} torr region, measured by an ionization gauge. The irradiation port is either a 5.08-cm diameter sapphire window or a 2.54 cm diameter lithium fluoride window, depending upon the wavelength of irradiation.

The sample was screw mounted on a temperature controlled copper substrate opposite the irradiation port. Sample reflectance measurements were made before, during, and after the irradiations by removing the sample from the chamber. The sample could be removed, replaced, and pumped down within 30 min. No detectable recovery in Alzak took place during this time interval. During the earlier studies, *in situ* reflectance measurements of Alzak damaged by irradiations from a 123.6 nm source and a xenon arc indicated that recovery of damage was negligible when measurements were made within 8 hr after exposure to air. Reflectance measurements were made with an estimated error of ±½ percent due to variations across the sample face.

The UV irradiation sources were two low pressure microwave discharge lamps (krypton and iodine) and a high pressure xenon arc lamp with a bandpass filter centered at 240 nm. The relative spectral outputs of the three sources are shown in Figure 2, together with a solar UV irradiance curve for reference.

The krypton lamp emits three lines, 117 nm, 123.6 nm, and 247 nm. The 117 nm line is weak, being approximately 10 percent of the 123.6 nm line intensity. The 123.6 nm line is the primary irradiating wavelength and is used to simulate the solar Lyman-α line at 121.6 nm. The 2 nm difference between the two lines is assumed to have a negligible effect on the results. The 247 nm line contribution to sample degradation is evaluated by masking half the sample with a sapphire filter to eliminate the 123.6 nm line and pass the 247 nm line. A reflectance measurement on both sample halves then isolates the 247 nm line contribution. The krypton lamp output spectrum is blank from 247 nm to approximately 330 nm. The lamp is normally run gettered with a cold finger immersed in liquid nitrogen to eliminate contaminant lines. Krypton lamp intensities could be varied by the microwave generator from a fraction of an equivalent Lyman-α sun (i.e., one equivalent Lyman-α sun = 5×10^{-7} W/cm^2) to approximately 20 equivalent Lyman-α suns. The lithium fluoride window life was greatly reduced at the higher intensities because of the window sealing technique used.

The iodine lamp has a sapphire window and emits a group of lines centered at 185 nm and a strong line at 206.2 nm. The lamp is normally run with a cold finger immersed in ice to maintain the proper pressure in the iodine reservoir shown in Figure 1. The lamp spectrum above 206.2 nm is blank up to 400 nm. Elimination of the degrading contribution of the 185 nm lines, so that only the 206.2 nm line has effect, is achieved with the use of a gas filter of butene-1 (Reference 5). The butene-1 cell absorbs the 185 nm lines while reducing the 206.2 nm line intensity by only 10 percent. The iodine lamp output was variable up to one-half an equivalent sun at 185 nm and 206.2 nm (i.e., 40 Lyman-α suns). The 185 nm lines contributed approximately one-half of the total intensity, the balance being contributed by the 206.2 nm line.

The xenon arc lamp used had a continuum at 240 nm, and the filter centered at 240 nm had a bandpass of 30 nm. Maximum output was approximately equal to one-half an equivalent sun at 240 nm (i.e., 75 Lyman-α suns).

The intensity monitor for all the lamps was a sodium-salicylate-coated photomultiplier (1P28) referenced against a calibrated nitric oxide ionization chamber using the 123.6 nm krypton line. The photomultiplier could be rotated to a position between the sample and the irradiating source. The calibration measurements were performed with the ionization chamber in the sample position as shown in Figure 1. The sodium salicylate quantum efficiency was assumed constant over the wavelength region of interest. This assumption is supported by the literature (Reference 6). The photomultiplier calibration was checked periodically during the experiments and found to remain within 5 percent of the original calibration.

Calculation of equivalent sun irradiance for each source was based on Johnson's data, using a 10 nm bandwidth of each line. The 185 nm lines were treated as one line between 180 nm and 190 nm. Actually the bandwidth of each line was known from the vacuum monochrometer measurements. Use of the actual bandwidth, 2.5 nm, just increases the equivalent sun hour exposures. Since line sources were used to simulate the Sun's continuum spectrum at select wavelengths, the 10 nm interval was used. Another convenient way of looking at the data would be in terms of Lyman-α suns, since part of the experiment is aimed at studying the effect of Lyman-α radiation.

Figure 3 shows the changes in reflectance at 295 nm of Alzak samples exposed to different irradiating wavelengths. Exposure to 123.6 nm light used to simulate solar Lyman α produces the slowly developing damage shown in the lowest curve. Exposure to combined 185-206.2 nm light produces the steep curve shown at the left. This curve was constructed from three samples as indicated by the legend.

Shown in Figure 4 is a plot of the percentage of ΔR at 295 nm versus wavelength for constant incident energy.

Before discussing the data in Figure 3 and Figure 4, two additional experiments should be mentioned. The first is a single Alzak exposure to 123.6 nm irradiation at an intensity equivalent to that for the 185 nm to 206.2 nm irradiations shown in Figure 3. For a 36.5 hour exposure at 1.4×10^{-5} W/cm^2 (i.e., $\simeq$30 times Lyman α), Alzak showed a 4 percent ΔR at 295 nm compared to the 11 percent shown in Figure 3. The second result is a UV screening test on Alzak using a filtered 2.5 kW Xenon arc lamp (Spectrolab Solar Simulator model X-25). The UV irradiation tests performed through quartz vacuum chamber ports produced at 12 percent ΔR in Alzak after 57 equivalent sun hours at a one sun rate. Therefore this sample saw the complete solar spectrum starting at the quartz cutoff of the simulator and vacuum system optics. The UV content (i.e., below 220 nm) for this test was not known, but the point is presented to emphasize the damaging effects of short wavelength UV. The energy output ratio (in W/cm^2) of the simulator to the microwave discharge lamp is approximately 10,000 to 1.

Two conclusions can be drawn from the data presented. First, on a solar irradiance basis, Alzak is damaged faster and further by 180 to 210 nm radiation than by Lyman α (see Figure 3). Second, on an equivalent incident energy basis, Lyman α does less damage than 180-210 nm radiation (see Figure 4). These two points, coupled with the previous studies of Alzak with radiation above 220 nm, provide a general behavior picture for Alzak degradation: Above approximately 300 nm no degradation is observed for long exposures (100 hr), and below 300 nm increasing degradation with decreasing wavelength is observed. This degradation peaks somewhere between 150-210 nm (on a solar irradiance basis) and reaches a lower value at Lyman-α wavelengths. In addition, most of the damage caused by 180-210 nm radiation occurs within the first 50 hours of exposure and may approximate the damage observed under standard solar irradiation tests.

From the standpoint of solar environmental testing of Alzak, it is evident that Lyman-α radiation need not be included in laboratory testing. Every effort should be made, however, to include radiation between 150-200 nm. Other materials may behave differently and should at least be checked for their behavior under Lyman-α radiation.

At this point in the studies it is only of academic interest to determine the precise shape of the Alzak damage curve because of the large reflectance changes observed when an iodine lamp is used. However, efforts are being made to develop a bromine resonance lamp to provide a line source at 163 nm, a wavelength that will bridge the wavelength interval between the iodine and krypton irradiation sources.

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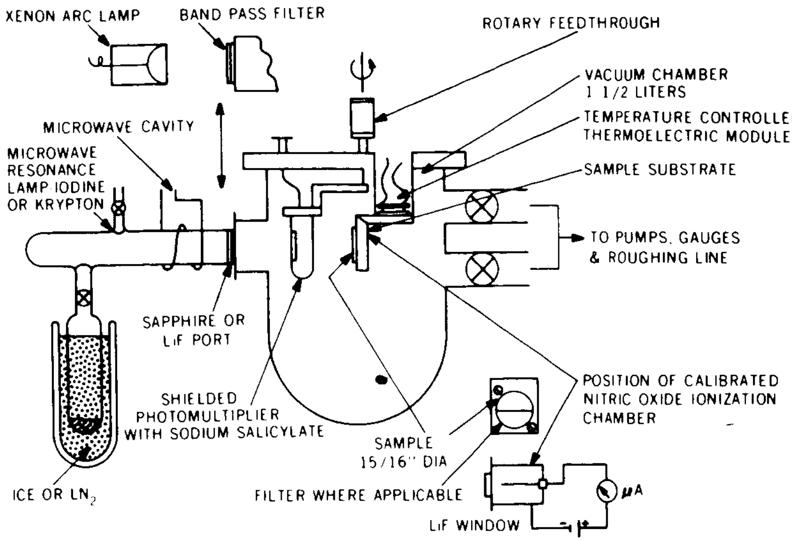

Figure 1—Experimental apparatus.

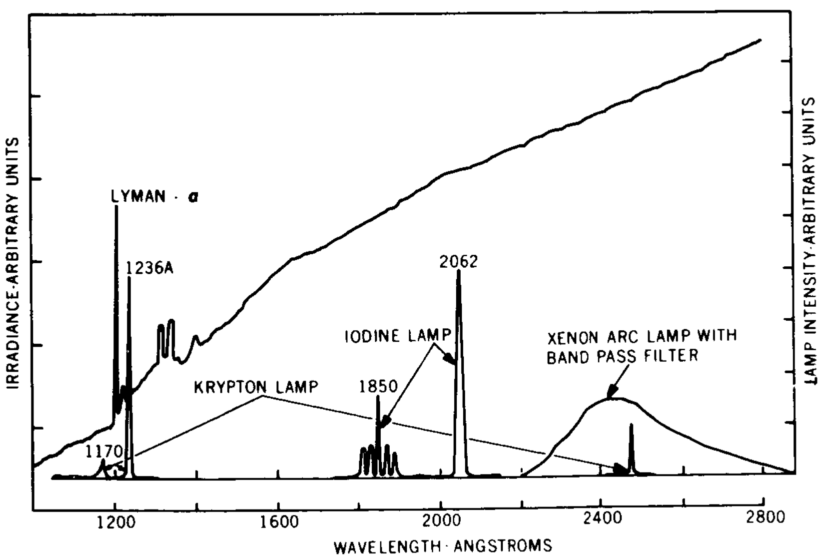

Figure 2—Solar UV spectral irradiance and UV irradiation source spectra.

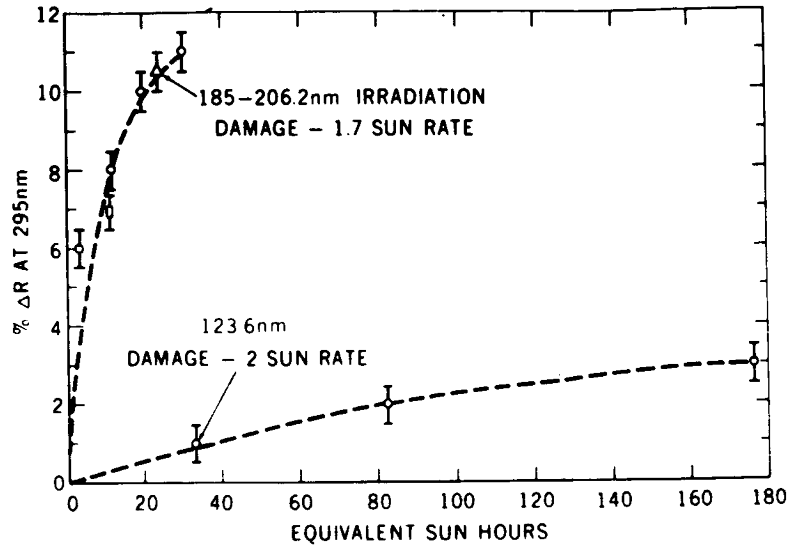

Figure 3—Comparison of Alzak degradation produced by 123.6 nm with 185- to 206.2-nm irradiation.

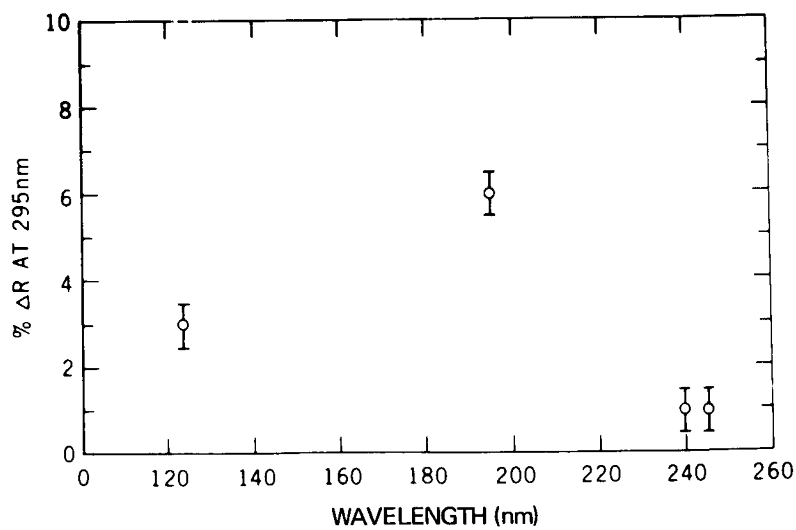

Figure 4—Irradiation damage as a function of wavelength for constant incident energy (1×10^{-4} W/cm^2 $\times$ time).