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# THE PRODUCTION OF CONTAMINATION ON SPACECRAFT SURFACES BY HYPERVELOCITY DEBRIS IMPACTS

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**ABSTRACT.** *A study of the mechanical damage and the contamination produced by hypervelocity debris impacts on spacecraft was conducted in a space chamber capable of accelerating debris simulating particles to 7.5km/sec and other components of the Low Earth Orbit environment. Damage characteristics and the nature and extent of contamination generated by the impact of 3mm diameter, 3 micron thick aluminum particles, accelerated to 4.5 km/s, were investigated. Scanning electron microscopy, optical microscopy, and spectrophotometry were used to measure the mechanical damage and the loss of transmission through solar photovoltaic cover glass materials.*

## 1. INTRODUCTION

Spacecraft placed in low-Earth orbit (LEO) are exposed to a large flux of hypervelocity impacts by small particles which originate from micro-meteorites and man generated debris<sup>1,2,3</sup>. At risk are multiple satellite constellation systems and proposed large inflatable space structures. Many of these satellite systems, which are primarily used for communications, will be placed in low earth, nearly polar, orbits. The amount of damage experienced by space based assets in LEO from hypervelocity debris impacts can be extensive and can decrease the performance levels of subsystems below critical specifications. In LEO, the particle flux existing in circular orbits at altitudes near 500 kilometers<sup>4</sup> can be, for 1 cm size pieces, as low as 1 hit /m<sup>2</sup>/100,000 yr., while it can vary between 10 and 100 hits /m<sup>2</sup>/yr for particles of about 0.1 mm. The damage generated by debris particle impacts on solid materials can be grouped into three distinct phenomena: a) mechanical property changes due to cratering (which is often many times larger in diameter than the particle itself) and surface damage produced by direct hits; b) internal and back surface spallation of

materials resulting from the shock wave produced by the hypervelocity impact; and c) molecular contamination generated by hypervelocity debris particles which arises from the vaporization of the particle itself as well as that of the material struck. Particles traveling at hypervelocities generate temperatures in the range of 5,000K and pressures of several megabars when they strike a surface. Consequently, one would not expect that the constituents of the vapor produced by the impact would be the same as those produced under ambient conditions and that fragmentation of the contaminant may not proceed by the Rice-Herzfeld mechanism.

This paper presents results on research carried out to study the production of debris generated contamination on the surface of thin, large area, solar cell cover glass materials and the degradation of their optical transmission. Large area solar cell arrays are desirable because they reduce the cost and complexity of this subsystem, but are viable only if the toughness of the cover glass can be increased so that they can withstand the rigors of ground handling and launch and deployment stresses.

## 2. EXPERIMENTAL

The technique used in this work to accelerate the debris particles is a laser driven method which has been described by Roybal et al, elsewhere<sup>5</sup>. The method used to fabricate the metal-to-glass laminate to create the debris particle is critical to produce the acceleration desired. In the method which we have developed, a metal foil of the desired thickness for the debris particle, is tenaciously bonded to a glass substrate by atomic diffusion of the metal into the glass. Both elevated temperature and a DC voltage are applied across the laminate to produce a very tenacious bond.

The metal foil is vaporize by a laser beam focused at the glass/metal interface. The vapor pressure thus produced reaches levels in the giga Pascal range which cuts out and accelerates a metal disk the diameter of

the periphery of the laser beam. Velocities from 4.5 to 7.5 km/s have been achieved by the authors. This compact method is suitable for impacting targets at hypervelocities in a space environmental effects chamber which has the additional capability of exposing samples, simultaneously, to energetic electrons, ultraviolet radiation and atomic oxygen. In this work, impact testing was carried out on solar cell cover glasses using flat aluminum debris particles, 3mm in diameter and 3 microns thick. The cover glass targets, which were 40mm by 40mm in size, consisted of two thin glass sheets laminated together with a thin layer of Teflon or CV2500 resin between them. The debris particles, which traveled a distance of approximately 12 mm before impacting the target had their velocities determined by a laser interferometer system<sup>6</sup> in which a small Doppler shift in the frequency of the laser beam, returned from the surface of the moving debris particle, is measured. Only one impact was made per target so that an assessment of the amount of re-deposited contamination attributed to the ejecta from a single impact could be determined. The damage observed in these experiments included: front surface cratering, front and rear surface radial and concentric cracks, rear surface uplift and spall; and contamination in the form of vaporized material ejected from the crater which re-deposited on the front surface. The mechanical damage to the targets was characterized using optical and scanning electron microscopy (SEM).

A neodymium-glass, pulsed laser with energies ranging from 2 -5 joules and a 18 ns pulse was used in this work.

### 3. RESULTS

Figure 1 shows a typical optical micrograph image of an impacted coverglass target in which the mechanical damage resulted from an impact at 4 km/s. Radial cracks extend from the impact crater to the edge of the 4 cm sample. The dashed circle in the center of the image represents the size and impact location of the 3 mm flyer. Figure 2 is a typical SEM image of the rear surface of an impacted target and shows that some glass material has been removed from the rear surface. The predominant damage observed on the rear surface of targets was cracking and uplifting of the glass, however the glass remains attached to the laminate, similar to common safety glass.

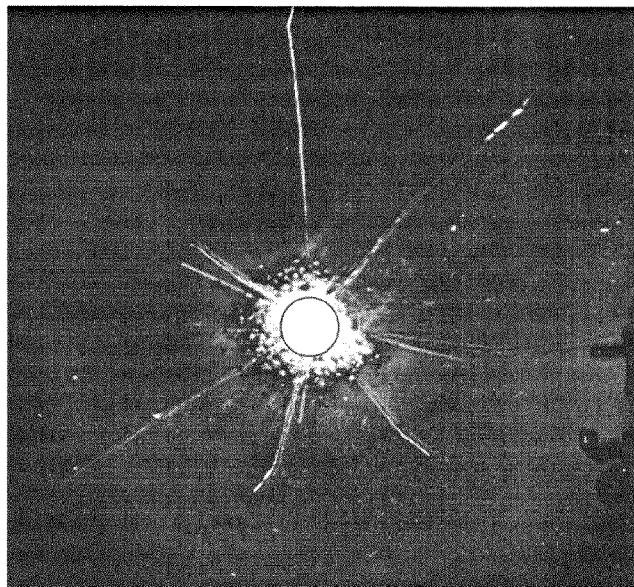


Fig. 1. 4X Optical image of a coverglass laminate.

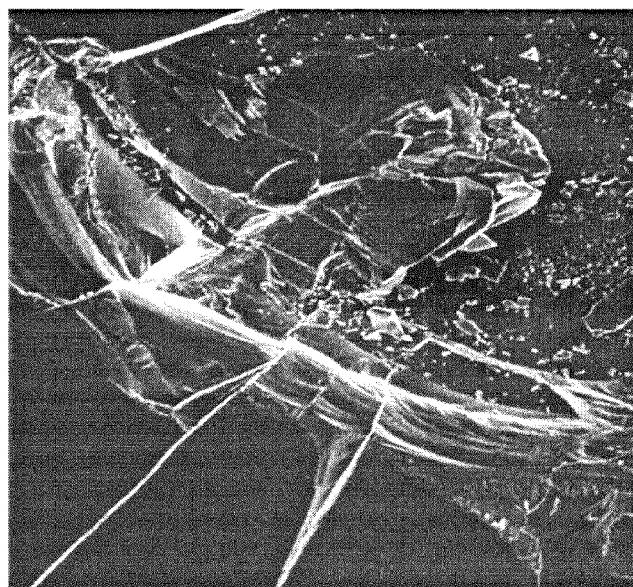


Fig. 2. A 40 X Typical SEM image of rear surface of a coverglass laminate.

Figure 3 shows a typical image of the cross-section of an impacted cover glass laminate sample. The impacted side, as well as the surrounding areas, suffered extensive damage to both layers of the glass laminate. The damage included extensive cracking of the glass layers and permanent deformation primarily within the impact area. Upon impact, the aluminum particle formed a crater concave towards the impact

direction. As a result, the glass on the impact side was extensively cracked but still remained attached to the deformed laminate. On the other hand, much of the

cracked glass on the rear side of the impacted cover glass was uplifted and spalled off.

IMPACT SIDE

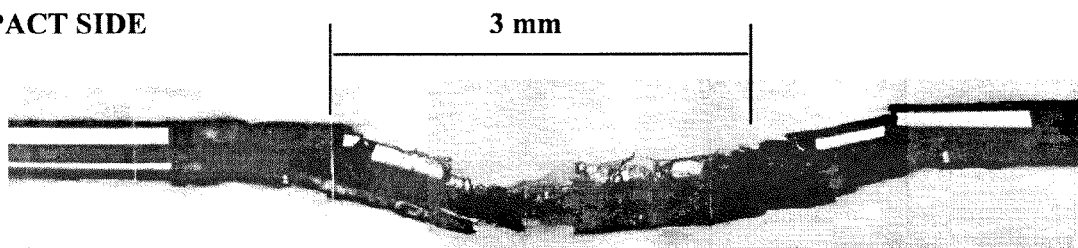


Fig. 3. Optical image of a cross section of an impact site on a coverglass laminate.

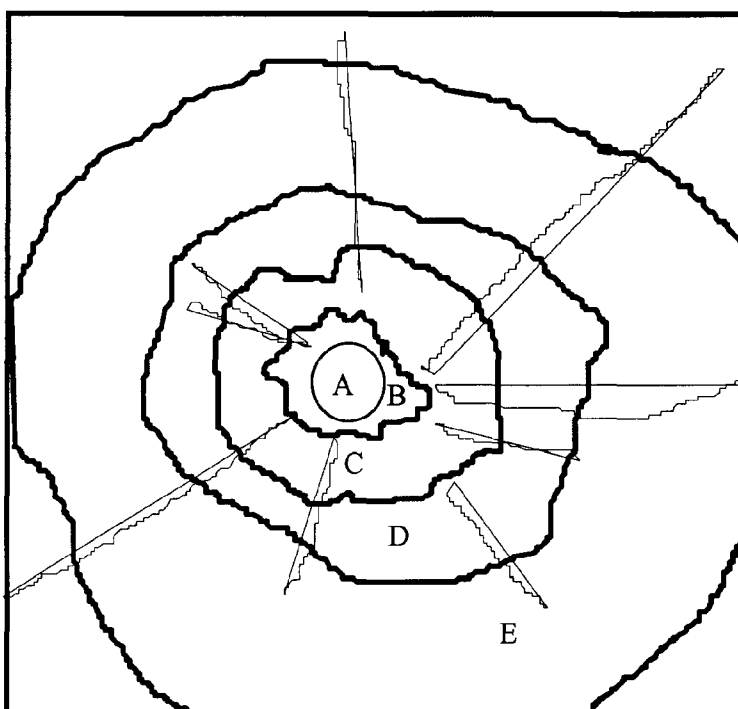


Fig. 4. Schematic of an impact area showing outlines of re-deposition regions.

When considering the overall efficiency of the solar cell, contamination from the vapor blown out of the impact crater may actually be the most serious consequence of damage to the cover glass. An interesting phenomena is seen when examining the deposition of ejecta from the impact crater onto the target surface. The ejected plasma forms bands of different material densities radiating out from the crater. Fig. 4 is a schematic diagram of the impacted sample shown in Fig.1, where area (A) represents

the size of particle impacting the surface; region (B) is the crater area in which material has been removed from the target; molten aluminum is found in area (C), where aluminum is also found on the entire sample in the form of trace deposited vapor; area (D) remained relatively free of re-deposition; and at a distance of over 1 cm from the impact site, area (E), the surface is heavily coated with the vapor removed from the crater.

An elemental analysis of the coverglass surface was completed using a PGT energy dispersive system attached to our scanning electron microscope, and produced the qualitative elemental analysis shown in Figures 5, 6 and 7. Figure 5 shows a "control" spectra consisting primarily of silicon and potassium for a coverglass sample that has not been impacted. Figure 6 is an energy dispersive spectra of the impact crater,

area (A). In the crater area, much of the glass has been removed, revealing the resin layer below which produces the resulting fluorine and carbon lines with reduced intensities of Si and K. The energy dispersive spectra in Figure 7 was collected for area (E) on the coverglass and shows the presence of carbon, fluorine, silicon and aluminum.

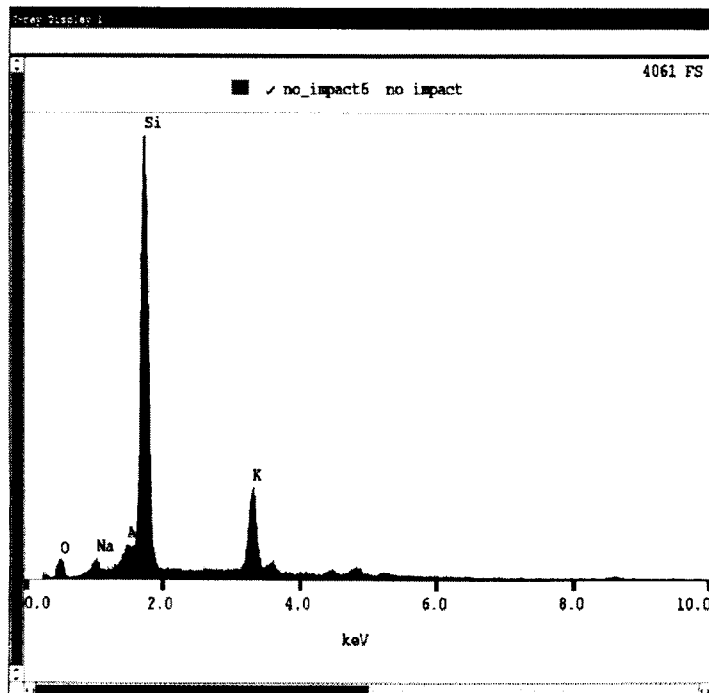


Figure5. Energy dispersive spectrum of a non impacted coverglass.

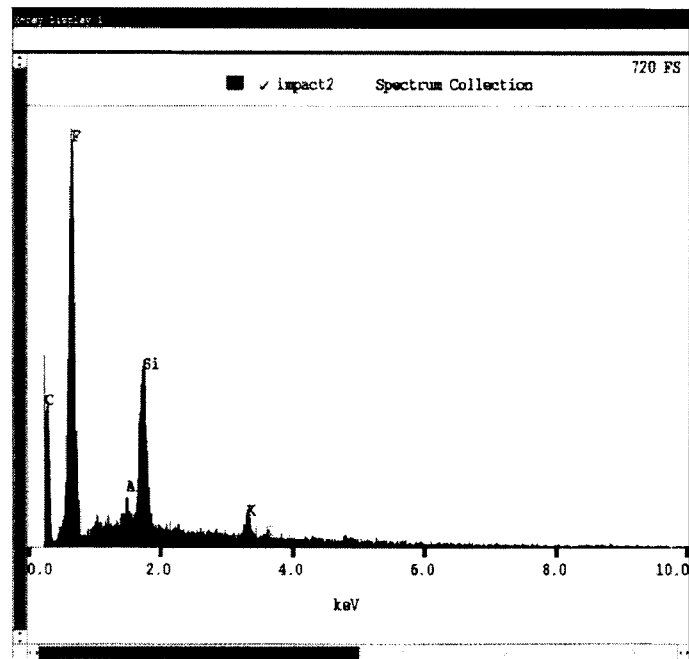


Fig. 6. Energy dispersive spectrum of the crater area (A) on an impacted coverglass.

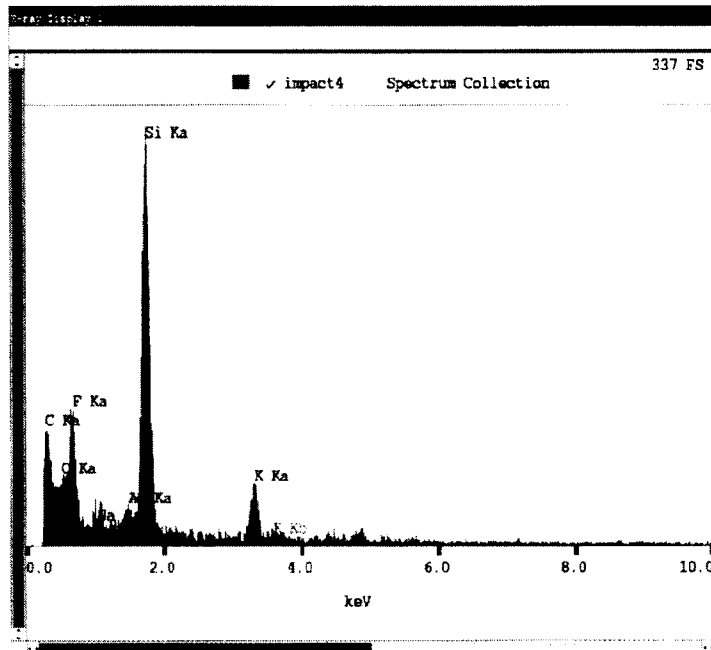


Fig. 7. Energy Dispersive spectrum of area (E) on an impacted coverglass.

The above spectra show that a deposition of fluorine, carbon, and aluminum are now present in regions of the once clean surface. The fluorine and carbon are generated from the vaporization and ejecta of the Teflon resin layer of the laminate. The probable source

of aluminum comes from vaporization of the aluminum flyer.

Light transmission measurements over the wavelengths from 300 nanometers to 1500 nanometers

were made using a Cray 5ev Spectrophotometer through impacted targets and control samples. This wave length range covers the useful solar spectra for solar cells. Figure 8 compares transmission spectra of an undamaged control sample to transmission spectra measured in area (E), 1.6 cm from the crater of an

impacted sample. These spectra show that a maximum transmittance of 90 percent exists at the wavelengths of interest in a control sample. However, degradation in the original sample transmittance by approximately 10 - 15% was measured across area (E) of the impacted sample.

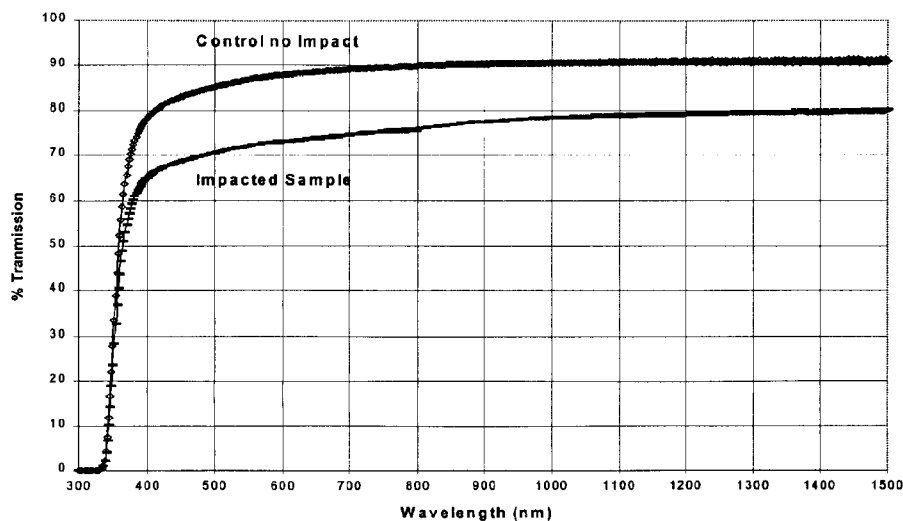


Figure 8 Transmission spectra of UV light through a coverglass target pre and post impact.

#### 4. DISCUSSION AND CONCLUSIONS

The results of our investigations revealed a very complex morphology at the damage site of the cover glass samples exposed to hypervelocity impacts by aluminum debris particles at velocities ranging between 2.5 km/s and 5.0 km/s. The range of velocities and energy used in these experiments are relatively small and were limited by the configuration of the laser used in this set of tests. As such, the data reported in this paper are not sufficient to establish a quantitative relationship between the debris' velocity, its kinetic energy and the size and geometry of the post impact damage sites. Nevertheless, the results of our semi-quantitative analyses clearly indicates that there is a typical damage pattern consisting of both mechanical damage and contamination. Formation of the impact crater is accompanied by the presence of molten aluminum and post impact deposition of contamination on the surface of the damaged cover glass sample. The ejecta consists not only of the cover glass laminate material removed from the crater, but deposition of vaporized contaminant and some fragments of the aluminum debris particle as well. Over 90 percent of the 40mm X 40mm sample experienced at least a 10 percent loss in solar transmission. Degradation of the solar cell efficiency due to loss of solar transmittance may be more critical to the solar cell performance than the actual mechanical damage from impact. Results of the work presented in this paper were a part of our systematic

and comprehensive effort to investigate the response of nonhomogeneous and composite materials to the harsh space environment, including hypervelocity space debris impact damage.

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