THE DEVELOPMENT OF LASER DRIVEN FLYER SYSTEM AND RESEARCH ON MICRON SPACE DEBRIS IMPACT EFFECTS

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ABSTRACT

A system for launching flyer using a Q-switched Nd: YAG laser with flattop appearance beam has been developed for simulating space debris impact effects. Flyer targets consisted of a layer of aluminium film and an ablation layer deposited on a circular fused silica substrate by ion beam sputtering method. The velocities of flyer were obtained by laser no-contact velocity measurement apparatus. Using this facility, three kinds of outer surface functional material of spacecraft, OSR, fused silica and white paint, have been experimented for studying their properties changes under space debris impact. The results showed that OSR thermal radiation properties had obvious degradation, white paints had only a little change, and the optical transmittance of fused silica nearly half decreased.

1 INTRODUCE

The Laser Driven Flyer (LDF) technique has been developed to be employed in many kinds of research fields, including micrometeoroids and orbital debris (MMOD) impact effect simulation [1-5], explosive initiation [6] and the dynamic properties investigation of materials [7]. While directing a laser pulse through the transparent substrate on which a metal film has been diffusion bonded or deposited, the metal foil is accelerated by expanding metal vapour produced by laser ablation, as shown in Fig. 1. LDF technique has advantages of little chemical contamination, simple and easy operations and low cost.

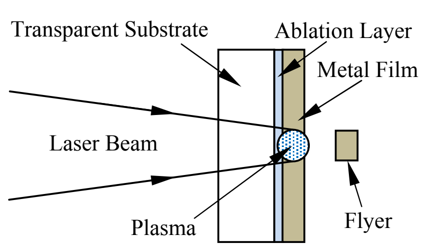


Figure 1. Schematic of Laser Driven Flyer Technique

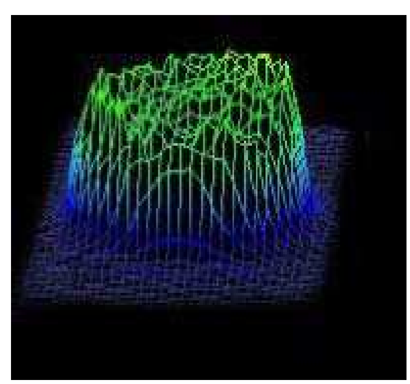
Spacecraft in the low earth orbit (LEO) are exposed to large amounts of space debris, diameter from few microns to few meters and even larger. The micron debris impacts would have great influence on the outer surface functional material of spacecraft, such as change of thermal control properties and degradation of surface optical properties.

2 DEVELOPMENT OF LDF SYSTEM

More than ten years, a set of Laser Driven Flyer system has gradually been developed at Beijing Institute of Spacecraft Environment Engineering (BISEE). The laser used in BISEE LDF system was a Beamtech SGR-20 Nd: YAG laser with the fundamental wavelength of 1064nm. A range of pulse energies was available from 120mJ to 1.2J. The beam diameter was from 0.8mm to 1.2mm and Q-switching produced 10ns full-width at half-maximum duration pulses.

2.1 Laser Beam

To obtain the higher effectiveness of the laser energy coupling to the metal foil, the desired shape of the laser beam profile is a flattop appearance, which has a distinct step in energy at the boundary as shown in Fig. 2. The flattop laser beam profile might result in a uniform distribution of energy to accelerate a single flat flyer to a desired velocity. Fig.3 shows that a poor laser beam profile and impact test result.



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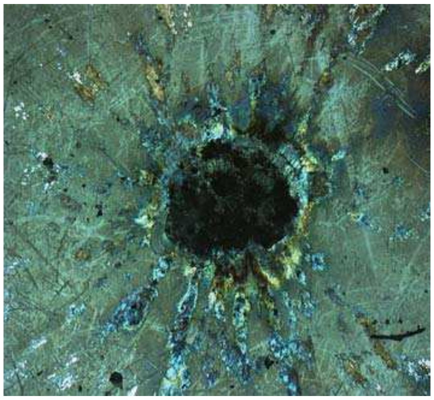

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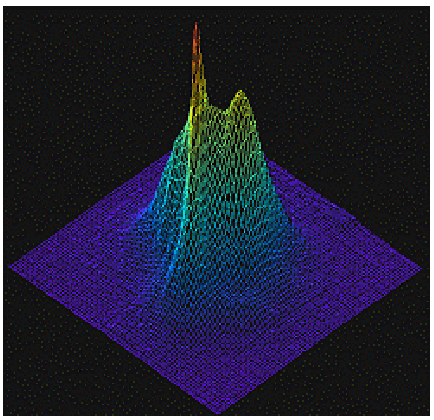
Figure 2. 3D Beam Profile of BISEE Laser Beam and Impact Test Result



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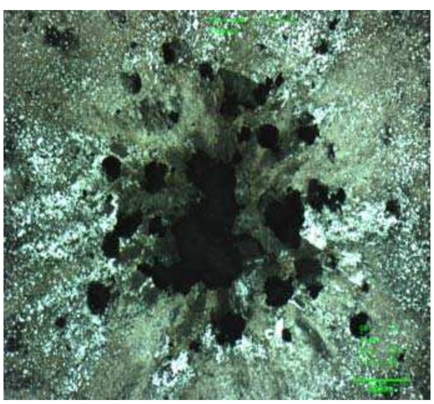

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Figure 3.3D Beam Profile of a Poor Laser Beam and Impact Test Result

Compare impact test results between Fig. 2 and Fig. 3, a non-uniform distribution of the beam energy in Fig. 3 resulted in a rupture of the flyer and produced a number of small foils rather than the desired single, flat flyer impact, shown in Fig. 2.

2.2 Flyer Target

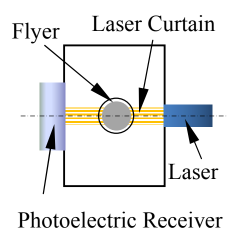
Because of theory of LDF launching technique, different transparent glasses were always chosen as the substrate material, such as fused silica [1], BK7 glass [2], Soda glass [3]. Although there were different damage thresholds among different glasses, generally they were enough to fit the requirement of experiments.

The metal foil material was aluminium considering its density close to the average reported debris density in LEO. The bond methods to fabricate the metal to glass substrate are critical to obtain the tenacious bonds between them in order to achieve the desired higher velocities. The field-assisted diffusion bond method [2,3], magnetron sputtering method [1], ion beam sputtering [4] and electron beam vaporizing [4] were several effective method in fabricating flyer target.

Besides a layer of aluminium film deposited, an additional ablation layer was always added between the substrate and aluminium film to improve the energy coupling efficiency, as shown in Fig. 1. The chosen ablation layer m aterial is more suitable for forming plasma than generating high pressure shocks on impact, so that the flyer kinetic energy might increase by a factor of nearly three [5].

2.3 Velocity Measurement

A high precise He:Ne laser was incorporated in our flyer velocity measurement set-up with photoelectric receiver, shown in Fig. 4.



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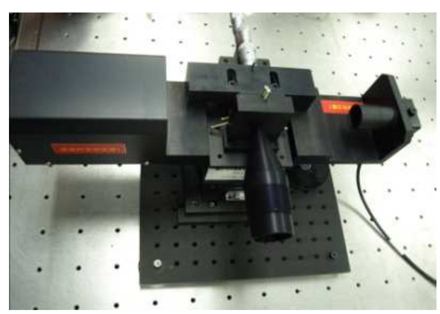

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Figure 4. Schematic of Laser No-contact In-site Velocity Measurement Set-up

When the flyers are driven through the laser beam, one light signal is caught by photoelectric receiver and one peak is detected by the oscillograph attached to it. By calculating duration times, the flyer velocity would be obtained using known flying distances. Laser curtain is 30μm in width.

3 EXPERIMENTS

Several outer surface functional materials of spacecraft had been studied for impact effect and properties degradation by BISEE LDF system. In the experiments, flyer target consisted of an aluminium film deposited by ion beam sputtering on a circular fused silica substrate, which was 30mm diameter and 5mm thick. The thickness of aluminium film was 7 μm and the beam diameter was 1 mm.

3.1 OSR

OSR is a kind of silvered glass second surface mirrors, which are applied as spacecraft outer surface material to reflect sunlight. OSR samples were 20 mm square with 0.15 mm thick, adhered to 2A12 aluminium substrates with 30 mm in diameter and 5 mm thick.

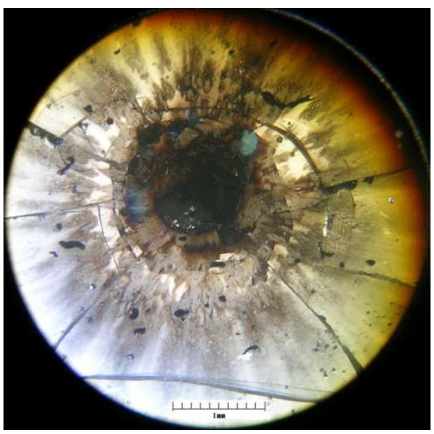

Figure 5. OSR Impact Result

Fig. 5 showed that at 4.7 km/s velocity impact, one 1.04 mm diameter crater had been formed on the sample and there were a few circular cracks and radial cracks around the crater. The solar absorptance of OSR sample was increased from initial 0.0980 to 0.5467 and the hemispherical emissivity had little change, decreasing from 0.811 to 0.805. The surface thermal radiation properties degradation was obviously.

3.2 Fused Silica

Fused silica glass has low coefficient of thermal expansion and exceptional optical quality, which is used for the outermost pane of the window as the critical part of the thermal protection system of spaceship. Fused silica samples were 30 mm in diameter and 5 mm thick.

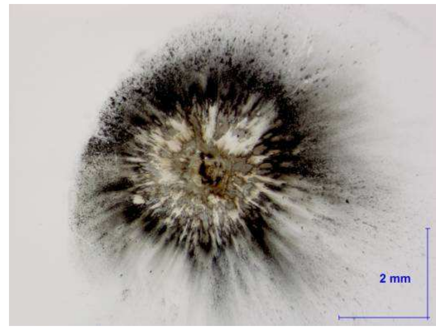

Figure 6. Fused Silica Impact Result

Fig. 6 showed that at 4.9 km/s velocity impact, there was one 0.97 mm diameter crater had been produced on the glass sample and the ejected zone with 5.12 mm diameter was around the crater. The transmittance of fused silica decreased from 0.92 to 0.48.

3.3 SR107-ZKWhite Paint

SR107-ZK white paints are able to withstand the abrupt temperature changes. The samples were 1.8 mm thick, sprayed on 2A12 aluminium substrates with 30 mm in diameter and 5 mm thick.

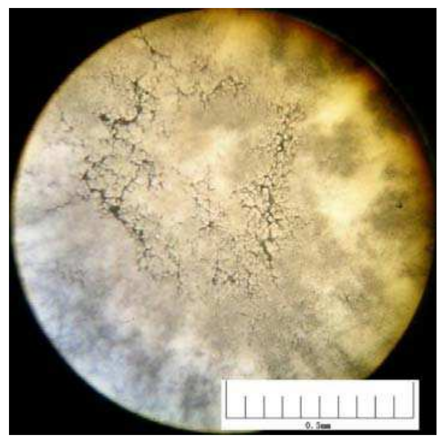

Figure 7. White Paints Impact Result

Fig. 7 showed that at 3.2 km/s velocity impact, no crater had been formed on the sample and there were a few fissures on the surface, 10μm maximum width. The surface damage zone was 2.99 mm diameter. The solar absorptance of white paints sample was increased from initial 0.2190 to 0.3914 and the hemispherical emissivity had little change, increasing from 0.863 to 0.873. So the absorptance-emissivity ratio of SR107-ZK white paints had a little change after flyer impact, compared with OSR.

4 CONCLUSIONS

A Laser Driven Flyer facility has been built for launching micron-thickness flyer with 2-8 km/s to simulate MMOD impact effect.

Three kinds of outer surface materials, OSR, fused silica and white paint, have been impact using LDF facility. OSR thermal radiation properties had a severe degradation, while white paints had only a little change after impact. The transmittance of fused silica decreased nearly 50%.

5 ACKNOWLEDGMENT

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