Hypervelocity Impact Experiment on Thin Film Structure

By Yoichi NAGAOKA1), Koji TANAKA2) ,and Susumu SASAKI2) ... for plasma measurement.

1
38V 10μF
10mm
Diameter:6mm
Resistor
        (a) External view                (b) Circuit

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Light-weight thin film (plate) structure is expected to play an important role in space development in the near future. Thin film solar array, large planar antenna, inflatable structure, and Solar Power Satellite (SPS) are the typical examples. We have carried out hypervelocity impact experiments on thin materials using the railgun accelerator at the Institute of Space and Astronautical Science, with the aim of clarification of the process of the plasma generation in case of the thin target. In our experiments, the velocity of the projectile is around 4.5 km/s. Copper (Cu), Aluminum (Al) and Silver (Ag) were used as the thin plate targets. Propagation of the impact-generated plasma was observed by a high-speed video camera and plasma probes. In the front side of the target, a spherical-shape plasma was observed, which propagated near the same velocity as the projectile. On the other hand, the impact-generated plasma propagating along the surface of the target was observed in the rear side. In particular, the plasma propagating along the plate surface in the rear side is practically important in the design of solar array paddle.

Key Words: Hypervelocity Impact, Impact-generated Plasma Propagation

1. Introduction

For a large structure in space, space debris or micrometeoroid impact at a hypervelocity can not be avoided. However, very few studies have been conducted on the hypervelocity impact phenomena to the thin film structure. We have studied the propagation of impact-generated plasma generated by the thin plate material, which will be important to design the thin (film) structure in space. The hypervelocity impact to the thin film structure usually generates an impact hole through the film and spreads impact ejectors in the surroundings. These effects are rather complicated than expectations. The size of the hole is often much larger than that of the projectile. The ejectors propagate not only in the forward direction, but also in the backward direction. In this paper, we present the behavior of the impact-generated plasma that was observed by plasma probes and a high-speed video camera.

2. Experiment

The impact experiments on thin film structure were conducted by the Space Plasma Laboratory at the Institute of Space and Astronautical Science. The accelerator consists of a railgun launcher, a vacuum chamber and a velocity measurement system. The railgun accelerates a projectile by electromagnetic force. We used a polycarbonate projectile, which is 13.9 mm in diameter, 8.0 mm long, and 1.0 grams in weight. In our experiments, the typical velocity of the projectile is around 4.5 km/s. The plasma generated at the impact was observed by a high-speed video camera and plasma probes. We took video images by the high-speed camera, Hyper Vision HPV-1 (Shimadzu Corp.). All images were taken with a framing speed of 500,000 frames per second and spatial resolution of 312 × 260 pixels. Plasma were measured by double probe system consisting of two disk-electrodes 6 mm in diameter, separated at a distance of 10 mm, as shown in Fig. 1 (a). Each plasma probe were connected to a power supply, a capacitor and a resistor, as shown in Fig. 1 (b). In order to trigger the measurement system, we used a wire grid. The double probes were configured in the rear and front side of the target, as shown in Fig. 2. “Front” and “Rear” in Fig. 2 are defined by the propagation direction of the projectile.

The experiments were carried out in a vacuum around 100 Pa in an experimental chamber. The experimental conditions are summarized in Table 1.
3. Results and Discussion

3.1. Measurement of plasma probes

As a typical example, the waveforms of the plasma probe current using the Cu target (Run 2) are shown in Fig.3. The time 0 represents the time of the impact on the target. The timing of the half maximum of the signal peak is used as the arriving time. Propagation velocity was calculated by the distance from the impact point to the plasma probe divided by the arriving time. We define an angle \( \theta \) measured from normal to the target surface to the direction toward the probes. Table 2 shows the results of Ch1 and Ch2 probe signals in Run 2.

### Table 1. Experimental condition

<table>
<thead>
<tr>
<th>Run</th>
<th>Target</th>
<th>Thickness [μm]</th>
<th>Projectile velocity [km/s]</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Cu</td>
<td>300</td>
<td>4.46</td>
<td>yes</td>
</tr>
<tr>
<td>5</td>
<td>Al</td>
<td>300</td>
<td>4.87</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>Cu</td>
<td>300</td>
<td>4.21</td>
<td>yes</td>
</tr>
<tr>
<td>8</td>
<td>Ag</td>
<td>100</td>
<td>4.35</td>
<td>yes</td>
</tr>
</tbody>
</table>

*1: Plasma probes, *2: High-speed video camera

### Table 2. Results of Ch1 and Ch2 measurement

<table>
<thead>
<tr>
<th>Target</th>
<th>Distance [mm]</th>
<th>Angle [°]</th>
<th>Time [μs]</th>
<th>Propagation velocity [km/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1</td>
<td>33.7</td>
<td>42.1</td>
<td>28.7</td>
<td>1.17</td>
</tr>
<tr>
<td>Ch2</td>
<td>24.7</td>
<td>66.1</td>
<td>14.6</td>
<td>1.69</td>
</tr>
</tbody>
</table>

3.2. Observation by the high-speed video camera

We observed the plasma propagation using the high-speed video camera with a framing speed of 2 μs per frame. Figure 4 shows a typical example of the camera image, together with the definition of the velocity vectors. Three representative directions with respect to the impact point are defined in the rear and front sides. In the rear side, (i) \( v_\parallel \) and (ii) \( v_\perp \) are the direction propagating along the surface of the target to the upper and lower directions, respectively. (iii) \( v_{II} \) is the opposite direction to the flight direction of the projectile. In the front side, (iv) \( v_\perp \) and (v) \( v_\parallel \) are the upper and lower directions along the surface. (vi) \( v_{III} \) is the same direction as the projectile’s flight. Figure 5 shows a series of video camera images obtained for Run 8 (target: Ag, 100 μm thick). First image shows the impact on the target occurred at 2 μs. Afterwards, generated plasma was propagating in space. The impact-generated plasma propagating along the surface of the target was always observed in the rear side. The spherical-shape cloud was observed, propagating and expanding in the front side. We calculated the propagating velocity of the plasma by the motion of edge of the bright cloud. In our previous study, it was confirmed that the bright cloud in the image approximately coincides with the plasma plume detected by the plasma probes. Table 3 summarizes the results of the calculated velocity for the three samples; Al 300 μm, Cu 300 μm, and Ag 100 μm. Figure 6 illustrates the velocity distribution in two dimensional map.
3.3. Dependence of plasma velocity on the target surface density

The velocity of the impact-generated plasma observed by the probes and video camera depends on the target material and the velocity of the projectile. Target surface density is defined by the product of volume density and thickness (Table 4). Figure 7 summarizes the velocity dependence on the target surface density in case of directions in (iii) (rear side), (iv) (front side), and (v) (front side). In the figures, the plasma velocity is normalized by the velocity of the projectile. Figure 7 suggests that the velocity of plasma generally increases with the target surface density. This means that the plasma particles are more heated or accelerated by the impact with the target of higher density.

<table>
<thead>
<tr>
<th>Run</th>
<th>Target</th>
<th>Volume density [g/cm$^3$]</th>
<th>Thickness [μm]</th>
<th>Surface density [g/cm$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Cu</td>
<td>8.92</td>
<td>300</td>
<td>0.268</td>
</tr>
<tr>
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<td>Al</td>
<td>2.70</td>
<td>300</td>
<td>0.081</td>
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<tr>
<td>7</td>
<td>Cu</td>
<td>8.92</td>
<td>300</td>
<td>0.268</td>
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<tr>
<td>8</td>
<td>Ag</td>
<td>10.49</td>
<td>100</td>
<td>0.105</td>
</tr>
</tbody>
</table>

4. Summary

We have studied the propagation of the plasma generated by the hypervelocity impact on the thin film (plate) structure. The propagation of the impact-generated plasma was observed directly by the plasma probes, as well as by the high-speed video camera. It has been confirmed that a spherical-shape plasma in front propagated near the same velocity as the projectile and a plasma cloud in the rear side propagated in parallel to the target plate. The plasma velocity was found to increase with the density of the target for the three different samples. In order to get a definite dependence of the impact-generated plasma on the target material, we need to make more experiments on a variety of targets. Since the momentum of the projectile seems to play an important role in the production and propagation of the impact-generated plasma, we plan to study the laser-induced plasma using the same target for comparison.
Acknowledgments

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References


Fig. 7. Velocity dependence on the target density. Propagating velocity is normalized by the projectile velocity (Vp).