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薄板への超高速衝突におけるプラズマ発生の研究

Plasma Generation caused by Hypervelocity Impact against Thin Sheet Materials

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衛星軌道上に存在するメテオロイドや宇宙デブリのような超高速飛翔体の脅威は年々深刻化しており、デブリバンパをはじめ、その対策が活発に研究されている。超高速飛翔体との衝突は、衛星の物理的破壊とともに、電気回路には衝突時に発生するプラズマが影響を与える可能性がある。超高速飛翔体による衝突破壊において、衝突した瞬間に運動エネルギーの一部は熱に変換され、その周囲の固体が気化する。気化した物質がイオン化してプラズマを発生させる。特に最近の衛星の大電力化に伴い、バス電圧や太陽電池パドルにおける発生電圧は高電圧化しており、衝突により発生したプラズマが契機となって、ショートやアーク放電を引き起こし、それにより高電圧機器を損傷させる可能性がある。また、プラズマの発生に伴い、電位変動現象も確認されている。
我々は、超高速飛翔体との衝突破壊現象において発生するプラズマの定量的計測や電位変動に関して研究を行っている。本報告では、宇宙科学研究所のレールガンや2段式軽ガス銃を使用した薄膜材料への衝突破壊実験に関して述べる。

Space debris is recognized as a serious threat to man's utilization of space. When debris collide the spacecraft, plasma will be generated and may make a impact on the spacecraft's equipments. To simulate the debris impact against the spacecraft, we carried out the experiments on the detection of the generated plasma by the hypervelocity impacts concerning the thin sheet materials using a two stage light gas gun and a rail gun accelerator of the Institute of Space and Astronautical Science. We observed phenomena when the projectile collided a target using a high-speed video camera, plasma probes and spectral photo sensors. Figure 1 shows a bright cloud of the impact experiment. After the projectile impacted against the target, a bright cloud was generated and moved both forward and backward directions from the target. Results of the experiments were compared with the estimations by our simple impact model for thin sheet targets.

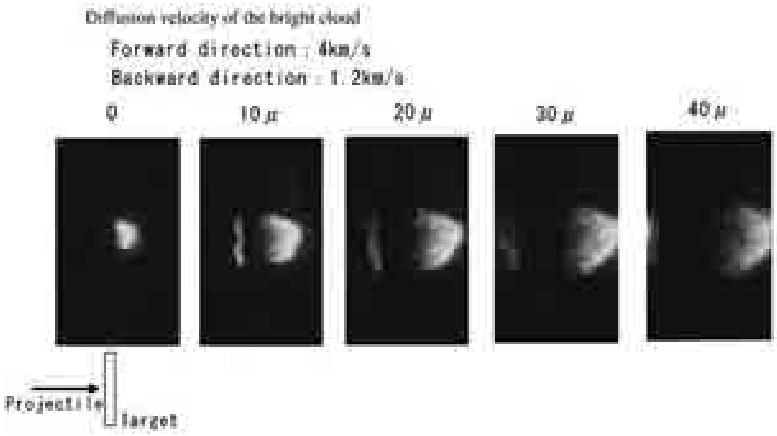

Fig1 Impact event recorded by the high speed video camera. Target : Al, Velocity of Projectile ; around 4km/s, Projectile: Polycarbonate, around 1g.

Plasma Generation by Hypervelocity Impact on Thin Sheet Materials

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Background

- The increase of the orbital debris are recognized as a serious and growing threat to man’s utilization and exploration of space.
- Typical debris impacts against a spacecraft in orbit are thought to occur at a velocity of around 10 km/s .
- Such hypervelocity impact against the spacecraft will possibly cause serious damages mechanically and electrically.

The Habble Space Telescope

Impact damage caused by meteoroid

Thin film solar array of IKAROS

B.Henson *et al.*, Preparing for the Future, Vol.5, No.4, 1995, pp.16-17.

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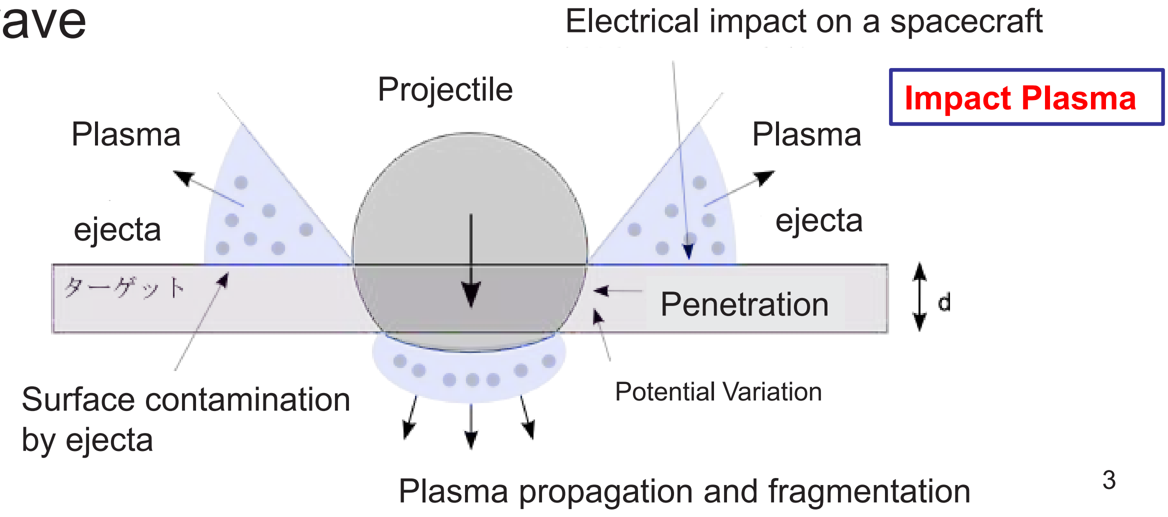
Phenomena by Hypervelocity Impact

Mechanical Phenomena : Crater, Penetration, Impact fragmentation

Electrical Phenomena : Plasma generation, Potential variation, Radiation of electromagnetic wave



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The purpose of this study

Measurement and estimation of the plasma generated by the hypervelocity impact.

Clarify the effect of the debris impact against the thin sheet materials of the spacecraft.

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Experimental Method

- Impact experiment concerning the thin sheet materials using a two stage light gas gun.
- Phenomena when the projectile collided targets were observed using a high-speed video camera, plasma probes and spectroscopic measurement.

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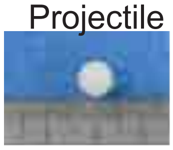
ISAS Two Stage Light Gas Gun

Maximum Speed of the Projectile
: 6 km/s

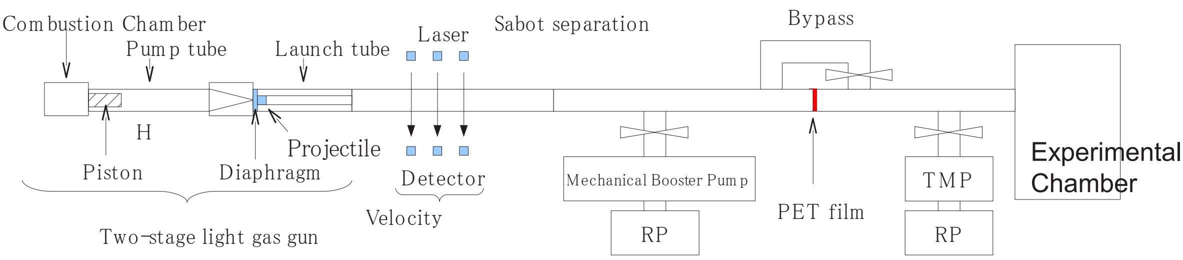
Light Gas : H2, He

High Speed Video Camera

Projectile



Material : Nylon 66
Aluminum



Vacuum conditions in the experimental chamber : less than 4×10^{-2} Pa (to avoid the collisional effect of the residual gas to the plasma propagation)

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Temperature Measurement by Photo diode

- Black body approximation was assumed.
- Wavelength : 500nm, 700nm, 900nm


Configuration of photo diodes

Calibration of light intensities by photo diodes

Wavelength [nm]	Spectral sensitivity [A/W]	Transmission factor [%]	Corresponding value
500	0.30	66	5.05
700	0.48	61	3.42
900	0.57	66	2.66

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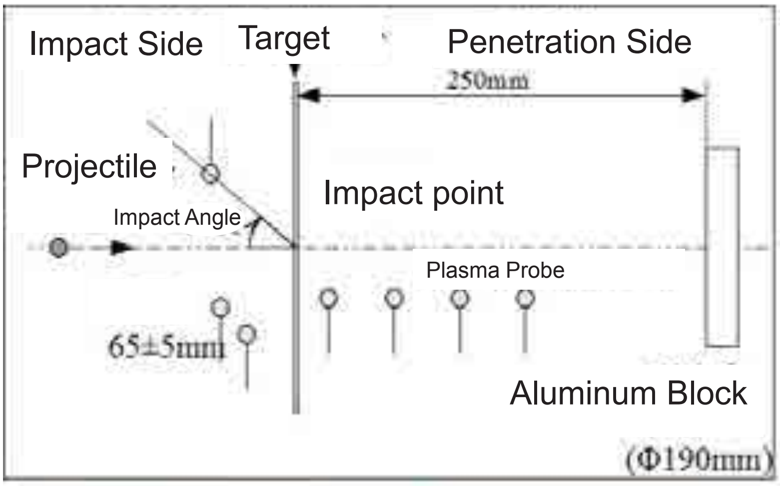
Plasma Measurement



Impact Side

Penetration Side

Double Probe

Measurement Circuit

κ=0.61

$$I_{i0} = \kappa N_e e S \left(\frac{kT_e}{m_i}\right)^{1/2}$$

Probe current

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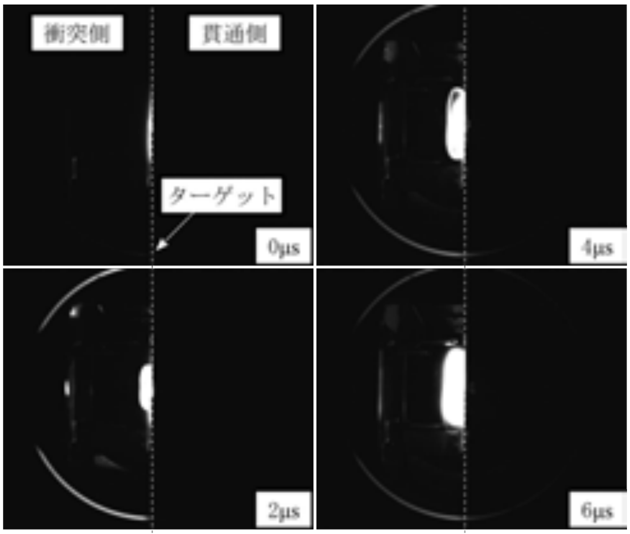
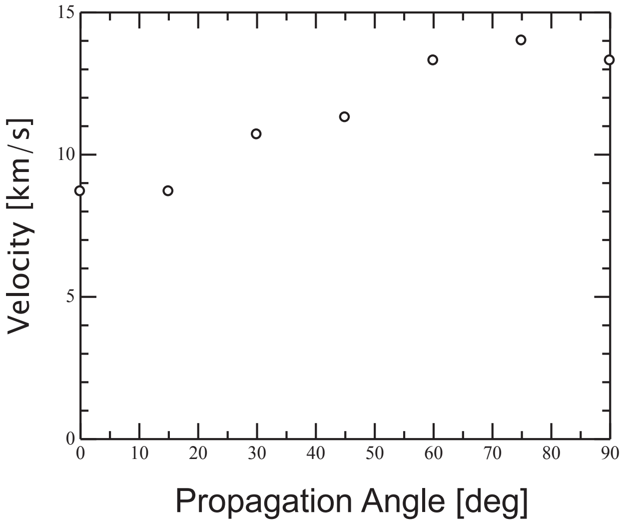
Propagation of luminous cloud（Al500μm）



Photograph by high speed video camera



Propagation velocity of luminous cloud

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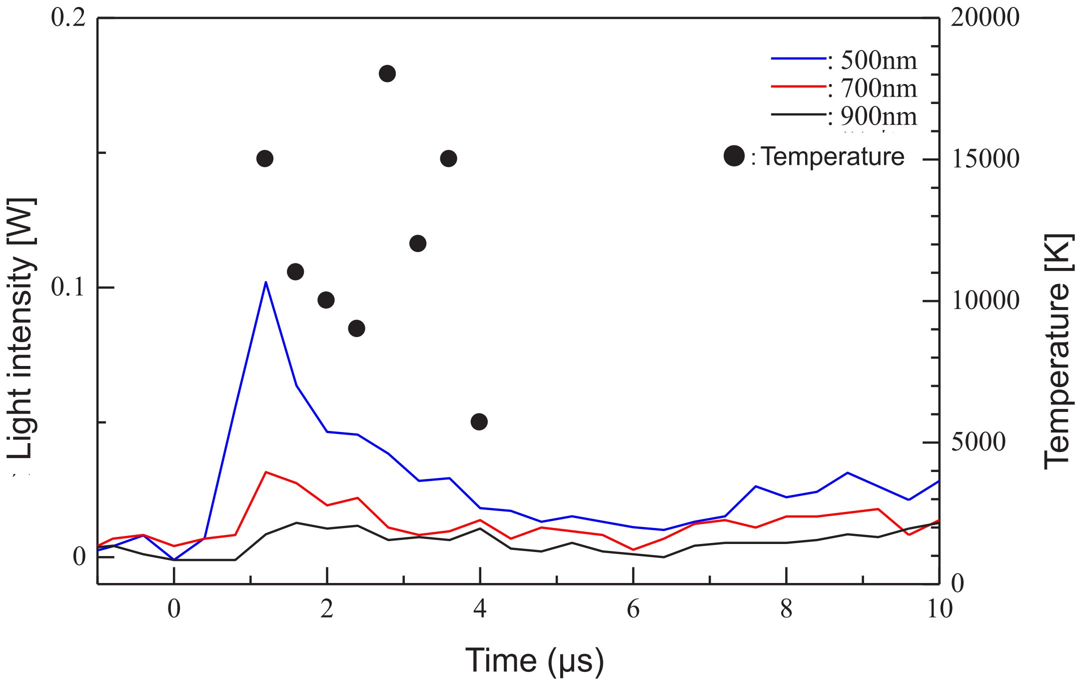
Light Intensity Variation
Target : Al（Thickness: 500μm）



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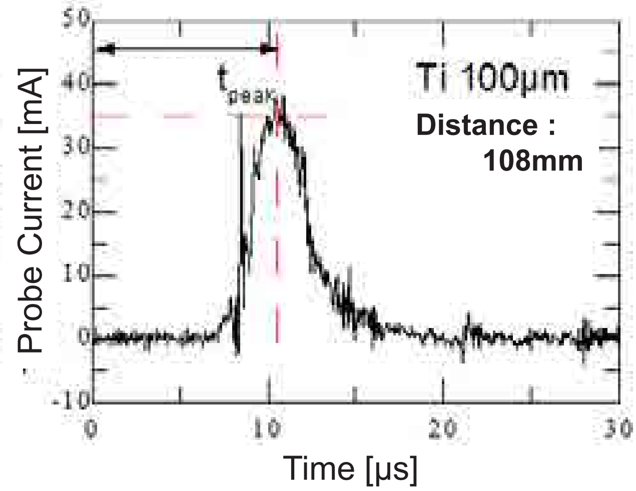
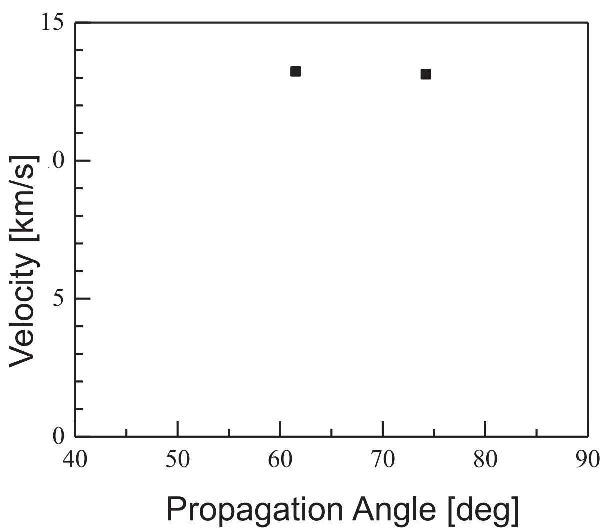
Waveform measured by plasma probe

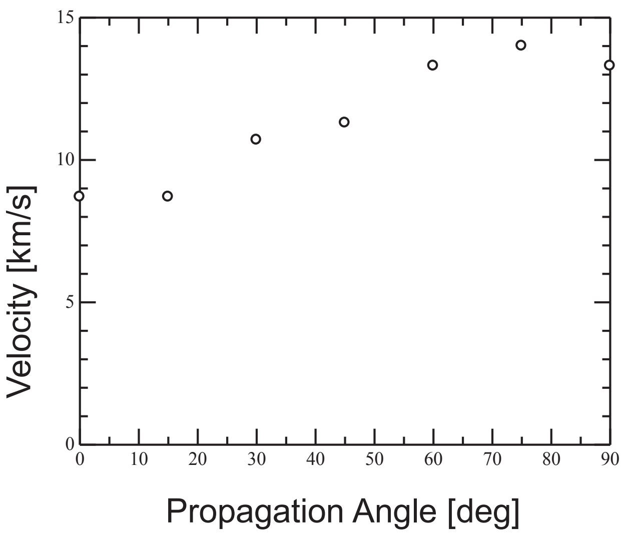


Plasma propagation velocity was calculated by hitting time of plasma at the probe.

Comparison between Propagation Velocity by Luminous Cloud and one by Plasma (Al, Thickness:500μm)

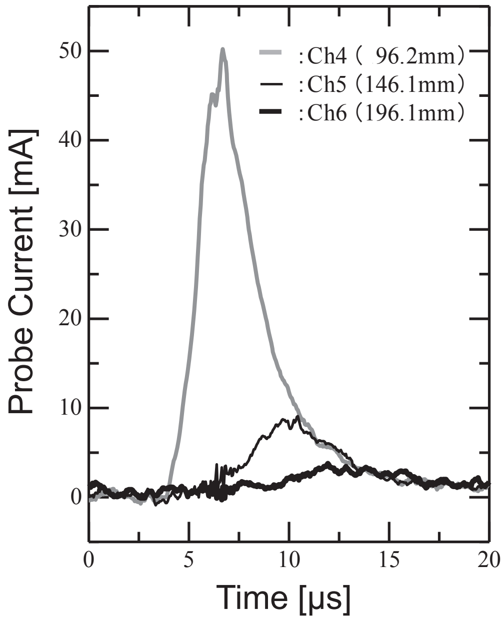


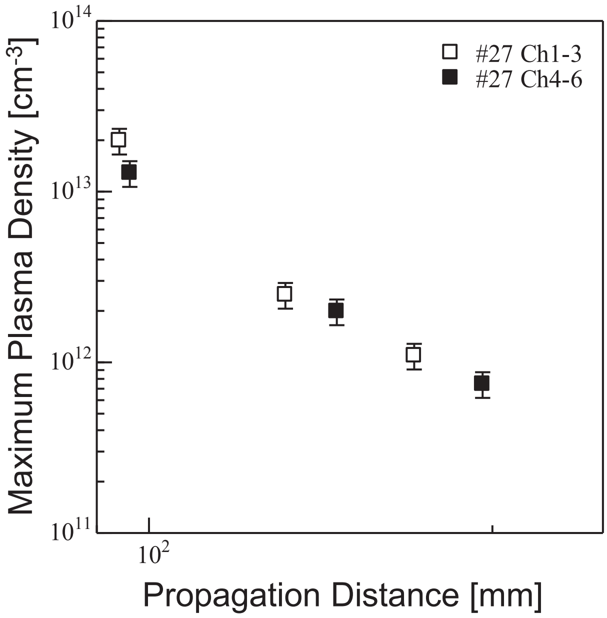
Plasma



Luminous Cloud

Plasma density – Distance Relationship





Plasma density decayed with propagation distance.

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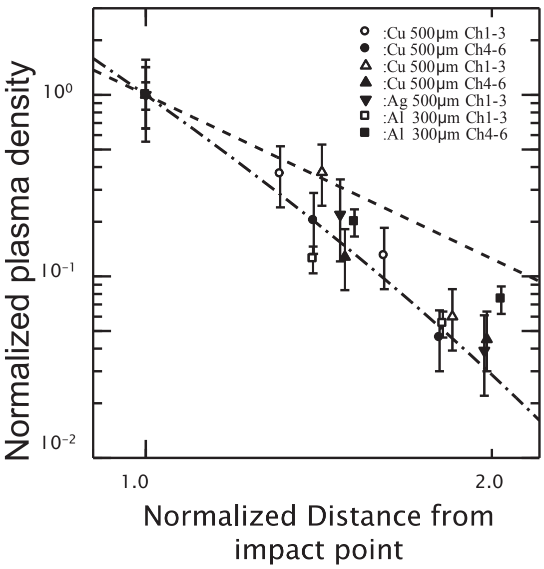
Relationship between plasma density and propagation distance



The experimental results show that the maximum plasma density decreased as L^{-4} ~ L^{-5}.

L：mean free path

If we assume that the background gas density temporarily increased at the impact, the experimental results should be affected.

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Propagation of impact plasma

The model based on a drift Maxwellian distribution suggests that the maximum plasma density n_{max} is deceased with the distance from the impact point (L) as L^{-3}.

$$n_{max} \propto \frac{1}{L^3}$$

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Results

- The experimental results show that the plasma density was maximum between 70° and 90° and decreased with the decreasing angle.
- The maximum plasma density is deceased with the distance from the impact point as L^{-3} when a drift Maxwellian distribution is assumed. However, the experimental results show that the maximum plasma density decreased as L^{-4} ~ L^{-5}.
- The plasma velocity was generally highest along the target surface and decreased with the angle from the surface.

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Conclusions

- The plasma density observed in the experiment was as much as 10^{13} cm^{-3} at 10 cm from the impact point, which is much higher than the plasma density in ionosphere by the 7th order of magnitude.
- It is reported that the high voltage solar array with more than 100 V has a potential risk for the electrical discharge in the ambient plasma density more than 10^{10} cm^{-3}.
- The amount of the plasma production depends on the impact velocity, mass and material of the projectile, and thickness and material of the target.
- Our experimental results suggests that the area with the discharge risk on the solar array panel of the spacecraft in space could be extended 1-2 m around the impact point of space debris.

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