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微小デブリ衝突による電力ハーネスの電気的損傷

Electrical failure on satellite's power harnesses due to small debris impacts

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デブリ衝突による衛星の機能損失には，衛星構体を物理的に破壊する機械的損傷だけでなく，太陽電池や電力ハーネスといった電源系機能の低下・喪失をもたらす電気的損傷も含まれる．特に，電力ハーネスの持続放電およびそれに起因した地絡・短絡故障といった電気的損傷は，比較的衝突頻度の高い直径 1 mm 以下の微小デブリでも発生しうることが，これまでの研究により示唆されている．したがって電力ハーネスの電気的損傷リスクを正しく評価することは，衛星に適切なデブリ防護設計を施す上で重要である．本講演では，従来研究よりも実環境に近い衝突条件および回路構成を用いた衝突実験の結果を報告する．衝突実験には JAXA 宇宙科学研究所の二段式軽ガス銃を用い，直径 1 mm 以下の酸化アルミニウム粒子単発を秒速 7 km で衝突させた．実験の結果，太陽電池裏面の電力ハーネス単線に関しては，微小デブリ衝突により持続放電といった甚大な電気的損傷が発生するリスクは低いことが示唆された．

Loss of satellite functions due to space debris collisions includes not only mechanical failures like breakup of satellite main bodies but also electric failures such as decrease in power supply from solar arrays and power harnesses.
In particular, the past hypervelocity impact experiments suggest that sustained arcs and resulting ground faults on the power harnesses could be triggered by impacts of tiny space debris particles smaller than 1 mm which constantly impact on satellite surfaces. To perform the appropriate satellites' design for debris protection, it is important to adequately assess the risk of electrical failures on the satellite power harnesses. This presentation reports the results of hypervelocity impact experiments with more realistic impact conditions and simulated internal circuits than the past studies. In the experiments, single particles of aluminum oxide smaller than 1 mm were accelerated to nearly 7 km/s by the two-stage light gas gun of JAXA/ISAS. Our results suggest that the risk of fatal electric failure on a single line of power harness routed behind the solar array paddles is lower than that expected from the past studies.

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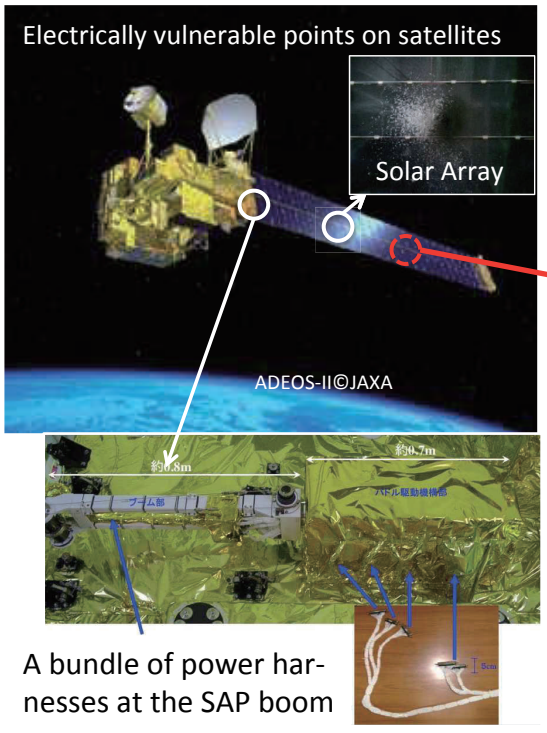
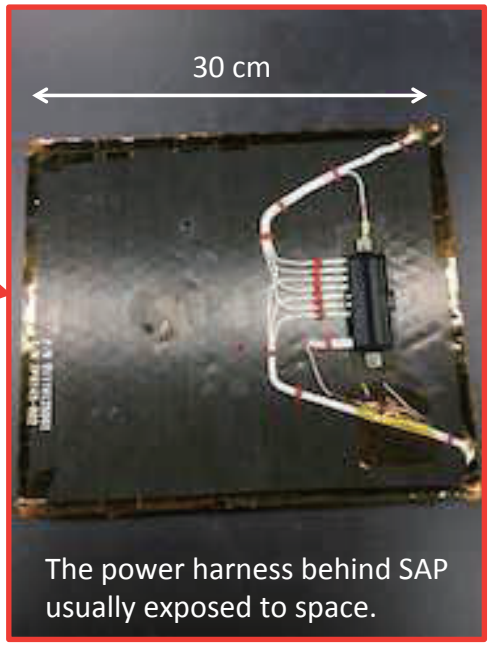
Electrical failure on satellites due to small debris impacts

Electrical failure on satellites
= Malfunction of satellites power system due to impact-induced sustained discharge



A bundle of power harnesses at the SAP boom



The focus of today's presentation

Electrical failure on satellites due to small debris impacts

Impact-induced sustained discharge on the power harness (ground experiment)
Projectile: ϕ300μm, SUS304, 4.0km/s, Power: 100V/3A

Small space debris (<1 mm) could cause the considerable failure on satellites.

3

Electrical failure on satellites due to small debris impacts

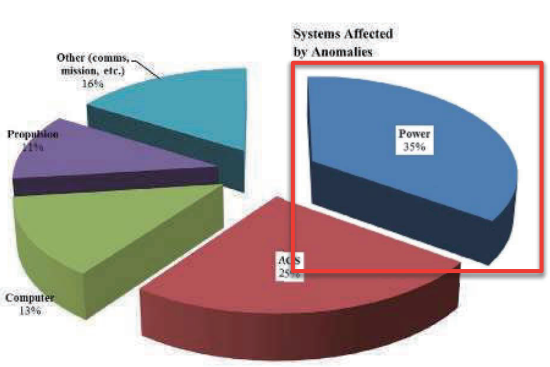


Fig. 1. The system most affected by anomalies is the power system which largely includes solar arrays and batteries.

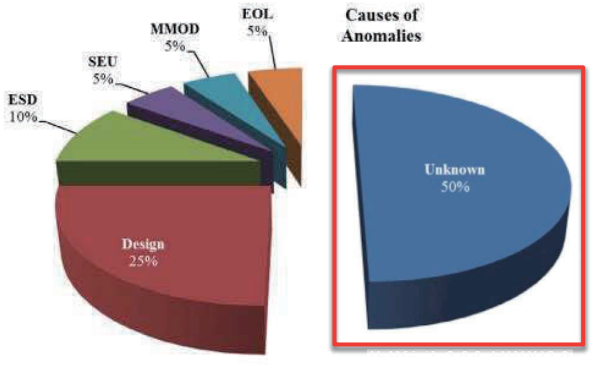


Fig. 2. Half of the anomalies are of unknown cause – this is fairly normal in databases of anomalies.

McKnight, D.S. 2016, "Orbital debris hazard insights from spacecraft anomalies studies", Acta Astronautica 126, 27-34

35% of in-orbit failures was occurred on power system
and the cause of 50% of in-orbit failures was unknown.

4

Previous work 1: Investigation of impact-induced discharge on the harness bundle at the SAP boom

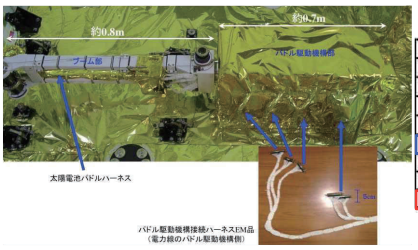
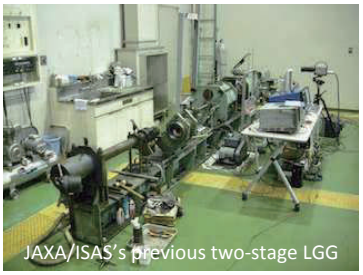


表 II- 2 電力ハーネス衝突試験結果

No.	束数	電源仕様	プロジェクタイル	サイズ (mm)	速度 (km/s)	放電時間 (msec	衝突痕	結果
1	単層	110V/2A	Glass	0.1	3.55	8	多数	芯線みえる
2	単層	110V/2A	Al2O3	0.3	3.3	0	数個	芯線みえる
3	単層	110V/2A	Glass	0.2	4.17	5	数個	芯線みえる
4	単層	110V/2A	Al2O3	0.5	3.35	持続放電	2個	地絡
5	単層	60V/2A	Al	0.15	3.34	0	数個	被覆のみ損傷
6	三層	60V/2A	Al	0.6	3.97	持続放電	数個	断線
7	三層	100V/3A	Glass	0.5	4.35	持続放電	数個	持続。上下線間短絡
8	三層	100V/3A	Stainless	0.3	4.01	持続放電	2から3個	持続。上HOT断線。

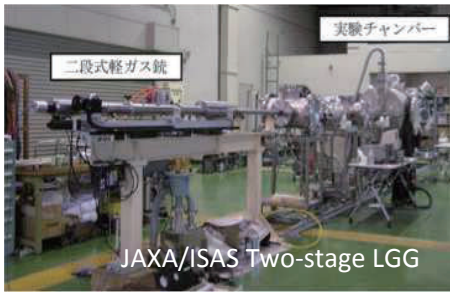
JERG-2-144-HB001A, Space Debris Protection Manual, 7.2.4 Power harness

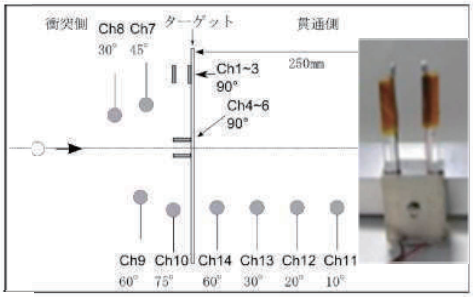


The JAXA's Space Debris Protection Manual recommends to protect the satellites from impacts of 0.2mm debris particles.

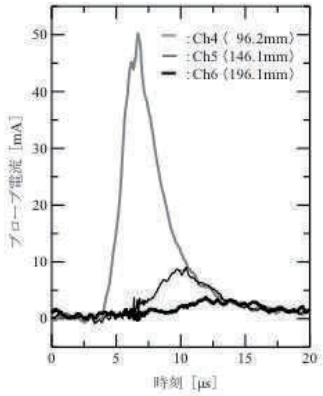
Previous work 2: Modeling of impact-induced plasma

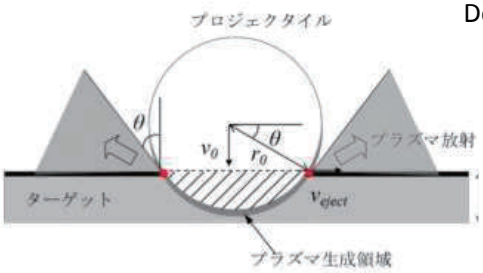
Nagaoka2013, 宇宙機の薄型パネル構造への超高衝突における電気的現象の研究





Double probe method





$$n(t,L)=\frac{2}{\pi}\alpha^2 q(\theta)\frac{1}{L^2 t}\left(\frac{L}{t}-v_d\right)^2 exp\left\{-\alpha\left(\frac{L}{t}-v_d\right)^2\right\}$$

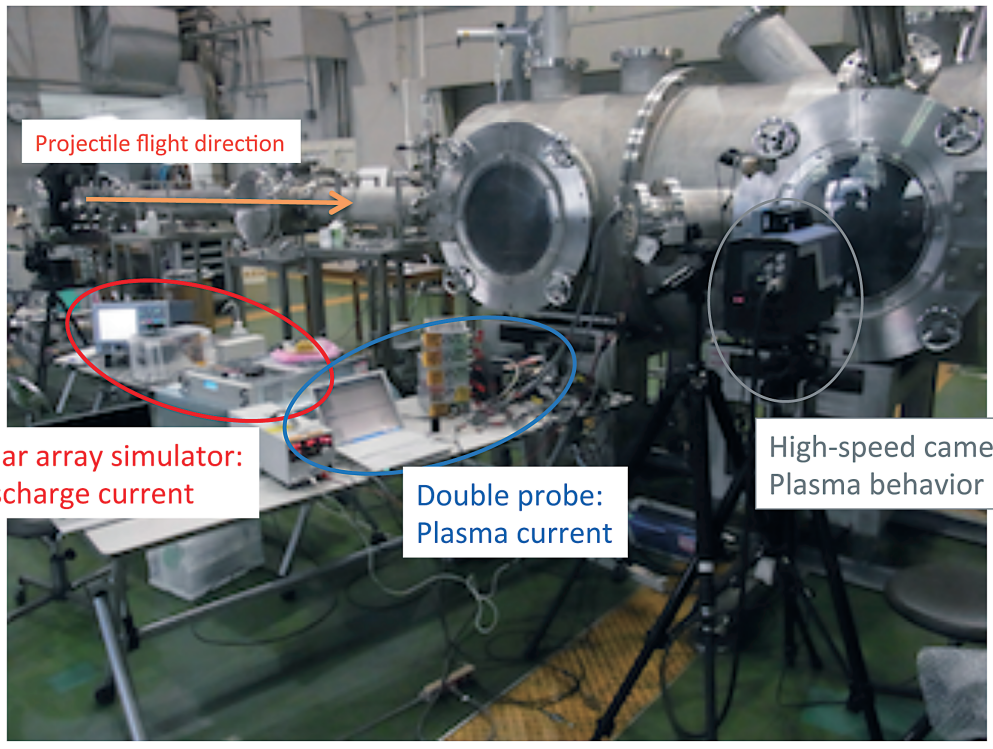
The equation of impact-induce plasma density and diffusion

Our ultimate goal

To develop the physically-based risk assessment method for electrical failure on the satellite power harness.

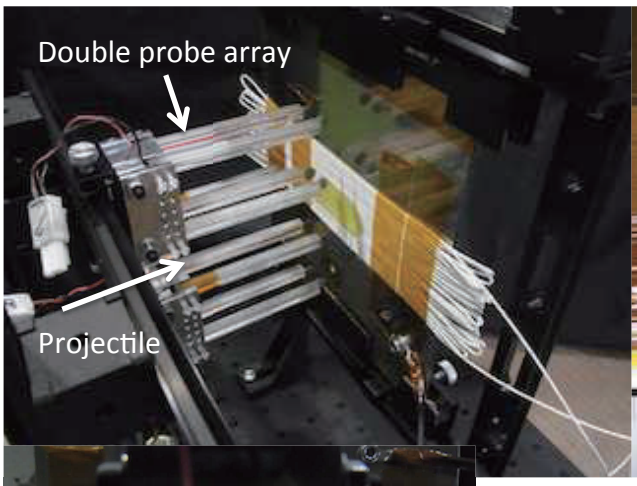
7

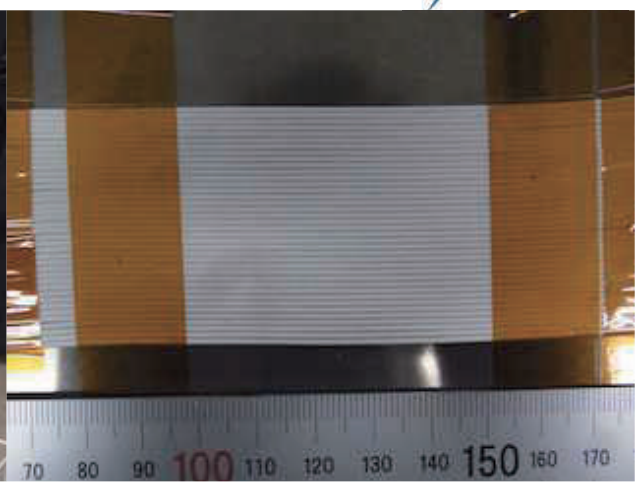
Hypervelocity impact experiment: Simultaneous measurement system for discharge and plasma

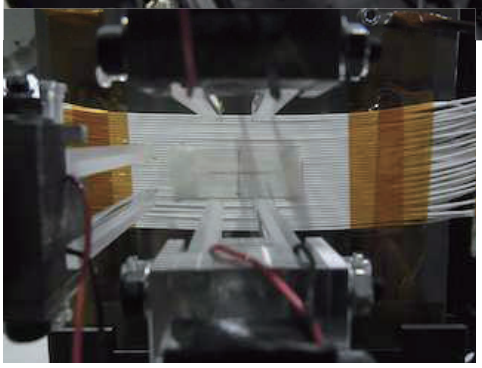


8

Impact target







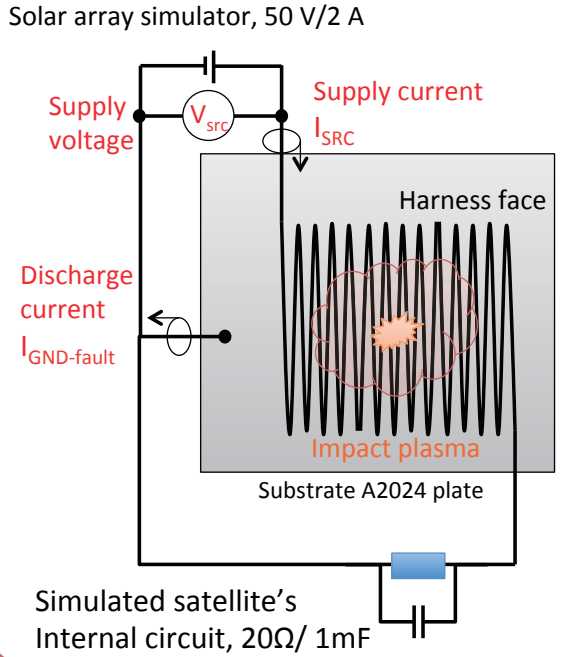
Harness: TE connectivity SPEC55 AWG22
Substrate: A2024 plate t3mm

Projectile passes through the double probe array

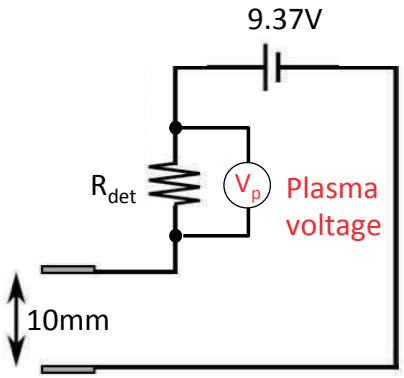
9

Measurement circuit

Discharge measurement



Plasma measurement



Electrode ϕ6 mm

・Five double probes set between 1cm and 5cm from the impact point with a 1cm step.
・Detection resistance R_{det}: 24.0Ω～9.76kΩ

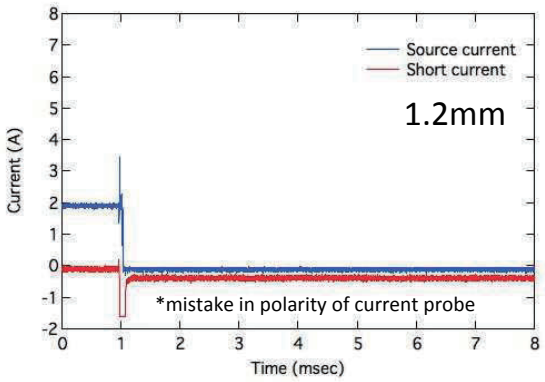
10

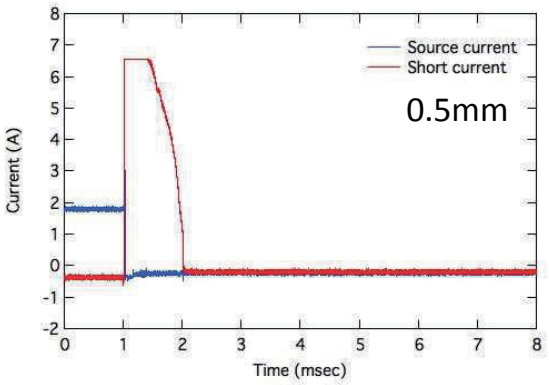
Experiment condition

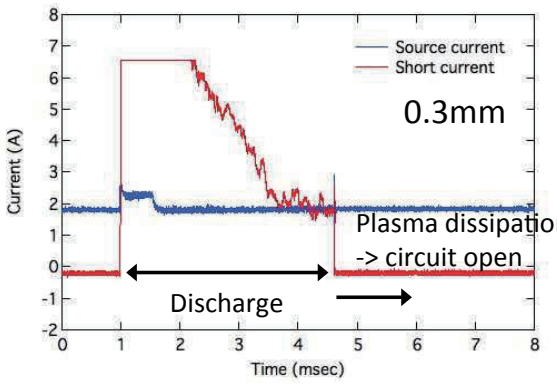
Shot ID	Material	Diameter (mm)	Impact velocity (km/s)	Power supply
160205-1	SUS304	0.5	6.09	50V/2.5A
160628-1	Al_2O_3	1.2	6.94	50V/2A
160630-3	Al_2O_3	0.5	6.70	50V/2A
160630-4	Al_2O_3	0.3	6.89	50V/2A

11

Results 1: Discharge measurement







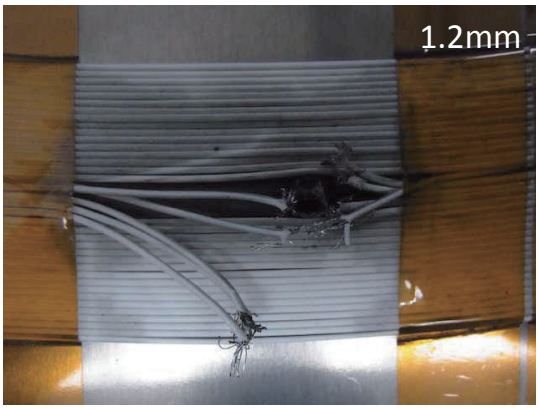
・No sustained discharge (>100msec).

・The smaller projectile impacts, the longer discharge.

・0.3 mm impacts kept the harness connection.

12

Results 2: Damage observation

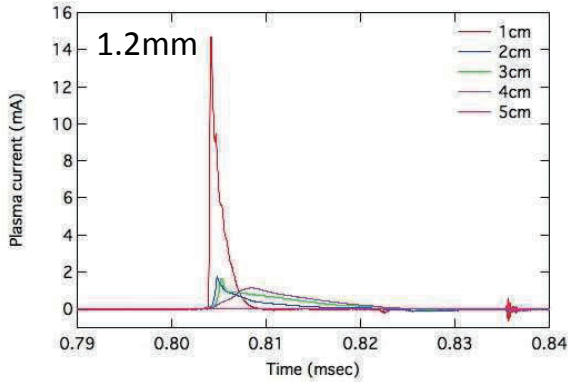


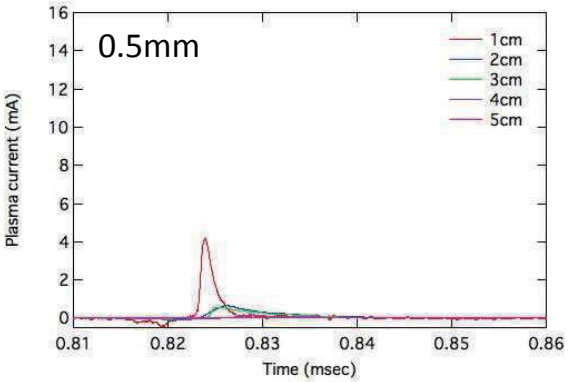
・The larger projectile impacts,
the farther distance between the substrate plate (GND) to the exposed harness core (HOT).

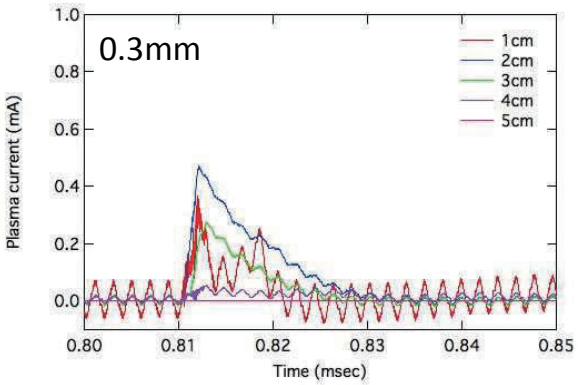
-> Shorter the distance between GND and HOT, more longer discharge?

13

Results 3: Plasma measurement





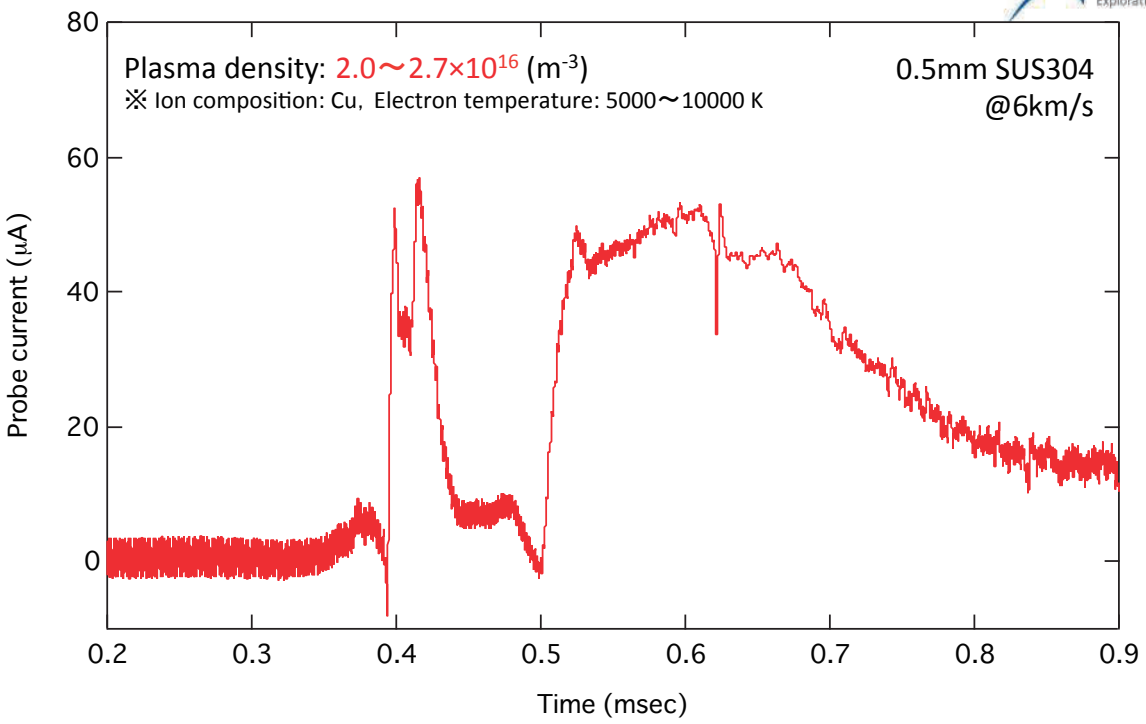


・The larger projectile impacts,
the higher plasma current (=density).

・The closer probe basically showed
the higher plasma current (=density).

14

実験結果 3: プラズマ計測



Nagaoka model predicts the peak plasma density of 5.4×10^{16} (m^{-3}).
-> consistent with the experiment result within an order

15

Summary and future work

- ✓ The developed simultaneous measurement system for discharge and plasma density functioned well.
- ✓ No sustained discharge was observed on the simulated power harness behind SAP by impacts of 0.3-1.2mm Al_2O_3 projectiles at 7km/s.
- ➢ To apply the plasma density model to the obtained experiment data.
- ➢ To obtain more statistics to check if the sustained discharge is probabilistically occurred.
- ➢ To revisit the risk assessment for the harness bundles at the SAP boom.
  *In the previous work, shot-gun style which provide multiple impacts of projectiles at one shot.

16