MATERIAL DEPENDENCE OF MICROWAVE EMISSION DUE TO A HYPERVELOCITY IMPACT

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ABSTRACT

Formerly, microwave emission due to a hypervelocity impact to a metal had been found. The same experiments were carried out for various kinds of material: metal, ceramic, brick and rubber. The waveforms are quite different each other. For an aluminum plate, many pulses are observed in addition to almost continuous generation of random noise in 22GHz-band. For an alumina ceramic, most signal power is in the form of random noise with a small number of pulses. In the cases of a red brick and a polyurethane rubber, a small amount of random noise is observed. The generated power for each material is correlated with electric conductivity and density. The result shows especially that the averaged microwave power has strong correlation with the density. The mechanism of the microwave generation is, therefore possibly related with the destruction process of materials.

1. INTRODUCTION

An impact velocity of space debris to a satellite reaches a hypervelocity, several km/sec. We carried out experiments to study associated effects due to a hypervelocity impact, and detected microwave emission [1]. The phenomena were reported for the first time though a light flash[2] and a plasma generation[3] had been known.

Some features of the microwave emission are confirmed. The strength of the emission is dependent on the destruction degree of the target [4]. Simultaneous measurement of the microwave and the light image are also carried out. There is a different feature that the microwave emission is intermittent while the light emission is continuous [5]. A dependence on the impact velocity is also investigated. The strength of the microwave emission increases with the impact velocity with a power more than 2.

The final goal of our research should be to understand the characteristics of the microwave emission due to an impact, and to clarify the mechanism of the phenomena. But it needs much effort and a long time which will be satisfied in a widely accepted collaboration.

Meanwhile, the purpose of this paper is to investigate the dependence of the microwave emission on target materials, and to clarify the correlation to the physical properties of the materials. In the experiment, we chose 4 kinds of materials: aluminum as a typical metal, alumina ceramic as a similar material to a thermal protector, red brick and polyurethane rubber both to compare with the former two materials.

In Sec. 3, the experimental results at 22GHz frequency band are explained. In Sec. 4, the emitted power is formulated to be estimated with calibration. Finally, the emitted power is studied in correlation with the physical properties of the target materials.

2. EXPERIMENT SET-UP

The experimental set-up is shown in Fig.1. A projectile is accelerated by a rail gun, an electromagnetic accelerator, and impacts on a target in a vacuum chamber. The velocity is kept about 4 km/sec. The projectile is cylindrical polycarbonate with a weight of 1 gram, a diameter of 13 mm and a length of 6 mm. The chamber is 480 mm inner diameter and equipped with two windows. A receiving antenna for microwave detection is located near a window out of the chamber.

A light emission is measured by an image converter camera located on the opposite side. Thin wires are located before the target to give a trigger to instruments. We choose four materials as the targets: an aluminum plate with a thickness of 27 mm, an alumina ceramic plate with a thickness of 10 mm, a red brick with a thickness of 60 mm and a polyurethane rubber with a thickness of 100 mm.

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The receiving system in 22 GHz band is shown in Fig.2. A horn antenna whose gain is 21 dBi is used. Microwave emission is detected by a heterodyne scheme and a low noise amplifier (LNA) to enable high sensitivity. The radio frequency (RF) band from 22 to 23 GHz is converted to the intermediate frequency (If) band by the mixer. Accordingly, the half-power frequency bandwidth in the IF band is from 150kHz to 500MHz, as shown in Fig.3. the total gain of the receiver is 62 dB. The linearity of the receiver is important to estimate the detected power level. Measured characteristics are shown in Fig.4. Below 10^{-5} W, the output voltage is not saturated and proportional to the square-root of the power so that the linearity was confirmed. The sampling frequency is 4 GHz and the measured period is 500 μsec from the trigger input. The signal is recorded 50 μsec before the trigger input.

3. EXPERIMENTAL RESULTS

In case of the aluminum target, the projectile made a crater of 30mm diameter and 12mm depth on the plate. In cases of the alumina ceramic and the red brick, the projectile broke up the targets to hundreds of pieces and dispersed these fragments in the chamber. The target of the polyurethane rubber was made a crater.

The measured waveforms are shown in Fig.5. The impact time is indicated by a dotted line in each figure. With the aluminum target shown in Fig. 5(a), a small pulse is found 4 μsec after the impact and a large pulse appear from 22 μsec after the impact, and many pulses intermittently continue till the end of measurement. The pulses are most dense for 120 μsec from the impact. Besides the pulses, the noise level increases after the impact. Any signals are not found before the impact.

With the alumina ceramic target shown in Fig. 5(b), the voltage gradually increases after the impact, and these signals continue until the end of measurement. Striking pulses appear at 224 μsec and 419 μsec. The increase of the noise level can be clearly recognized after the impact. Any signals are not found before the impact.

With the red brick target shown in Fig. 5(C), the ordinate is expanded to clearly show the effects of the impact. A pulse is found 11 μsec before the impact. The noise level is increased from the impact time to about 100 μ sec. There are no pulses after the impact.

With the polyurethane rubber target, there are not any signals of pulses nor the increased noise level after the impact, as shown in Fig. 5(d).

The detected signals are composed of two kinds of waveforms: sharp pulses whose width is about 2 nsec, and continuous small wave like white noise. The signals have quite different features between four targets. For example, the number and the amplitude of pulses from the aluminum target are quite larger than those from other targets.

4. ESTIMARION OF EMITTED POWER

The experimental results should be analyzed from the viewpoint of two kinds of emitted microwave powers: an average power given by total signals and the power of a maximum pulse in each measurement.

Only a part of the total emitted power P_0 is received by the antenna in Fig.1. Assuming the isotropic radiation from the impact point, the received power by the antenna is expressed by

$$P_r = P_o \frac{1}{L} Gr, \tag{1}$$

where G_r is the antenna gain. And the free space loss L is given by

$$L = (4\pi d / \lambda)^2, \tag{2}$$

where d is the distance between the target and the antenna, and λ is the wavelength of a microwave.

The P_r is amplified and added with a circuit noise. Therefore, the average signal power P_a is given by the average measured power P_m subtracted by the average noise power P_n. P_a is derived from

$$P_a = P_m - P_n \tag{3}$$

On the other hand, the corresponding voltage to P_m is shown on the oscilloscope and recorded in it. Therefore, P_m is calculated as

$$P_m = \frac{1}{R}\left[\frac{1}{T_m}\int_{T_m} \{v(t)\}^2\, dt\right] \tag{4}$$

where $v(t)$ is the instantaneous measured voltage, T_m is the time between the impact and the end of the measurement and R is the impedance. And the added noise P_n is calculated in the same manner as

$$P_n = \frac{1}{R}\left[\frac{1}{T_n}\int_{T_n} \{v(t)\}^2\, dt\right] \tag{5}$$

where T_n is the time before an impact which is actually taken between the beginning of the measurement and the trigger input (for about 50 μsec).

The P_a in Eq. (3) can be transformed to the value at the output port of the antenna, P_r in Eq. (1) by dividing with the receiver gain G_{rec} so that

$$P_r = \frac{1}{G_{rec} R}\left[\frac{1}{T_m}\int_{T_m} \{v(t)\}^2\, dt - \frac{1}{T_n}\int_{T_n} \{v(t)\}^2 dt\right] \tag{6}$$

In Eq. (6), the constant value of G_{rec} R should be calibrated.

The maximum emitted power of a pulse is also derived from Eq. (6) taking T_m to be a short time of a pulse width. In this case, of the second term of the noise in Eq. (6) can be neglected.

5. CORRELATION WITH MATERIAL CONSTANTS

The maximum emitted power of a pulse for different target materials is calculated from Fig.5 for each target using Eqs. in Section 4. The result is correlated with the electric conductivity, and shown in Fig.6. With the aluminum target, the power and the number of pulse are the largest of all the targets. This fact supports the hypothesis that an excited current on the target causes the microwave emission, and accordingly the emission from a conductor target should be larger than that from an insulator target.

The average emitted power is calculated, and correlated with the density of the target. The result is shown in Fig.7. Although the sharp pulses are most significant in the case of aluminum, the average power is highest in the case of alumina ceramic. Therefore, it can be said that the power of continuous small signal dominates the majority of the average emitted power even in the case of aluminum. The average emitted microwave power is almost proportional to the density of the target.

6. CONCLUSION

We carried out the microwave measurement in 22 GHz band in hypervelocity impacts. The following features were obtained:

(1) The detected waveforms are composed of two kinds of elements: intermittent sharp pulses and the increase of white noise.
(2) The waveform from aluminum target is characterized by sharp pulses, and that from ceramic target is by the increase of white noise.
(3) The number and amplitudes of pulses from an aluminum target are much larger than those from the other targets of ceramic, brick and rubber.
(4) The total emitted microwave powers were calculated, and show strong correlation to the electric conductivity and the density of the target material.
(5) The microwave generation is possibly related with the destruction process of materials.

7. REFERENCES

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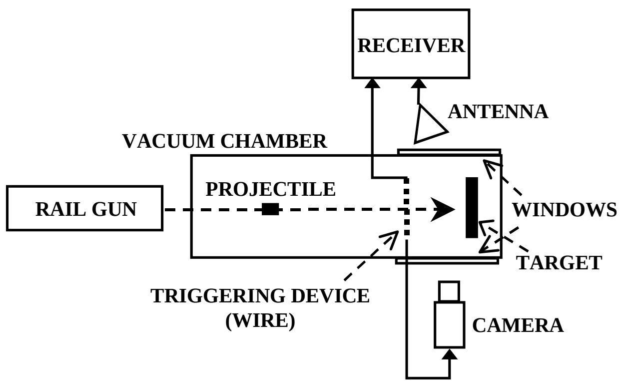
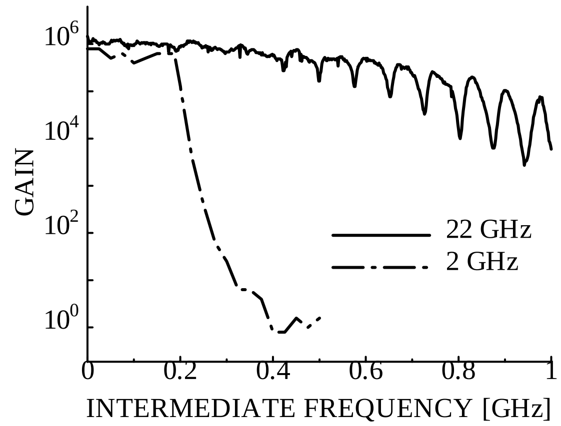


Fig.1 Experimental set-ups.



22 GHz and 2 GHz bands
Fig.3 Frequency response of receivers.

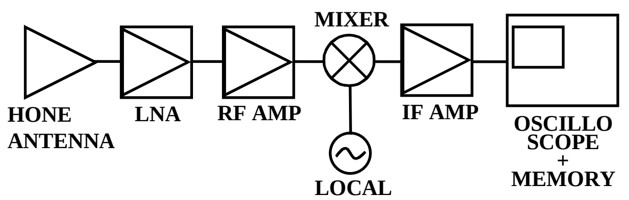
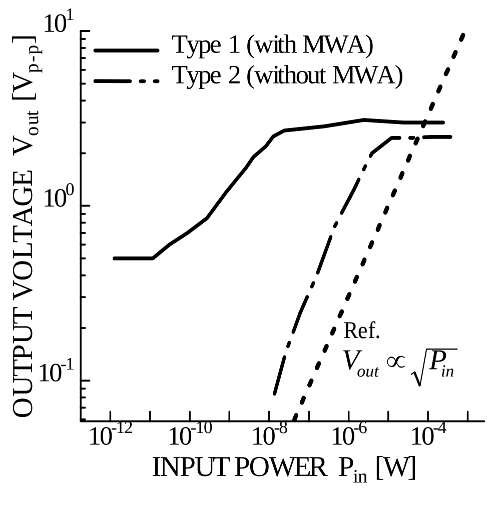
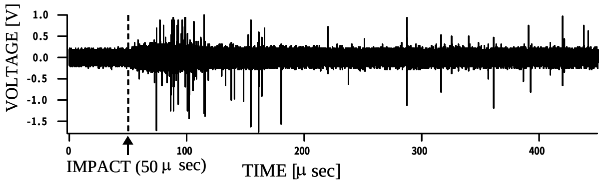


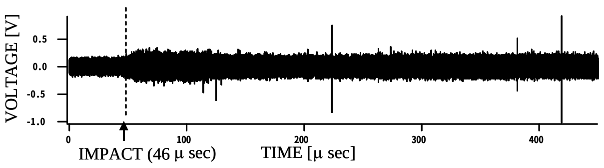
Fig.2 Receiving system.



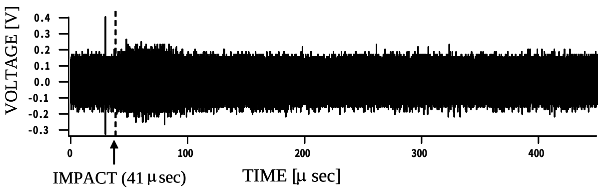
22 GHz band
Fig.4 Indicated voltage versus input power for receivers.



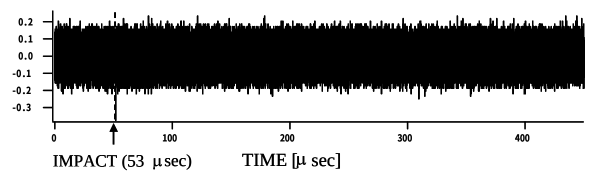
(a) Aluminum



(b) Ceramic



(c) Brick



(d) Rubber

Fig. 5 Waveforms from various target materials (at 22GHz).

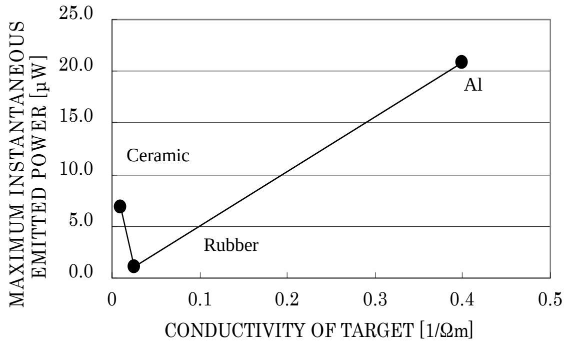


Fig. 6 Maximum emitted microwave power of pulse for different target materials. (22GHz)

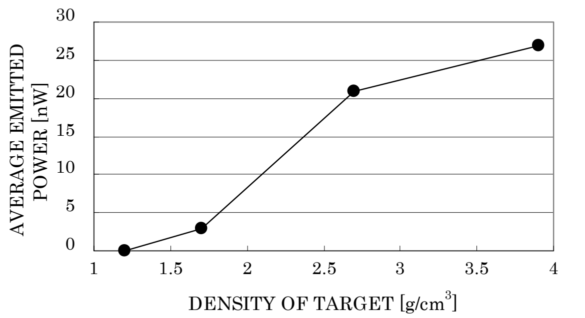


Fig. 7 Average emitted power versus density of a target material. (22GHz)