Velocity evolution of electro-magnetically driven shock wave for beam-dissociated hydrogen interaction experiment

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Abstract. We present the velocity measurements in electro-magnetic shock tube for beam interaction experiment by three methods; laser refraction, photodiode for self-emission, and high speed framing camera. The laser refraction showed that the average shock velocity was 6.7 km/s when the initial pressure was 1000 Pa and the initial charging voltage was 16 kV. The self-emissions from piston discharge plasma were measured by photodiodes and by high speed framing camera. The measurements showed that the duration between shock and piston was up to 8 microseconds with a 400-mm propagation in the shock tube, which is enough time as dissociation target for beam interaction experiment.The complementary velocity measurement is significant for understanding the electro-magnetically driven shock physics.

1. Introduction

Heavy ion fusion, ion-driven fast ignition [1, 2], heavy-ion-driven high energy density physics experiment and astrophysics [3] require the knowledge of stopping power. Grisham [4] proposed $\sim$ MeV/u ion beams driven high energy density physics experiment using a subrange target and showed a possibility of the high homogeneous energy deposition to the target. In the proposal, the interaction between the projectile and the target becomes strong and the stopping power depends strongly on the electronic state of the target because the projectile velocity is close to the electron velocity of the target. The change of the stopping power due to the target condition is of interest to the moderate energy ion-driven high energy density physics experiment. However, the stopping power with the effects of dissociation of the target molecules have not been experimentally investigated, whereas that in the plasma target were studied [5, 6]. The main purpose of our research is measurement of the stopping power with the dissociation. We selected the hydrogen as the dissociated target because the molecule has only valence electron.

In order to measure the stopping power in matter, the target condition should be well-defined. We proposed electro-magnetically driven shock wave as a tool to produce dissociated targets because an electro-magnetic shock tube generated one-dimensional steady shock wave [7]. In this method, Rankine-Hugoniot relations with the shock wave velocity can give the physical condition behind the shock. Previous studies [8, 9] showed that the duration of the shock compression region between the shock front and the discharge plasma working as a piston is required to be the order of microseconds for the stopping power measurement. A long shock tube can generate the shocked matter with long duration time since the shock-compressed area

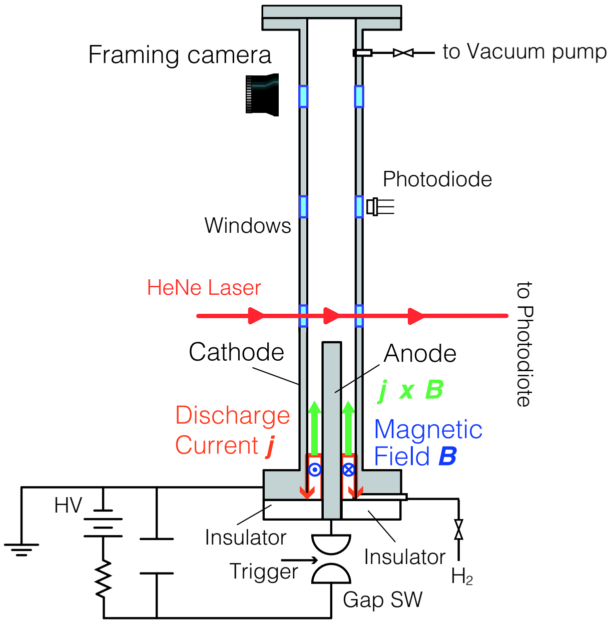

Figure 1. This experimental setup is shown including electro-magnetically driven shock tube, equivalent circuit, and velocity measurement system with laser refraction, photodiode, and framing camera.

between the shock and the piston increases with the propagation length of the shock wave. An electro-magnetic shock tube with long propagation section were developed. Precise velocity measurement in electro-magnetic shock tube is required to identify the physical state and the duration between shock and piston. In this paper, velocity measurements by the laser refraction, photodiode for self-emission, and framing camera are presented.

2. Experimental setup

2.1. Electro-magnetically driven shock tube

We shows the experimental setup in Fig. 1. The hydrogen gas pressure in the electro-magnetic shock tube was from 300 to 1000 Pa. The electrodes were connected with capacitors with a total capacitance of 3.5 μF and a gap switch. The charging voltage was applied from 16 to 18 kV. The central electrode, which worked as the anode with a 12-mm outer diameter, was 250 mm length. The electrode length was designed to generate long duration between shock and piston for beam interaction experiment considering the previous experiments [9]. The inner diameter of the cathode was 30 mm. After the trigger signal was sent to the gap switch, the discharge plasma was formed between the electrodes. The discharge current sheet accelerated by the magnetic pressure produced a shock wave. When the shock wave has a proper velocity, we have the dissociated hydrogen behind the shock wave.

2.2. Velocity measurement system

We have three methods; laser refraction, photodiode for self-emission, and framing camera as velocity measurement. The laser refraction, which needs only simple and compact devices, gives the shock wave transit time. He-Ne lasers as probe were led to some photodiodes (S5972, Hamamatsu, Inc.) via the optical windows on the outer hollow cylinder. The density gradient at the shock front caused a laser refraction when the shock reached to the window position. At this moment, the photodiode detected the change of the laser signal. From the two photodiode

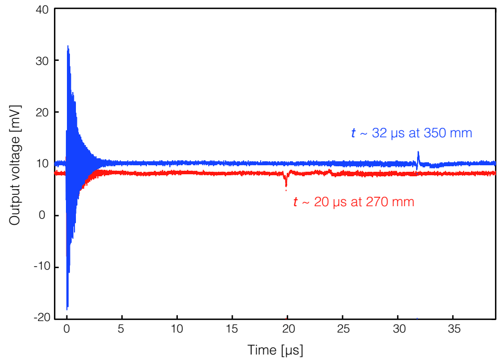

Figure 2. Photodiode output signals by laser refraction.

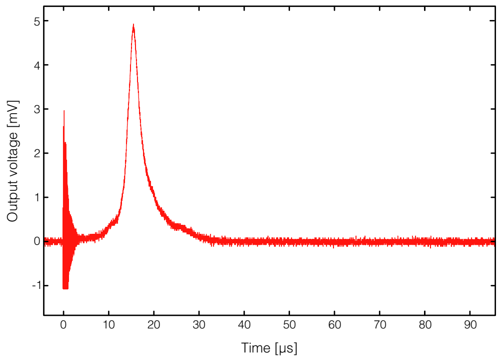

Figure 3. Photodiode output signal from self-emission by the piston discharge plasma. The photodiode is placed at 270 mm from the bottom of the electrodes.

signals with two different positions, we obtained the time of flight between the two positions of the shock wave. In this measurement, the averaged shock velocities were estimated.

Photodiodes and framing camera behind the optical windows on the outer hollow cylinder detected the self-emission from discharge plasma which worked as piston to drive the shock wave. The high speed framing camera system had three CCDs (C6588, Hamamatsu, Inc.) with the high-speed gated image intensifier unit (C2925-01, Hamamatsu, Inc.) which realize to take three pictures simultaneously. A delay pulse generator (DG535, Stanford Research System, Inc.) controlled the framing camera and supplied the trigger signal to the gap switch for the main discharge.

3. Experimental results

3.1. Laser refraction

Output signals from the two photodiodes which were placed at 270 mm and at 350 mm from the bottom of the electrodes are shown in Fig. 2. The horizontal axis stands for the time after the main discharge starts. The initial hydrogen gas pressure was 1000 Pa and the initial charging voltage was 16 kV. The signal baselines from two photodiodes were 8 mV and 10 mV, respectively because the CW lasers were used. We observed discharge noise signals from the both photodiodes until 5 μs. The changes of the photodiode signals at 20 μs and at 32 μs by laser refraction were observed. The averaged shock velocity is estimated to be 6.7 km/s.

3.2. Photodiode for self-emission

In order to estimate the duration between shock front and piston, we directly measure the self-emission from the piston discharge plasma by photodiodes. The photodiode output signal from baseline is shown in Fig. 3. The initial hydrogen gas pressure was 300 Pa and the initial charging voltage was 16 kV. Noise signal was observed until 5 μs due to the main discharge. The transit time of the piston discharge plasma is expected to be corresponding to the peak time of the output.

3.3. Framing camera

The framing camera gives the three pictures from the self-emission by the piston discharge plasma in Fig. 4. The white dashed circles show the effective windows. Emission except the effective window was reflection of the discharge plasma. Fig. 4 shows that the discharge plasma

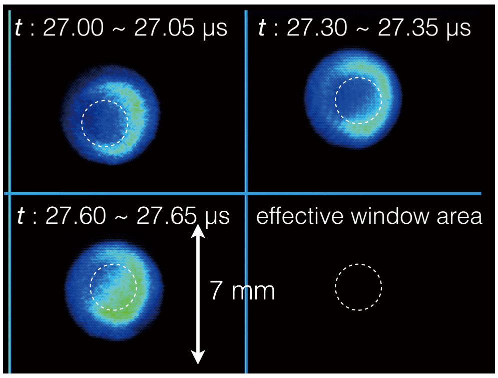

Figure 4. t represents the time after the main discharge starts. Each exposure time is 50 ns. The window is placed at 350 mm from the bottom of the electrodes.

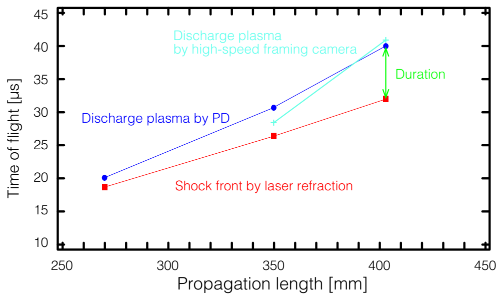

Figure 5. The relationship between time of flight and propagation length between the bottom of electrodes and window is shown.

arrived at 350 mm from the bottom of the electrode on $\sim 27\ \mu$s. The initial hydrogen gas pressure was 400 Pa and the initial charging voltage was 17 kV in this measurement.

3.4. Duration between shock and piston

The velocity measurements by three methods is shown in Fig. 5. The initial pressure was 400 Pa and the initial charging voltage was 17 kV in the measurement as shown in Fig. 5. The duration was up to 8 μs with a 400 mm propagation in the shock tube, which was enough for synchronization with projectile. The transit time of the piston discharge plasma by photodiode is agreement with that by the framing camera. On the other hand, the emission from shock compression region was not observed. In this condition, the calculation from the EOS code[8, 9] shows that temperature at the shock compression region is not high due to low Mach shock, which is supposed to be the too weak emission from this region.

4. summary

The shock wave velocity and the piston discharge plasma velocity were measured by the three methods. The experiment showed the duration between the shock and the piston increased with the propagation length. No emission from shocked matter was observed because the temperature was not high. In this experimental condition, the laser refraction method is useful to detect the shock front. The complementary velocity measurement is helpful to understand the electro-magnetically driven shock physics for the stopping power measurement.

4.1. Acknowledgments

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