Production of dissociated hydrogen gas by electro-magetically driven shock

Kotaro Kondo, Takao Moriyama, Jun Hasegawa,*
Kazuhiko Horioka, Yoshiyuki Oguri (Tokyo Institute of Technology)

Evaluation of ion stopping power which has a dependence on target temperature and density is an essential issue for heavy-ion-driven high energy density experiment. We focus on experimentally unknown dissociated hydrogen atoms as target for stopping power measurement. The precise measurement of shock wave velocity is required because the dissociated gas is produced by electro-magnetically driven shock. For beam-dissociated hydrogen gas interaction experiment, shock velocity measurement using laser refraction is proposed.

(Pulsed power, Electro-magnetically driven shock, Dissociated hydrogen, Ion stopping power)

1. Introduction

The Evaluation of ion stopping power which depends target temperature and density is important for heavy ion fusion target design and heavy-ion-driven high energy density physics experiment. Stopping power is defined as the average energy loss of the particle per unit path length in the target. The stopping power in solid matter was studied in ion implantation or radiology(1) (2). The stopping power for low energy beam depends on the electronic state. For example, the stopping power in high temperature and low density plasma is larger than that in room temperature gas because free electrons in plasma are carriers of energy transfer between ion beam and target. The stopping power in warm dense matter is lower due to electron degeneracy(3). However, the effects of dissociation of the target molecules up to ionization in stopping cross section have not been experimentally investigated. We are interested in dissociation effect on the stopping power of hydrogen target.

Electro-magnetically driven shock wave was proposed for production of well-defined dissociated target, which is desirable for the stopping power measurement. The method generated quasi-steady and one-dimensional strong shock wave(4). The discharge plasma with piston velocity u_p drives shock wave with shock velocity u_s to dissociate the target gas as shown in Fig. 1. The shock wave method has an advantage because Rankine-Hugoniot relations(5) with shock wave velocity can give the shocked condition.

For beam-dissociated hydrogen interaction experiment, the previous experiment showed that the duration of the shocked region between the shock front and the discharge plasma is desired to be in the order of microseconds. A long shock tube could generate the dissociated hydrogen target with long duration time because Fig. 1 shows that compression region length L increases with the propagation length of the shock wave. We have the new shock tube with long propagation section.

The previous experiment(6) showed 25 km/s shock velocity in initial pressure of 1000 Pa is required for pure dissociated hydrogen gas without ionization. We need precise shock velocity measurement because the shocked condition is sensitive to the velocity. The laser refraction, which needs only simple and compact devices, is proposed as the method of velocity measurement. In this paper, we showed the measurement results of the electro-magnetically driven shock velocity.

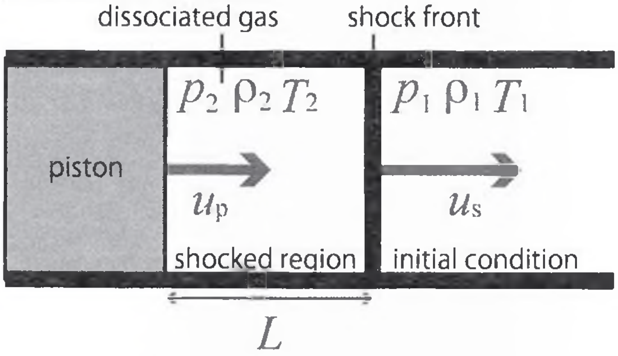

Fig. 1. It shows the region in front of the shock as subscript 1 with the subscript 2 defining the region behind the shock. p , ρ, T mean pressure, mass density, and temperature, respectively.

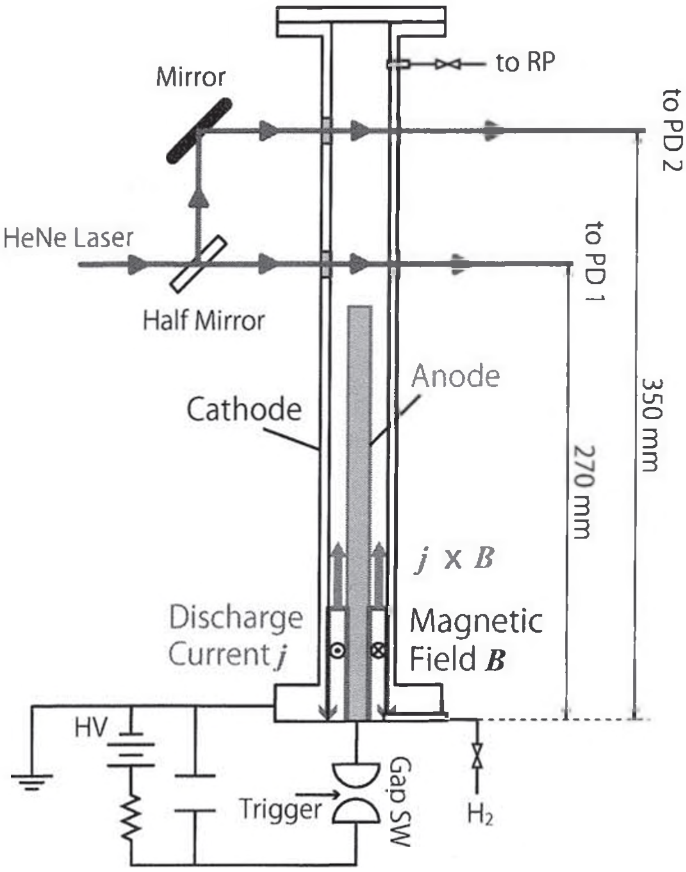

Fig. 2. This experimental setup consists of eletro-magnetically driven shock tube, equivalent circuit, and HeNe laser with optical devices for shock measurement.

2. Experimental setup and procedure

⟨2・1⟩ Renewed shock tube

Fig. 2 shows this experimental setup of electro-magnetically driven shock tube and the equivalent circuit with He-Ne Laser system for velocity measurement. Hydrogen gas with pressure from 300 to 1000 Pa was filled in the renewed shock tube. The electrodes were connected with a gap switch and capacitors with 3.5 μF. The charging voltage was from 16 to 18 kV. In order to produce the dissociated hydrogen with long duration, the center electrode with 12 mm outer diameter is 180 mm longer than before. The inner diameter of cathode is 30 mm. The discharge plasma is generated between the electrodes after the trigger signal into the gap switch. The discharge current sheet, which was accelerated by the magnetic pressure, produces a shock wave. The dissociated hydrogen target can be formed between the shock front and the discharge plasma when we have the proper shock velocity.

⟨2・2⟩ Velocity measurement using laser refraction

Shock velocity is sensitive to produce pure dissociated hydrogen target. In order to measure the velocity, we propose a laser refraction method as shown in Fig. 2. He-Ne laser (NEC, Inc., GLG5740, Max output: 50 mW), which is divided by a half mirror, passed through the optical windows on the axis of the shock tube. When shock wave reaches to the window, the density gradient at the shock front causes the laser refraction. At this moment, the photodiode (Hamamatsu, Inc., S5972) behind the shock tube detected the change of the laser signal and the arrival time of shock wave. The two divided lasers were alined with two photodiodes (PD1 and PD2). PD1 and PD2 were placed 270 mm and 350 mm from the bottom of the central electrode, respectively. From the two photodiode signals, the averaged velocity was estimated.

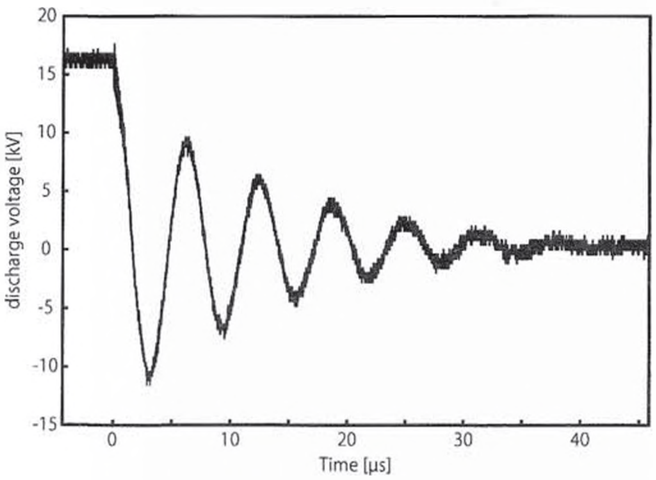

Fig. 3. It shows discharge voltage signal for charging voltage of 16 kV. That is a damped sine wave with period of 6.5 μs.

〈2·3〉 Experimental procedure

A delay pulser (Stanford Research System, Inc., DG535) with amplifiers controls the main discharge to supply the trigger signal to the gap switch. The discharge pulse shape was obtained by high voltage probe (Tektronix, Inc., P6015A) as shown in Fig. 3. In this experiment, dependence of initial hydrogen gas pressure and charging voltage is investigated. For dependence of initial pressure, we have initial pressure of 360 Pa, 700 Pa, and 1000 Pa with 16 kV charging voltage. For dependence of charging voltage, we have charging voltage of 16 kV, 17 kV, and 18 kV with 1000 Pa initial pressure. In order to investigate the reproducibility, three measurements were performed each experiment.

3. Experimental setup and procedure

〈3·1〉 Photodiode signal

Output signals from photodiodes are shown in Fig. 4. The vertical axis stands for time after the discharge. The discharge voltage was 16 kV and initial hydrogen gas pressure was 1000 Pa in Fig. 4. The signal baselines of PD1 and PD2 shifted to 8 mV and 10 mV, respectively because CW laser was used. Noise signals of two photodiodes were observed until 5 µs due to the discharge. As shown in Fig. 4, we observed signal changes at 19.9 µs and at 32.2 µs for PD1 and PD2, respectively.

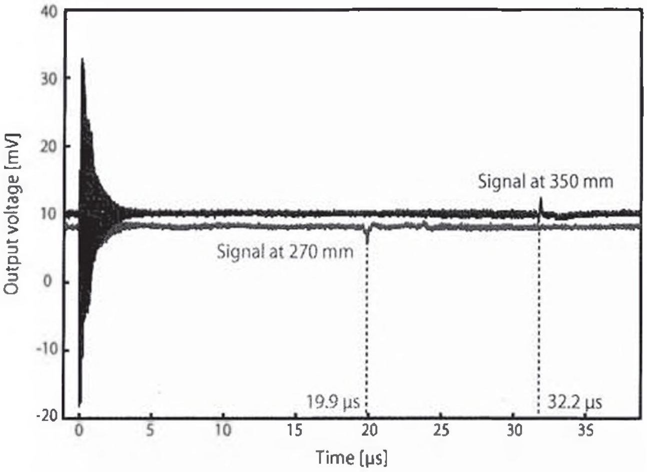

Fig. 4. Output signals from 2 photodiodes (PD1 and PD2).

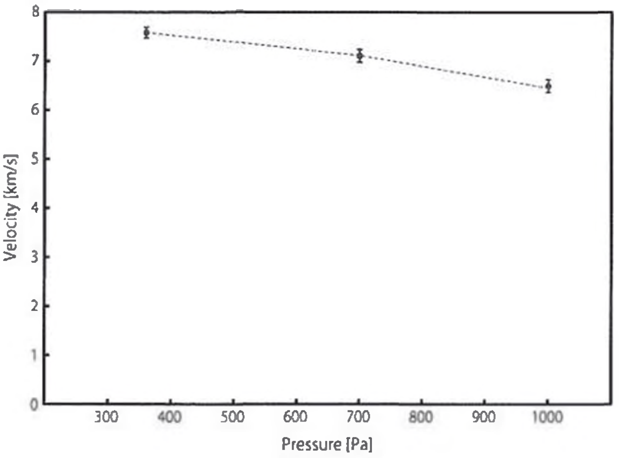

Fig. 5. Average shock wave velocity VS initial pressure (360 Pa, 700 Pa, and 1000 Pa). Dot means the average value for three measurements and error bar shows standard deviation. Each average point are connected by the dash line.

〈3·2〉 Initial gas pressure dependence

Average shock wave velocity for the initial hydrogen gas pressure is shown in Fig. 5. These results show that the higher velocity was observed for the lower initial pressure. The qualitative behavior could be correct because the the discharge voltage was fixed to 16 kV for these measurements. Fig. 5 shows reproducibility in this experiment.

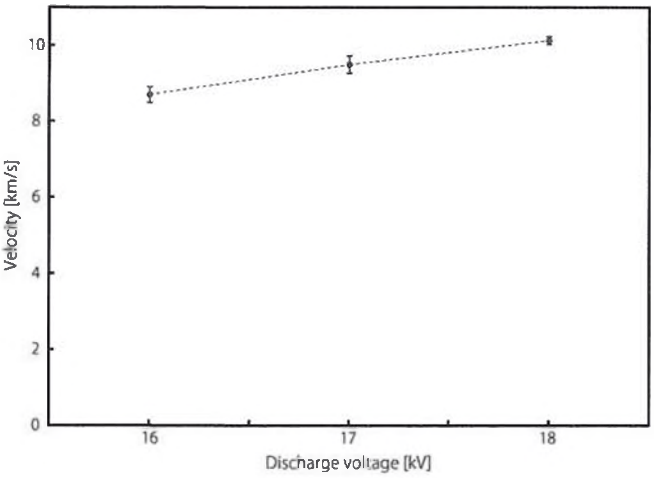

Fig. 6. Average wave velocity VS charging voltage (16 kV, 17 kV, and 18 kV). Dot means the average value for three measurements and error bar shows standard deviation. Each average point are connected by the dash line.

⟨3・3⟩ Discharge voltage dependence

Fig. 6 shows average shock wave velocity for the charging voltage. These results show that the higher shock wave velocity was observed for the high charging voltage. The qualitative behavior could be also correct. Reproducibility in this experiment is shown in Fig. 6.

4. Summary

We measured the average shock wave velocity by laser refraction. The velocity measurement by this method can be reliable because the qualitative behavior of the results can be correct from the initial gas pressure and discharge voltage dependence. On the other hand, the shock wave velocity is not enough to dissociate hydrogen gas. The more input energy is required for pure dissociated hydrogen gas target with large volume using the renewed long shock tube.

References

(1) D. I. Thwaites:"Current status of physical state effects on stopping power", Nucl. Instrum. Methods Phys. Res. B 12, No.1, pp. 84-89 (1985).

(2) P. Bauer, F. Kastner, A. Arnau, A. Salin, P.D. Fainstein, V.H. Ponce and P.M. Echenique:"Phase effect in the energy loss of H projectiles in Zn targets: Experimental evidence and theoretical explanation", Phys. Rev. Lett., 69, No.7, pp.1137-1139 (1992).

(3) P.T. Leon, S. Eliezer, J.M. Martinez-Val, M.Piera:"Fusion burning waves in degenerate plasmas", Phys. Lett. A 289, No.3, pp. 135-140 (2001).

(4) K. Kondo, M. Nakajima, T. Kawamura and K. Horioka: "Compact pulse power device for generation of one-dimensional strong shock waves", Rev. Sci. Instrum. 77, No.3, pp. 036104-1-3(2006).

(5) H.W. Liepmann and A. Roshko:"Elements of gasdynamics", Dover Publications, New York (1993).

(6) J. Hasegawa, H. Ikagawa, S. Nishinomiya, T. Watahiki and Y. Oguri: "Beam-plasma interaction experiments using electromagnetically driven shock wave", Nucl. Instrum. Methods Phys. Res. A 606, No.1-2, pp.205-211 (2009).