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2-D Ablated Plasma Production Process for Pulsed Ion Beam-Solid Target Interaction

Thanat Rungsirathana, Vorathit Rungsetthaphat, Shogo Azuma, Nobuhiro Harada

***Abstract*—**This paper presents a 2-D hydrodynamic model of the ablated plasma when irradiating a 50 µm Al solid target with a single pulsed ion beam. The Lagrange method is used to solve the moving fluid for the ablated plasma production and formation mechanism. In the calculations, a 10-ns-single-pulsed of ion beam with a total energy density of 120 J/cm^2, is used. The results show that the ablated plasma was formed after 2 ns of ion beam irradiation and it started to expand right after 4-6 ns. In addition, the 2-D model give a better understanding of pulsed ion beam-solid target ablated plasma production and expansion process clearer.

***Keywords*—**Ablated plasma, pulse ion beam, thin foil solid target, two-dimensional model

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I. Introduction

IRRIDIATING a thin foil solid target with a pulsed ion beam has been conducted research for many years for a wide range applications. In particular, some researchers at Nagaoka Universityof Technology have experimented and showed many reasonable results [1-2], while some have shown numerical simulation in order to explain the ablated plasma formation mechanism when a single-pulsed ion beam and solid target interaction [3].

However, most of numerical studies presented were carried out in one-dimensional hydrodynamics model. Therefore, this paper is to present results for the calculations in 2-dimensional hydrodynamic model.

The current study aims to improve the flyer acceleration model using a single-pulsed ion beam and Al solid target interaction. The 2-dimensional hydrodynamic model is developed and examined. The Lagragean difference method is used to calculate the moving plasma fluid when a single pulsed ion beam and a thin foil solid target interaction forming ablated plasma.

The significant finding in this study is that it indicates how long it takes in order to form the ablated plasma after focusing an Al thin foil with a single-pulse ion beam. In addition, the study also shows the image how the ablated plasma expansion and when it starts to expand.

Thanat Rungsirathana is an assistant professor at University of the Thai Chamber of Commerce, Bangkok, 10400 Thailand (phone: 66-2-6976709; fax: 66-2-2754892; e-mail: thanat_run@ utcc.ac.th).

Vorathit Rungsetthaphat is now a master degree student at Waseda University, Japan (e-mail: vorathit.r@gmail.com).

Shogo Azuma and Nobuhiro Harada are now professors at Nagaoka University of Technology, Japan (e-mail: nob@nagaokaut.ac.jp).

The results show that the ablated plasma is formed just after 2-4 ns of ion beam irradiation. Then, the ablated plasma expansion process starts after 4-6 ns. The ablated plasma pressure at the focal spot is extremely high (8-16 GPa). Once it starts to expand, the ablated plasma pressure was getting lower to the pressure below 10 GPa. In addition, the results show that ablated plasma expands with extremely high pressure.

This paper is organized as follows. The principle of ablated plasma production is stated first. Then, the numerical model as well as the governing equations are presented and discussed. After that, the significant findings and discussions are presented. Finally, the conclusion and summary of the study are stated.

II. Principle of Ablated Plasma Production

When a target material is irradiated with a single pulsed ion beam, it separates into two parts; one part evaporates forming the ablation plasma, while the unevaporated residue (remaining part) is termed a flyer. It is shown as in Fig. 1. This process is expected to show high-temperature and high-density ablation plasma formation [1-2]

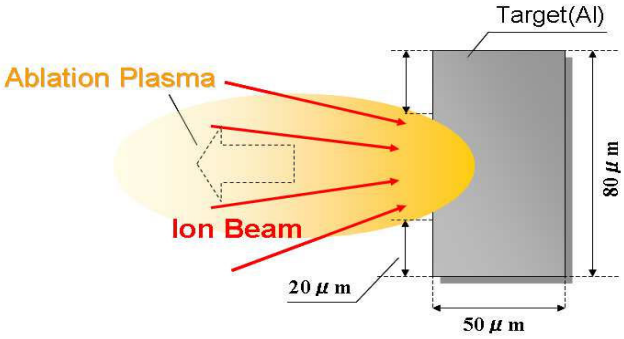

Fig. 1 A 2-D single pulsed ion beam - 50-µm Al target interaction

III. Numerical Model

In the previous model [4] C. Buttapeng and N. Harada have developed a one-dimensional hydrodynamic model to simulate the dynamics of solid target and ablated plasma when a pulsed ion beam interacts with the Al target [5,6] . To compare the results with the previous model and to understand the ablated plasma formation process more or less, a two-dimensional hydrodynamic compressible fluid model is introduced.

The model is based on the fact that the abaled plasma is formed by the instantaneously removal of the surface of the solid target so that this ablated plasma can be treated as a compressible fluid without any charge effects [4].

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The assumption is acceptable because the ratio of the Debye length to the electron mean free path is very much less than one for an electron density of about 10^{23} cm^{-3}, and an electron temperature is in the range of 10-30 electron volts (eV). The hydrodynamic equations (continuity, momentum and energy balance) used are as follows:

$$\frac{D\rho}{Dt}+\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)=0 \tag{1}$$

$$\frac{Du}{Dt}=-\frac{1}{\rho}\frac{\partial(P+q)}{\partial x} \tag{2}$$

$$\frac{Dv}{Dt}=-\frac{1}{\rho}\frac{\partial(P+q)}{\partial y} \tag{3}$$

$$\frac{DT}{Dt}=-\frac{(P+q)}{\rho C_v}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+S \tag{4}$$

When

$$\frac{D}{D\mathrm{t}}=\frac{\partial}{\partial t}+u\frac{\partial}{\partial x}+v\frac{\partial}{\partial y} \tag{5}$$

where u and v are relative velocities in x-and-y axis, P is pressure, ρ is density, t indicates time in seconds. The artificial viscosity q of von Neuman and Richtmeyer [5-6] is used in this calculation to cope with the compressible part of the target. This parameter is to handle the instability of the calculation results that may occur. C_v is specific heat at constant volume, and S is stopping power of free electron, bound electron and nuclei. This is because the ion beam energy deposition process in this study is considered to be a classical theory.

The ionization is expressed by Saha's equation because the ablation plasma is considered to be in local thermal equilibrium under extremely high pressure [5-6]. When the ion beam energy is deposited, a thin foil solid target is rapidly heated and evaporated forming high-density ablated plasma. In the experiment, the thermal conduction does not show any significant influence (~10^3 K), and it therefore can be neglected [3-4]. In this two-dimensional model, the thin foil solid target-ion beam interaction considers only the energy deposition process because the momentum of the ablation plasma is, in fact, very much larger than that of the ion beam. This means that the effect of an ion beam is ignored. The real gas equation of state from SESAME database is used [8-9]. The gas equation of state is as follows:

$$P=\left[e-aT^b\exp\left\{-\frac{(\rho-c)^2}{d}\right\}\right]f\rho^g, \tag{6}$$

where a, b, c, d, e, f, g are fitting parameters. T is temperature

The Lagrange coordinates are used to investigate the plasma production and acceleration mechanism. The boundary conditions for the calculations are described as follows:

$$\rho_{0,j}=0 \quad \rho_{MAX,j}=0 \quad \rho_{i,0}=0$$
$$T_{0,j}=T_{0,1} \quad T_{MAX,j}=T_{MAX-1,j} \quad T_{i,0}=T_{i,1}$$
$$P_{0,j}=0 \quad P_{MAX,j}=0 \quad P_{i,0}=0$$
$$\rho_{i,MAX}=0$$
$$T_{i,MAX}=T_{i,MAX-1}$$
$$P_{i,MAX}=0$$

where 0 is an initial mesh of the calculation (the edge of the target), and *MAX* denotes a maximum mesh. The above mentioned parameters are directed for free expansion of the ablated plasma. In a gas expansion process, a gradient of pressure and a gradient of density are significant. Therefore an initial mesh and a maximum mesh of both pressure and density are said to be zero. An initial relative velocity is zero, while an initial temperature is taken as 300 K. The total meshes used in this calculation are 1000. The physical parameters used in the simulations are based on results obtained at the experimental facility [1-4], Pulsed Power Generator "ETIGO II" at the Extreme-Energy Density Research Institute at NUT. The parameters are listed in Table I.

IV. Results and Discussions

Using the ion beam energy density of 120 J/cm^2 focuses to the Al thin foil, which is fixed at a distance of 100μm. The ion beam energy used in this study is in parabolic-shaped waveform. When the 50-μm-Al thin foil is irradiated with a 10-ns-single-pulsed ion beam, the ion beam penetrates the Al thin foil to a depth of about 9 μm. The surface of the Al thin foil where the ion beam energy is deposited is melted, evaporated and is ionized, forming ablated plasma.

Figure 2 shows the number density when ion beam energy reaches the Al thin foil. It can be seen that the ablated plasma is formed just right after irradiating the Al thin foil with a pulsed ion beam for 2 ns. After 4 ns, the ablated plasma is expanded to the opposite side of the Al thin foil, which resulted in accelerating and moving the Al thin foil forward. The ablated plasma plume is clearly formed and expanded in the direction of the same side as the ion beam irradiation. It can be observed in the Fig.2 when the position of 0-50 μm in x-axis represents the Al thin foil thickness, while the position of zero to minus fifty is the area where the ablated plasma expanded. This two-dimensional model can explain and observe the ablated plasma formation and expansion time better than using the one-dimensional hydrodynamic model [4]. In this model, it can be seen that the ablated plasma is formed just after 2-4 ns of ion beam irradiation. Then, the ablated plasma expansion process starts after 4-6 ns.

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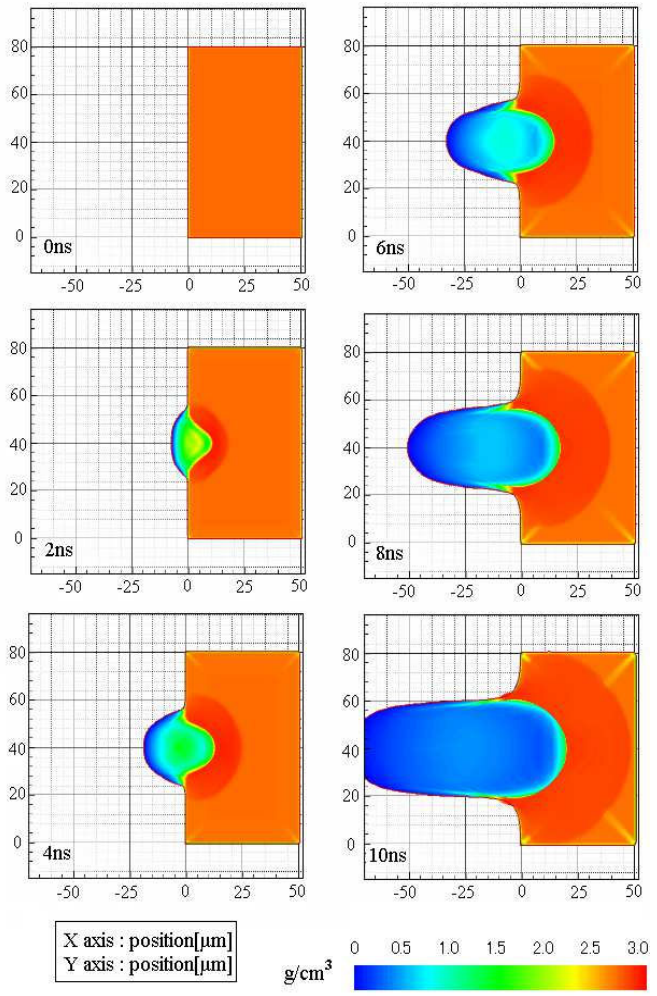

Fig. 2 Number density of the ablated plasma and ablated plasma plume when it is formed and expanded.

Figure 3 shows the ablated plasma pressure when it is formed and expanded. When the ablated plasma is formed (2 ns), the pressure at the focal spot is extremely high (8-16 GPa). Once it starts to expand, the ablated plasma pressure was getting lower to the pressure below 10 GPa. And, from 4-8 ns of ablated plasma expansion, it expands with high pressure. This assumes that at this period of time the ablated plasma might accelerate the Al thin foil very fast. In consequence, the ablated plasma velocity is expectedly high.

TABLE I
SIMULATED PARAMETERS

Quantity	Unit
Total beam energy density	120 J/cm^2
Beam kinetic energy	0.7 MeV
Pulse duration	10ns
Beam particles	protons
Target material	Al
Solid thickness/size	50μm x 80μm
Ambient gas	N, 1 x 10^{-14} Torr
Grid size	50 nm
Time step	1 x 10^8

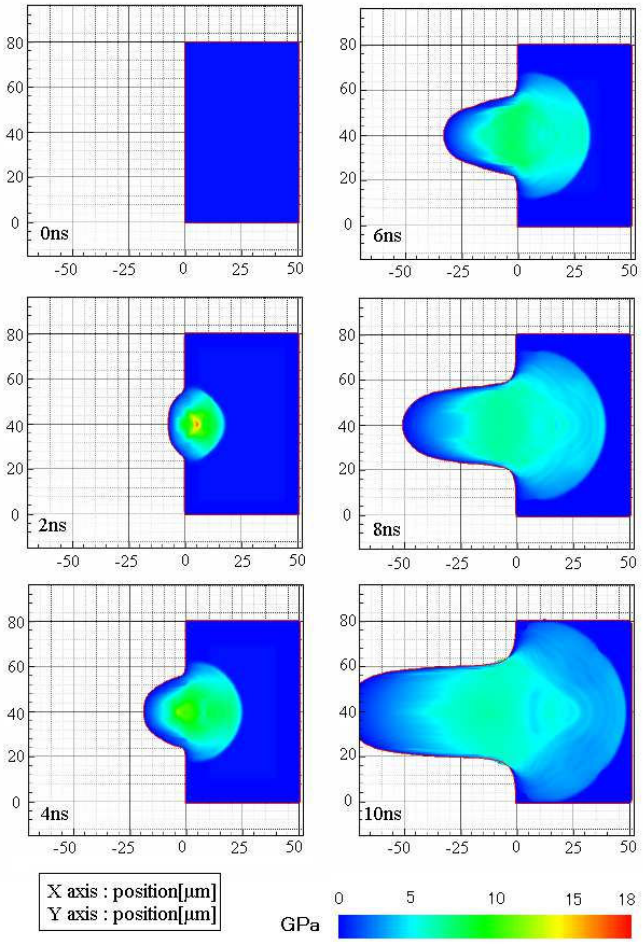

Fig. 3 Ablated plasma pressure when it is formed and expanded.

In consequence, the ablated plasma velocity is expectedly high. In addition, the study is also to examine how fast ablated plasma moves during the expansion process.

Figure 4 illustrates ablated plasma temperature on the surface of throughout the formation and expansion process. Temperature in the range of 10000-40000 K is evaluated.

It is apparent that this two-dimensional model has advantages over the previous one, one-dimensional model, in some respects. First, it shows the ablated plasma formation and expansion clearer. Second, it shows the timing of ablated plasma when the one-dimensional hydrodynamic model could not demonstrate or it could only show by approximation. However, this two-dimensional model is limited to only the simulation for 10 ns. This limitation is due mainly to the calculation server that we have. This makes and leaves some rooms for the improvement in order to understand the ablated plasma formation and expansion phenomenon more reasonable and advanced.

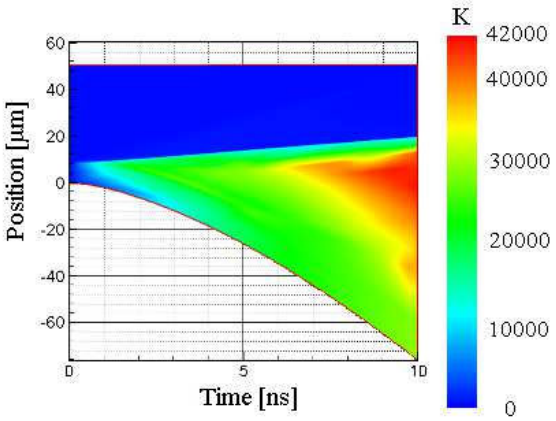

Fig. 4 Ablated plasma temperature on the Al thin foil surface

V. Conclusion

This paper has presented the improvement model of ablated plasma formation and expansion process when irradiating an Al thin foil with a single pulse ion beam. The two-dimensional hydrodynamic model was developed. In the calculation procedures, the Lagrangian scheme using a standard finite different method has employed. The results showed that the two-dimensional hydrodynamic model could be able to see the ablated plasma formation time and expansion process clearer. It was also able to understand when the ablated plasma started to expand and how much the ablated plasma pressure was. In this study, the ablated plasma was formed after 2 ns of ion beam irradiation and it started to expand right after 4-6 ns. Although this two-dimensional model was not that perfect, it was able to see and observe the ablated plasma production and expansion quite well.

References

[1] K. Yatsui , X. D. Kang , T. Sonegawa, T. Matsuoka, K. Masugata, Y. Shimotori , T. Satoh, S. Furuuchi, Y. Ohuchi, T. Takeshita, and H. Yamamoto, "Applications of intense pulsed ion beam to material science," Phys of Plasmas, Vol. 1, 1994, pp. 1730-1737

[2] W. Jiang, T. Sakagami, K. Masugata, and K. Yatsui, "Three-dimensional, tight focusing of intense pulsed light-ion beam by spherical plasma focus diode," Laser and Particle Beams, Vol 13**,** 1995, pp. 343-350.

[3] K. Yatsui, H. Shinkai, K. Kashine, W. Jiang, and M. Kagihiro and N. Harada, "Foil acceleration by intense pulsed ion beam ablation plasma, " Jpn. J. Appl. Phys., **Vol. 40**, 2001, pp. 955-959.

[4] Harada, M. Yazawa, K. Kashine, W. Jiang, and K. Yatsui, "Development of a numerical tool for foil acceleration by an intense pulsed ion beam," Jpn. J. Appl. Phys., Vol. 40, 2001, pp. 960-964.

[5] M. Yazawa, C. Buttapeng, N. Harada, H. Suematsu, W. Jiang and K. Yatsui, "Application to space propulsion with ablation plasma produced by pulsed ion beam, " Trans. JSASS Space Tech. Japan, Vol. 3, 2005, pp. 1-6.

[6] Duderstadt, J.J. and G.A. Moses, 1982. Inertial Confinement Fusion. Wiley. New York, pp: 65-179

[7] T. Yabe, F. Xiao and T. Utsumi, "The constrained interpolation profile method for multiphase analysis," J. Comp. Phys, Vol. **169**, 2001, pp. 556-593.

[8] K. Holian: Los Alamos National Laboratory report LA-10160-MS, 1984

[9] R. More, J. Barnes, and R. Cowan: Bull. Am. Phys. Soc., II 21, 1976, pp. 1153.

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