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The ablation mass of metals by intense pulsed ion beam irradiation

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ABSTRACT

Ablation effect plays an important role in the process of material modification by intense pulsed ion beam (IPIB). As a direct observable in the process of target irradiated by IPIB, the ablation mass is a crucial physical quantity for understanding the interaction between IPIB and target material. Moreover, it is critical to uncover the mechanism of ablation by IPIB. In the present work, we used IPIB provided by BIPPAB-450 accelerator at Beihang University to bombard Zn, Pb, Sn, Cu, and W targets. By measuring the ablation masses under different energy densities, the ablation thresholds of Zn and Pb have been obtained. In addition, correlations between experimental data and incident beam parameters have been investigated. The results are helpful to understand the influence of beam parameter and material properties on the ablation mass.

1. Introduction

Since the intense pulsed ion beam (IPIB) technique first sought its applications [1], it has been proven to be a distinctive method for the surface processing application [2–4]. As a kind of flash heat source, the effect of IPIB on matter is the high compression of energy on time and space. By using short pulse high power density of ion beam, IPIB can realize high density deposition in a very short time and high material surface heating rate (10^8–10^{11} K/s) [5]. During the process of IPIB irradiation, the metal surfaces may endure super-fast heating, melting, evaporation, and ablation.

Ablation plays an important role in the process of material modification by the intense pulsed ion beam or laser beam. The laser ablation is a well-known technique employed for fundamental research, industry, and so on. Many works have been done in this filed and the mechanism of laser ablation is quite clear [6]. In comparison with laser ablation, the mechanism of ablation by IPIB is still unclear because of nonuniform energy density of IPIB and the complicated interaction between beam and matter. Since the ablation mass, i.e., the mass loss of the target during irradiation, is a direct observable which can be measured experimentally, it is a good probe for investigating the interaction between IPIB and target material. Therefore, the investigation of ablation mass is very helpful for understanding the mechanism of ablation. In this paper, we studied the ablation threshold of several kinds of metals and measured their ablation masses under different incident beam conditions. The results are helpful to understand the influence of beam parameter and material properties on the ablation mass and ablation process.

2. Experiment

Experiments were performed on the BIPPAB-450 accelerator at Beihang University. The accelerator is able to produce the intense pulsed ion beam, electron beam and X-ray. The whole accelerator mainly includes the magnetic generator, double forming line (DFL), transformer, and magnetic insulated diode (MID), which are shown in Fig. 1. The maximum accelerating voltage is 500 kV. In the BIPPAB-450, the ion source is provided by using MID of polyethylene anode, and the main ion species of ion beam are about 70% H^+ and 30% C^{n+}. The constituent parts of MID are schematically displayed in Fig. 2. The diode voltage and current density profile of BIPPAB-450 are shown in Fig. 3. Typically, the peak value of accelerating voltage and current density are 450 kV and 150 A/cm^2, respectively. For the pulse duration (FWHM), it is around 80 ns.

In our experiment, Zn, Pb, Sn, Cu, and W were used to make samples with the dimension of 15 mm × 15 mm × 1 mm. These samples were used as target and impinged by IPIB under different energy densities and number of pulses. The ion beam diameter is 4.5 cm and the energy density is ranged from 0 J/cm^2 to 1.5 J/cm^2. Before and after IPIB irradiation, the masses of the samples were measured by Mettler XP205 analytical balance, which has the

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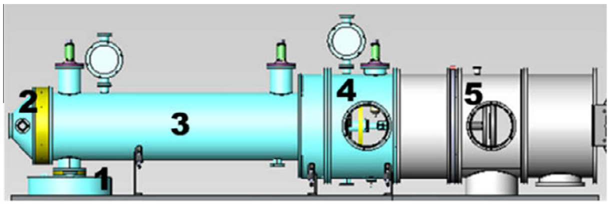

Fig. 1. BIPPAB-450 accelerator scheme: (1) generator, (2) spark gap switch, (3) DFL, (4) transformer, (5) MID.

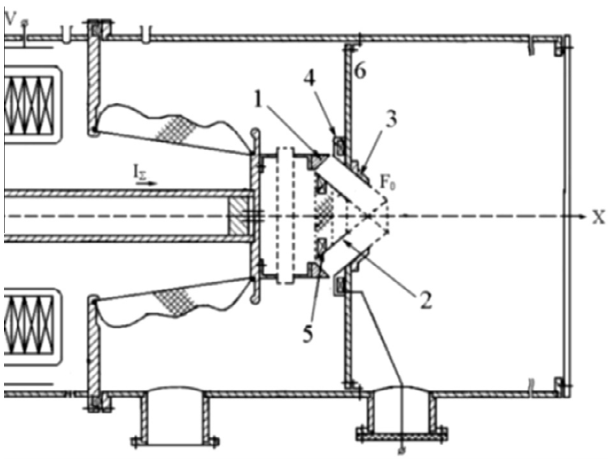

Fig. 2. The figuration of MID: (1) anode, (2) inner cathode, (3) outer cathode, (4 and 5) field coils, (6) disk.

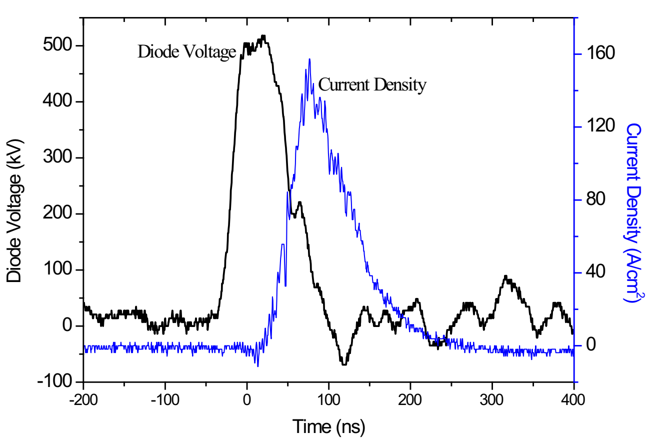

Fig. 3. Diode voltage and current density of BIPPAB-450 accelerator.

precision of 10 μg. The energy density distribution of IPIB was obtained by our infrared image diagnostic system which is shown in Fig. 4 [7]. After thin target was irradiated by IPIB, we can calculate the energy density distribution of IPIB by measuring the temperature variation distribution of the target. The SEM analysis was conducted on Hitachi S-530.

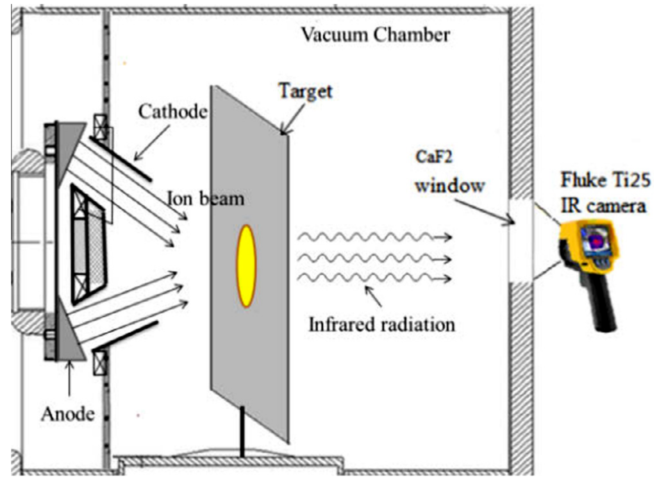

Fig. 4. Infrared diagnostic system.

0	0.07	0.01
0.10	1.49	0.38
0.03	0.30	0.08

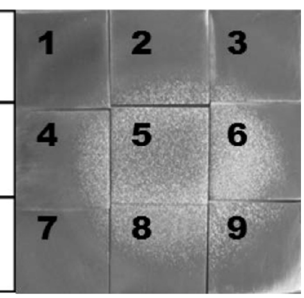

Fig. 5. Left: ablation mass of each sample (mg), right: surface appearance of Zn after irradiation by IPIB.

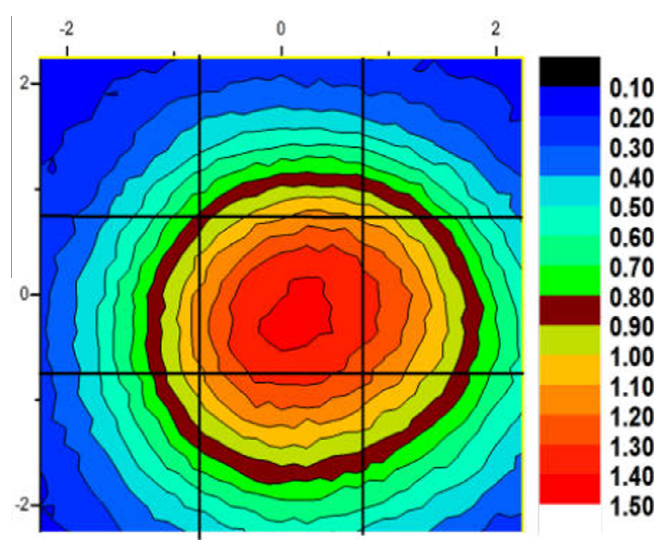

Fig. 6. Infrared diagnostic result of energy density distribution (J/cm^2).

3. Results and discussion

3.1. Ablation thresholds

In order to obtain the distributions of ablation mass versus energy density, a big zinc target which is made of nine zinc samples was constructed to cover the ion beam size and irradiated by IPIB with 20 pulses at the same time. The ablation mass for each sample, the surface appearance and the infrared diagnostic result of the ion beam's energy density distribution were shown in the Figs. 5–7. We calculated the deposition energy with different energy density threshold for each sample. From the Table 1, it is obvious that the ablation mass of each sample is proportional to the energy deposition when the energy density threshold reaches