Detection of Shocks Generated by the Irradiation of Nanosecond Intense Pulsed Ion Beam and Electron Beam[1]

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Abstract – When irradiated by intense pulsed ion beam (IPIB) or intense pulsed electron beam (IPEB), shocks will be formed. Since a pulse duration of IPIB or IPEB is only about 50 ns or shorter, it's very difficult to catch wave signals in such a short time.

In this paper, a detecting system was designed and manufactured carefully. A 100 μm poly- vinylidene fluoride (PVDF) film was chosen as a piezoelectric probe. Electric charges are delivered and are proportional to the stress applied on PVDF film. As the number of charges is measured, we could know the value of the stress applied.

All probe system (including cables) was shielded by aluminum and copper sheath. Because there was an intensive electromagnetic field affecting detecting system, we use two layers of shielding sheath for the whole system trying to get minimum noisy signals.

With this system, shocks, induced by IPIB and IPEB irradiations, were caught at the backside of metal target successfully. The thicknesses of our sample were 1mm and 2mm respectively. Wave profiles were caught and record by oscilloscope of model TDS2024 (200MHz, 2Gs) and TDS3052B (500MHz, 5Gs). Experimental results have shown in good accordance with our theoretical calculations.

1. Introduction

For intense pulsed particle beam, beam energy is compressed intensively in space and time. Once such kind of beam interacts with target material, a series process, such as fast heating, melting, vaporizing, ablating, rapid resolidifying, will be induced on the surface. And then shocks will be formed near the surface layer during the irradiations. It is said that these shocks are responsible for long range effect, especially for IPIB modification. And it has found many applications covered not only the fields of surface processing such as surface hardening, corrosion resistant and wear resistant improving, cracker healing, adhesion enhancing and mixing, but also those like film deposition, nano-powder synthesis and plasma ablation propulsion as well [1-5].

It is necessary to analyze behavior of shocks theoretically and experimentally to realize thermo- dynamic interaction between such intense pulsed particle beams and target material. There are a few studies concerning the IPIB irradiation effects theoretically, which study the dynamics for the interactions of IPIB with metallic targets. These studies are the calculation of mass transfer process (or mixing) driven by IPIB that considered chemical reactions and estimated the heating regime [6], the simulation of stress processes caused by IPIB with current densities of 10^3–10^6 A/cm^2, at which the target materials may be destroyed and therefore this density may be too high to be used in surface modification [7]. With our T-coupled fluid elastoplastic equations, and a computer program STEIPIB[8], we have calculate and analyzed temperatures, stresses and shocks for several kinds of metal targets generated by IPIB and IPEB irradiation successfully.

On the other hand, because pulse duration of IPIB is only about 50 ns or even shorter, it is very difficult to catch wave signal in such a short time. Thus to obtain temperature, stress and shock data, a detector with sufficient short response time will be needed. Ref. [9] reported detection of shocks generated by electron beam, but pulse duration was around several hundreds of nanoseconds. Ref. [10] reported shock detection of shorter duration time induced by pulse laser beam by detecting displacements of target backside.

Trying to get shock pressure on target backside directly, a detecting system composed of a PVDF probe was designed and manufactured carefully. In this paper, we'll discuss the experiments of catching such shocks induced by 50ns IPIB and IPEB irradiations.

2. Experiment

1) Intense pulsed particle beam sources:

In our experiments, we studied the measurements of shocks induced by both IPIB and IPEB bombardments. To get IPEB, a pseudospark discharge device was used. The key part of the device is a multi-gap pseudospark discharge chamber (MPC) [11]. The structure of MPC and a typical electron current profile are shown in Fig. 1. A typical duration of such IPEB is 20ns.

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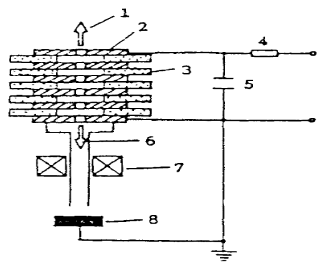


Fig. 1(a). Schematic diagram of the multiplate chamber for the production of pulsed electron and ion beams: (1) ion beam, (2) metallic plates, (3) insulating plates, (4) charging resistor, (5) external capacitor, (6) electron beam, (7) wideband current transformer, (8) target

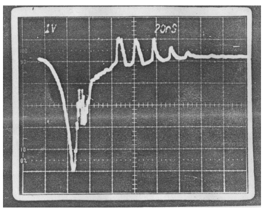


Fig. 1(b). A typical electron current profile

The main IPIB installation is TEMP II accelerator in Tomsk, Russia, and FLASH II accelerator in China. Fig. 2. shows a typical accelerating voltage and current profile of IPIB irradiating from TEMP II. The duration of IPIB is around 50 ns to 100 ns.

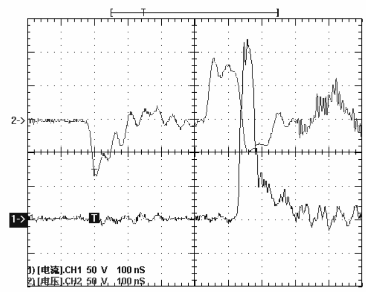


Fig. 2. A typical ion current and energy profile of TEMP II

2) Detecting System:

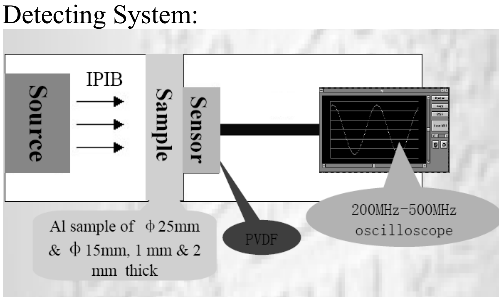


Fig. 3. Schematic diagram of PVDF detecting system

Our detecting system is composed of a sample shelf, piezoelectric probe, amplifier (if necessary), oscilloscope and cables. The key part of piezoelectric probe is a 100 μm polyvinylidene fluoride (PVDF) film. Table 1 is its main parameters. Electric charges delivered on both electrodes were transformed to voltage signal via two 50 ohm resistors. (Fig. 4)Two voltage signals were then coupled to an oscilloscope respectively. Wave profiles were caught and record by oscilloscopes of model TDS2024 (200 MHz, 2 Gs) and TDS3052B (500 MHz, 5 Gs).

Table 1. PVDF parameter used in experiments

Parameter Density	Sign ρ_0	Value 1.7-1.8	Unit g/cm^3	Remark
Thickness		100	μm	Tole-rance: ±10%
E-module (lon-gitudinal/ transverse)	L/E	2048/ 1700	MPa	
Piezoelectric constant	d_{33}	23	pC/N	60Hz~0.1 MHz
electromechani-cal coupling coefficient	k_{31}	0.2		
Dielectric con-stant	ε_p	9-10		Room tempera-ture, 1KHz
Dielectric Dissipation Factor	tgδ	0.02		
Pyro-coefficient	C_h	38-41	μc/(m·k)	Room tempera-ture, 2c/min
Operating temperature	T_h	<80	°C	
Electrodes		Silver		

Fig. 5 shows an equivalent electric circuit for our detecting system. Where R_a is the resistance of PVDF film and grater than 10^{12} ohm, R_L is 50 ohm coupling resistor, C_1 is the capacity of PVDF film and C_2 is the distribution capacity of detecting circuit. Electric charges produced on the opposite side of PVDF film are proportional to the stress that acts on the film. The relation between stress σ_p applied on the film and quantity of electric charge Q(t) is shown in eq.1. By integrating the voltage signal between two electrodes of PVDF film, as shown in eq.2, the stress applied on PVDF film and then shocks could be found as following.

$$\sigma_p(t) = \frac{1}{K_p A} Q(t) \quad (1)$$

$$Q(t) = \int_0^t \frac{1}{R} U(t) dt \quad (2)$$

Where in eq. 1 and eq. 2, A is the PVDF film area in cm^2, K_p is the dynamics piezoelectric constant, and R is the total resistance of circuit (shown in equation 3).

$$R = \frac{R_1 R_L}{(R_1 + R_L)} \quad (3)$$

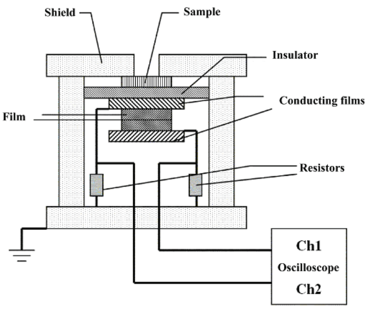


Fig. 4. Schematic diagram of PVDF detecting system

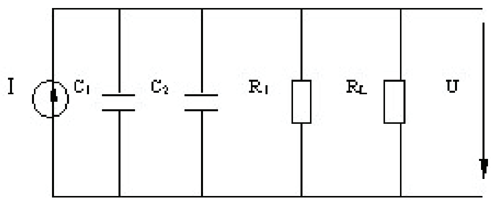


Fig. 5. Equivalent electric circuit of PVDF probe

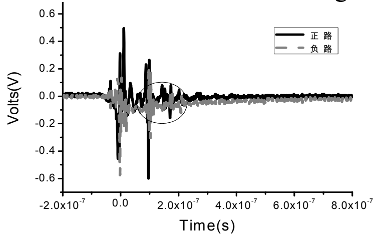
Irradiation experiments were taken at Particle Beam and Plasma Laboratory, Beihang University, China, laboratories in Northwest Institute of Nuclear Technology, China and Tomsk Polytechnic University, Russia. Al and steel samples of 1mm and 2 mm thick were irradiated by IPEB of 20 keV and IPIB of 250 to 400 keV with different current density.

3. Results and Discussions

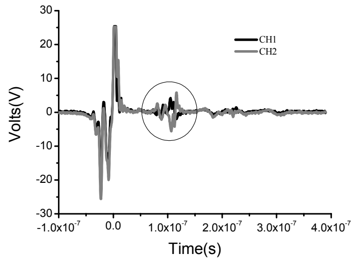
There was an intensive electromagnetic field accompanying beam's production and bombardment in our experiments. That affected SNR (signal-to-noise) of our detecting system seriously (see Fig. 6a). We used multi-layers of shielding sheath for the whole system trying to get minimum noisy signals. The whole shielding system is composed of a grounded stainless steel chamber which isolating detecting system from beam source, a grounded cylindrical aluminum sheath for PVDF probe and copper meshes for cables and electric charge catching system.

After the improvement of shielding system, we got better SNR signals which could recognize shock properly (shown in Fig. 6b). Although power density and energy of IPEB were much lower than IPIB produced by TEMP accelerator, signals of IPEB were much better than those of IPIB, as shown in Fig. 7, because it was difficult to add metal shielding for PVDF probe in TEMP chamber. The best result came for those experiments with FLASH II accelerator, which had got a rather complete shielding system.

Fig. 8 shows the signals caught by our PVDF detecting system. It was very interesting that each shock was composed of two pick. This structure was observed in all shocks induced by IPIB bombardments of FLASH II accelerator. The more intensive of incident ion beam, the more obvious two-peak structure of shock. So such two-peak structure may be due to the recoil impulsions of ablation material and intensive phase transformations near the surface region.



(a) Before improvement of shield system



(b) After improvement of shield system

Fig. 6. Shock signal induced by IPEB

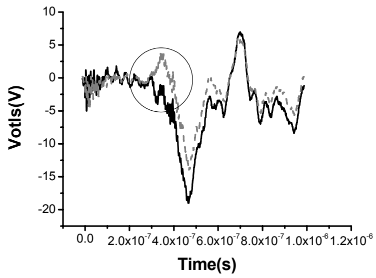


Fig. 7. Shock signal induced by IPIB of TEMP II

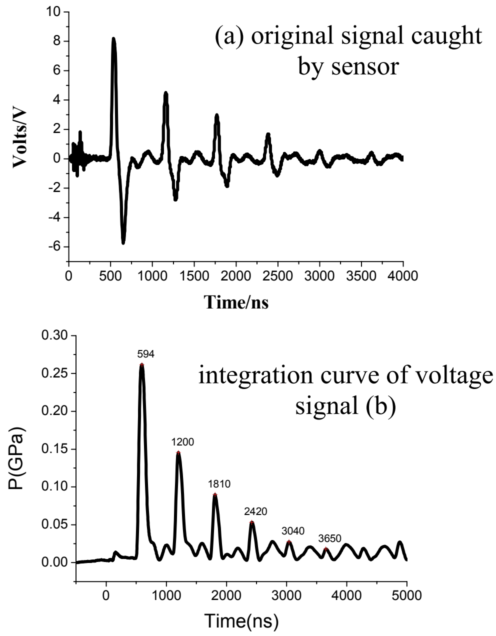
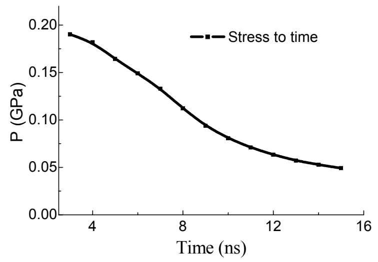
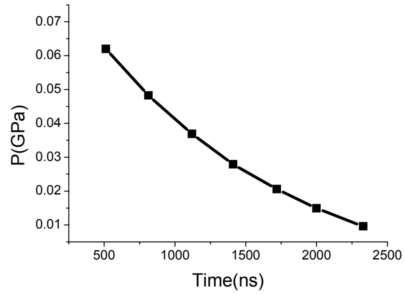


Fig. 8. Characteristics of shock behavior at the backside of 2 mm Al sample induced by IPIB of FLASH II accelerator



(a)



(b)

Fig. 9. Attenuation of shock peaks for Al sample induced by 390A/cm^2 IPIB:(a) simulated, (b) detected

In Fig. 9., detected shock peak decreased rapidly alone an exponentially curve just as we simulated via STEIPIB codes, and they got the same magnitude of 10^{-2}GPa. Furthermore, calculation result showed that peak stress in Al sample induced by 250A/cm^2 IPIB bombardment was around 0.4GPa, and measurement result for similar IPIB parameter of 232A/cm^2 is 0.053GPa. Thus experimental measurement results showed a good correspondence with our calculation of T-coupled fluid elastoplastic model.

4. Conclusion

1. A successful detection of shock signal generated by IPEB and IPIB irradiation of tens of nanoseconds was obtained by our detecting system.
2. A good and complete shield of detecting system is the key for high SNR shock detection.
3. A two-peak structure of shock was observed in our detecting experiments.
4. Experimental measurement results showed a good correspondence with our calculation of T-coupled fluid elastoplastic model.

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References

[1] A.D.Pogrebnjak, Phys. Stat. Sol. (a) **117,** 17 (1990).

[2] H.A.Davis, G.E.Remnev, R.W.Stinnett, and K.Yatsui, MRS Bulletin **21,** 58 (1996).

[3] G.E. Remnev, I.F. Isakov, M.S. Opekounov, V.M. Matvienko, V.A. Ryzhkov, V.K. Struts, I.I. Grushin, A.N. Zakoutayev, A.V. Potyomkin, V.A. Tarbokov, A.N. Pushkaryov, V.L. Kutuzov, M.Yu. Ovsyannikov, Surf. & Coat. Tech. **114,** 206 (1999).

[4] Hiroshi Akamatsu, Tsutomu Ikeda, Kingo Azuma, Etuso Fujiwara, Mitsuyasu Yatsuzuka, Surf. & Coat. Tech. **136**, 269 (2001).

[5] Kiyoshi Yatsui, Hiroyuki Shinkai, Kenji Kashine, Weihua Jiang, Makoto Kagihiro and Nob Harada, Jpn. J. Appl. Phys. **40,** 955 (2001).

[6] V.I. Boiko, A.N. Valyaev, A.D. Pogrebnyak, Physics-Uspekhi **42,** 1139 (1999).

[7] V.I. Boiko, I.V. Shamanin, K.V. Yushitsin, Phys. Stat. Sol. (a) **128.** 369 (1991).

[8] X. Y. Le, W. J. Zhao, S. Yan, et. al., Surf. & Coat. Tech. **158–159,** 14 (2002).

[9] Peng C.X., Lin P., Tan H.M., Chinese Journal of High Pressure Physics **16,** 7 (2002).

[10] Hong X., Wang S.B., Guo D.H., et al, Chinese Journal of Lasers **25,** 743.

[11] H.P. Schoelch, J. Appl. Phys. A **48,** 367 (1989).