COOLING OF A METAL TARGET AFTER INTENSE ION BEAM IRRADIATION

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ДИНАМИКА ОХЛАЖДЕНИЯ МЕТАЛЛИЧЕСКОЙ МИШЕНИ ПОСЛЕ ВОЗДЕЙСТВИЯ ИМПУЛЬСНОГО ИОННОГО ПУЧКА

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Аннотация. *Представлены результаты исследования динамики остывания металлической мишени после воздействия на нее импульсного ионного пучка с плотностью энергии 3-5 Дж/см^2. Эксперименты проведены на ионном ускорителе ТЕМП-4М (длительность импульса – 150 нс, ускоряющее напряжение – 250-300 кВ). Динамику остывания теплового отпечатка, формируемого мощным ионным пучком на мишени, регистрировали в режиме видео съемки с помощью тепловизора. Выполнен анализ и определение физического механизма охлаждения мишени в разных экспериментальных условиях: в вакуумной диодной камере ускорителя и на воздухе.*

One of the key problems in science and techniques is the development of new methods of surface treatment for improving the exploitation properties of the materials. Intense ion beam treatment is one of the progressive methods which technologically lead to the decision of this problem. Powerful ion beams [1] with energies ranging from 50 keV to 10 MeV, ion currents from1 kA to 10 MA, and pulse durations from 10 to 1000 ns are usually generated in the diodes with magnetic insulation [2].These intense pulsed ion beams (PIB) are expected to be applied to material processes since they have unique properties.

In order to obtain the material with desirable properties it is necessary to choose an optimal technological regime of treatment. In the development of the new high-tech accelerators which are going to be used for the materials surface modification, the main objective is to obtain the ion beam with the maximum energy input to the target and, more importantly, a uniform energy density distribution over the entire area of a treated item. Therefore, one of the most important parameters of the PIB, which is necessary to control, is the distribution of the energy density over the cross section.

For measuring the cross-sectional energy distribution of the beam an infrared imaging technique has been designed [3,4].The proposed technique has allowed to rapidly evaluate a large number of intense-ion-beam configurations for beam optimization, and to make quantitative measurements of beam energy-density profiles. The studies were performed using the TEMP -6 pulsed ion beam accelerator [5] located in Dalian University of Technology in China and the TEMP-4M accelerator [6] in Tomsk Polytechnic University in Russia.

The parameters of the ion beam were diagnosed by the thermal imprint on the target using both the Fluke TiR10 and Fluke Ti400 infrared cameras. The later allows for video recording.The registration scheme is shown in Fig. 1. As a target a steel plate with the thickness of 100 microns was used. To increase its emissivity the rear surface of the target was sprayed with the flat black paint (ε = 0,90). The thermal imprint of the beam was recorded by the infrared camera through the CaF2 infrared transmitting window at the TEMP-4M accelerator and the BaF_2 window at the TEMP-6 accelerator.

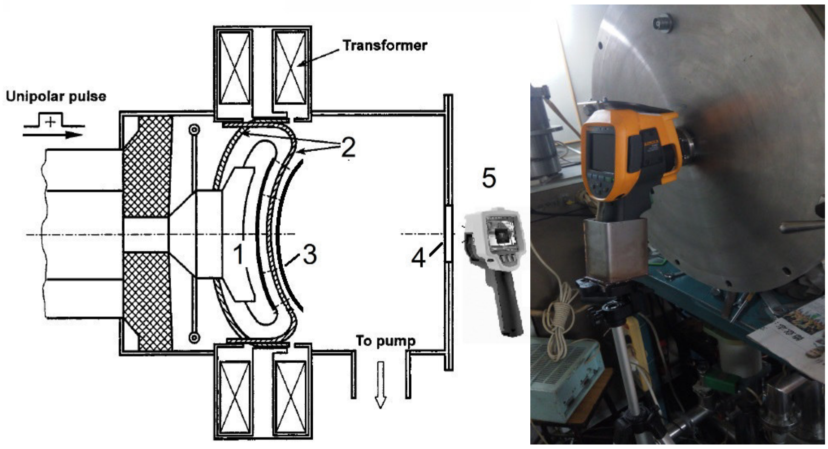
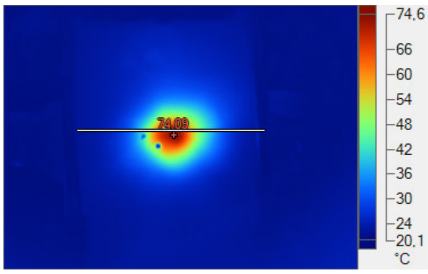
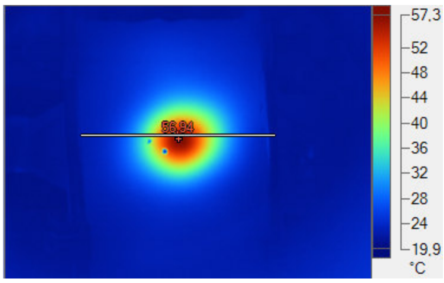


Fig. 1.Schematic of the infrared imaging diagnostic and a photograph the IR camera:
1 – anode with a dielectric covering; 2 – cathode; 3 – foil target; 4 - BaF_2 – window; 5 – IR-camera

Due to harmfull effect of bremstrellung radiation, which is produced during the ion beam generation, on both personal and electronic equipment such as IR camera, we can not leave the IR camera near the accelerator during its operation. The temperature on the target is therefore recorded after approximatelly 5 seconds since the arrival of an ion beam to the target. Because of the delay in temperature measurements we are unable to accurataly estimate the maximum temperature rise in the target caused by an ion beam irradiation. Therefore, it was important to study how the target, located in the diode chamber, is cooled down in vaccum conditions. To study the dynamics of target cooling in vaccum, we used an ion beam to create a temperature rise in the target and then measured the temperature at one point every 5 seconds using the Fluke Ti400 infrared camera in the video recording mode. Fig. 2 shows infrared images of the beam caprured after the beginning of the shot and after 5 seconds.



(a)



(b)

Fig. 2.Infrared image of the ion beam imprint on the target taken at the moment of the beam arrival (a) and after 5 seconds (b). The line shows the place of cross section displayed in Fig. 2.

One can see that the highest temperature at the point decreases from 74^{0}C to 56^{0}C for 5 seconds. Fig. 3 shows the comparison of the cross sectional temperature distribution profiles (cross section shown in Fig.2) at the beginning of the ion beam shot (curve 1) and after 5 seconds (curve 2). To understand the mechanism involved in heat transfer in the vacuum chamber, we performed experiments in the air and compared the rate of cooling for vacuum and air environment. It was assumed that the main models involved in heat transfer in vacuum chamber are though the conduction and radiation. Since the vacuum chamber is pressurized to 10^{-4} Pa in order to ensure the generation and propagation of ion and electron beams, the contribution of heat convection to the target cooling was assumed to be negligible.

To research how the target is cooled down in the air, we used a soldering gun to locally heat the target and then measured the temperature at one point every 5 seconds. Fig. 4 shows the decrease in temperature with time for the target being located in the vacuum chamber and for the target placed at the room temperature.

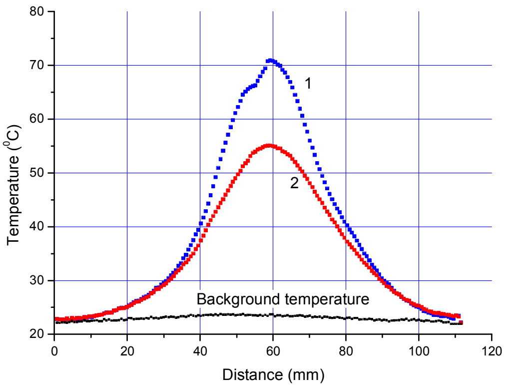


Fig. 3. Distribution of the temperature over the cross section (Fig. 1) at the beginning of the ion beam shot (curve 1) and after 5 seconds (curve 2). Background temperature at the target is shown to display the rise in temperature caused by ion beam pulse

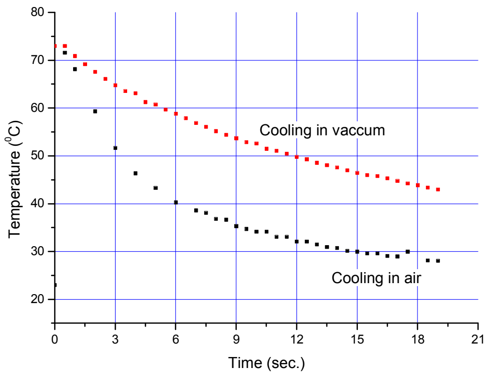


Fig. 4. Dynamics of target cooling in the vacuum chamber after ion beam irradiation (red curve) and in the air (black curve)

According to the data shown in Fig.4 the target placed in air cools faster than that in the vacuum chamber. It shows that the higher rate of hear transfer observed in the experiments in the atmosphere is due to the action of the three mechanisms of cooling, which are convection, conduction and radiation, while in the vacuum chamber only the last two are mainly involved. **Acknowledgements**. This work was supported by the Science State Project of Russia under Grant No. 2159 and by National Natural Science Foundation of China under Grants Nos. 51371043 and 51321004, and the 111 project.

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