BEHAVIOR OF MOLYBDENUM TARGET IN CONDITION OF IRRADIATION BY THE HIGH CURRENT RELATIVISTIC ELECTRON BEAM

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The problems of the stability of molybdenum targets to the action of concentrated energy fluxes are considered. A series of irradiations of a molybdenum target with a high-current relativistic electron beam was carried out. The mechanisms of the beam effect on the target are analyzed. The instantaneous introduction of energy into the target, causes the heating of the target, which leads to the generation of stresses due to the thermoelastic effect. Ablation of molten matter generates a reactive recoil momentum. Specific features of the microstructure of the target in the region of the melting effect of the beam and in the region of thermal action are determined.

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INTRODUCTION

The success of the practical implementation of new projects of nuclear power plants is largely determined by the availability of materials that can be operated under the influence of extreme values of ionizing radiation, high temperatures, pressure, and corrosive media. In this connection, it is important to carry out test studies of the change in the properties of materials when they are irradiated with concentrated energy flows whose energy parameters are comparable with those characteristic of nuclear power plants. For these purposes, as a rule, various sources of plasma are used, studying the problem of erosion of the materials of the first wall of thermonuclear reactors resulting from current failure [1, 2]. At the same time, in such studies, there are effects that seem promising, from the standpoint of creating independent technologies. Such areas include, for example, the modification of the properties of materials as a result of the action of plasma flows [3] and also the generation of vacuum ultraviolet radiation [4] for photolithographic purposes. Thus, there are two directions for using concentrated energy fluxes: it is a test effect involving obtaining information about the ability of a material to retain its characteristics and technological influences aimed at modifying the properties of a material or obtaining a secondary radiation flux of the required spectral range. Considering the questions of material science for the implementation of thermonuclear fusion facilities and technologically oriented issues, one should point out that one of the ways to initiate a thermonuclear fusion reaction was to consider a high-current relativistic electron beams (HCEB) [5] and its technological applications are described by us in [6, 7]. In connection with this method of initiating a thermonuclear fusion reaction, it is also necessary to create radiation-resistant reactor chambers. Since among the candidate materials of the first wall of the reactor, metals are generally considered to be refractory, it seems relevant to investigate the behavior of molybdenum specimens under the action of the HCEB.

1. MATERIALS AND EXPERIMENTAL EQUIPMENT

Irradiation was carried out at the accelerator TEMP-A NSC Kharkov Institute of Physics and Technology. Electron beam parameters: electron energy 350 keV, beam current 2 kA, pulse duration 5 μs. intervals between pulses of the order of 5 minutes, cathode diameter of 50 mm. Molybdenum plates with a thickness of the order of 0.5 mm were used as targets. Microstructural studies were carried out with a scanning electron microscope JEOL-840. The thermograms of the surfaces were analyzed by a Fluke 32 thermographic camera.

2. RESULTS AND DISCUSSION

A special feature of the impact of a SED on a solid body is that in view of the fast energy water in the zone of maximum energy release located in the subsurface region, a local melt of the superheated liquid is formed, which is ejected in the direction of the arrival of the beam when the pressure exceeds the strength of the surface layer. This sequence of processes results in both ablationary mass carryover and mechanical destruction due to a number of mechanisms, each of which should be considered separately. The above-mentioned release of molten matter generates a reactive recoil momentum whose pressure is determined by the expression [8]

$$p_i = (\gamma_{eff.} - 1) \cdot \omega \quad , \tag{1}$$

where $\gamma_{eff} = 1.2$ is the ratio of the specific heats of the solid and plasma; ω - the volume density of the energy of the radiation introduced into the target, J / cm^3. The instantaneous injection of energy into the target causes the heating of the target, which leads to the generation of mechanical stresses due to the thermoelastic effect. As a result, tensions are generated, the magnitude of which is determined by expression [9]

$$\sigma_t(r,t) = \frac{\alpha}{k \cdot \rho \cdot c} \cdot \varepsilon(r,t), \qquad (2)$$

where $\varepsilon(r,t)$ is the density of absorbed radiation energy in the medium, α – the coefficient of thermal expansion, k – compressibility, ρ – density, c – heat capacity.

Samples of the targets were irradiated with a series of pulses before failure, the power flux density was of the order of 10^{12} W /m^2. Molybdenum targets showed a sufficiently high resistance under irradiation, as can be seen from Fig. 1.

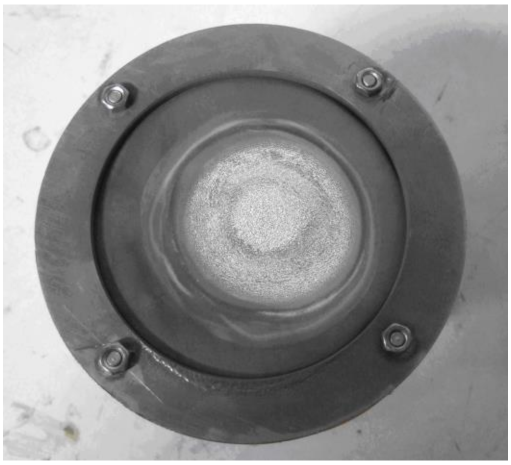

Fig. 1. The molybdenum target irradiated by the HCEB with a series of 8 pulses

On the surface of the target, due to irradiation, microcraters appear (Fig. 2), Their appearance is due to the release of a gas-plazma torch [10], whose products solidify on the surface. This is turn to a change of target surface optical characteristics. Assuming that the surrounding space has high temperatures at which an essential part of heat exchange occurs through radiative heat transfer, this can be important. On the surface of the target, due to irradiation, microcraters appear, which primarily affect its optical characteristics. Assuming that the surrounding space has high temperatures at which an essential part of heat exchange occurs through radiative heat transfer, this can be important. Modern approaches to the diagnostics of the divertor zone involve the use of infrared monitoring systems for the state of the material of the first tokamak wall [11]. It should be noted that the authors of [11] analyzed the radiation flux in the 3…5 μm range. In our case, a camera with a range of 8…14 μm was used. We analyzed the thermogram of a target irradiated by several pulses of tubular beams having different diameters.

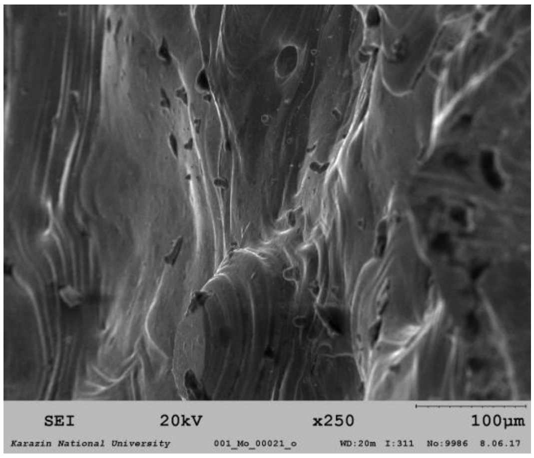

Fig. 2. SEM image of the surface of an irradiated molybdenum target

As can be seen, from Fig. 3, the beam prints appear as regions with a higher radiation temperature. At a emissivity coefficient of the order of 0.1…0.2, it is not advisable to seek to exact the exact value of the temperature, since the error will be too large. At the same time, the radiation temperature is indicative of areas with differing intensities of radiant heat transfer. An increase in the value of the radiation temperature is associated with an increase in the surface roughness, due to the formation of craters after irradiation. Thus, infrared diagnostic systems are advisable to use for on-line assessment of changes in the optical properties of irradiated surfaces. The use of such cameras in the conditions of the action of the pulse implies the necessity of their screening from the action of electromagnetic pulses. For these purposes, it is expedient to use composite metal polymeric materials [12, 13].

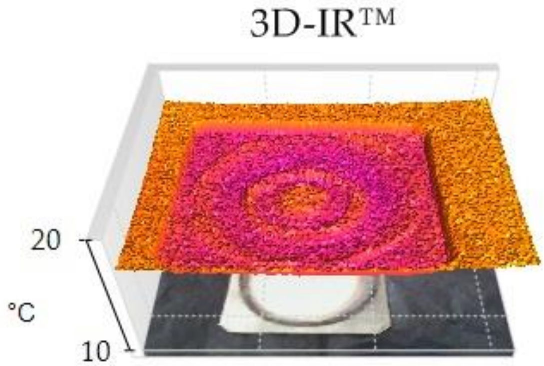

Fig. 3. Thermogram image of irradiated target

Of particular interest are structural studies of the transformations taking place in molybdenum as a result of the irradiation of the HCEB. So in work [14] it is noted that molybdenum is used as containers for sintering nuclear fuel. At the same time, after a certain number of heating cycles, the degradation of the operating properties takes place, the plasticity decreases with a low value of the microhardness. The mechanism of these effects is the grain-boundary diffusion of gaseous products, which lead to the formation of carbides and nitrides at the grain boundaries. At the same time [14], there is a promise of using concentrated energy fluxes, including relativistic electron beams to modify the surface properties of molybdenum. However, the authors, noting the complexity and high cost of these technologies, suggest doping the surface layer with niobium. Effects achieved by doping with niobium, such as a decrease in the grain size in the near-surface layer, are also observed as a result of irradiation of the HCEB Fig. 4.

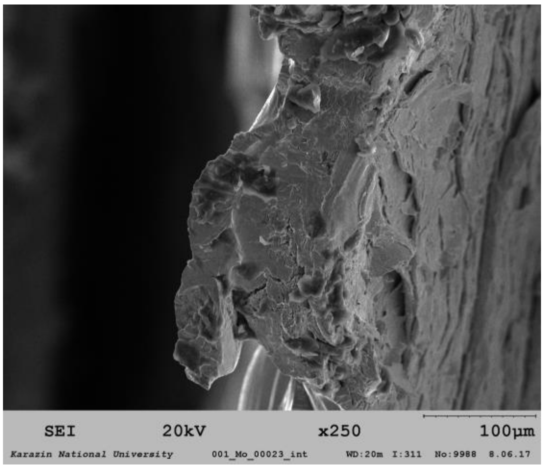

Fig. 4. SEM image of the near surface fracture of an irradiated molybdenum target

At the same time, it should be noted that irradiation of metal targets by HCEB, including molybdenum, is accompanied by the generation of internal stress in the target [15], in which the accumulated energy is released by the action of subsequent pulses. This phenomenon also contributes to the destruction mechanism in irradiated target. Modification of the grain structure, its actual grinding, can lead, in addition to generating internal mechanical stresses, to the rearrangement of the electronic subsystem at the grain boundaries and their charge state [16] and can influence to other operational properties like laser treatment [17]. It is seen from Fig. 4 that due to irradiation a composite structure is formed, consisting of a porous surface layer with crushed grains stretched perpendicular to the surface. Contact of these grains with the base material of the target is capable of creating special charge states, which, when taught by subsequent pulses, can serve as additional sources of defect formation. This can be one of the mechanics of the development of defects in the rear region of the target [19].

CONCLUSIONS

High-current relativistic electron beams can be considered as one of the tools to understand the behavior of refractory materials under extreme conditions. Irradiation with such beams leads to a change in the grain structure of the near-surface layer, and also creates a certain roughness. The resulting roughness is displayed on the value of the thermal radiation coefficient, which affects the mode of radiative heat transfer. The modification of the near-surface layer is associated with the generation of internal stresses, while the molybdenum target shows good resistance to the action of a high-current electron beam.

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ПОВЕДЕНИЕ МОЛИБДЕНОВОЙ МИШЕНИ В УСЛОВИЯХ ОБЛУЧЕНИЯ СИЛЬНОТОЧНЫМ РЕЛЯТИВИСТСКИМ ЭЛЕКТРОННЫМ ПУЧКОМ

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Рассматриваются проблемы стойкости молибденовых мишеней к действию концентрированных потоков энергии. Проведена серия облучений молибденовой мишени сильноточным релятивистским пучком электронов. Анализируются механизмы воздействия пучка на мишень. Мгновенное введение энергии в мишень вызывает нагрев мишени, что приводит к генерации напряжений, обусловленных термоупругим эффектом. Абляция расплавленного вещества создает реактивный импульс отдачи. Определены особенности микроструктуры мишени в области плавильного эффекта пучка и в области теплового воздействия.

ПОВЕДІНКА МОЛІБДЕНОВОЇ МІШЕНІ В УМОВАХ ОПРОМІНЕННЯ ПОТУЖНОСТРУМОВИМ РЕЛЯТИВІСТСЬКИМ ЕЛЕКТРОННИМ ПУЧКОМ

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Розглядаються проблеми стійкості молібденових мішеней до дії концентрованих потоків енергії. Проведено серію опромінень молібденової мішені потужнострумовим релятивістським пучком електронів. Проаналізовано механізми впливу пучка на мішень. Імпульсне введення енергії в мішень викликає нагрівання мішені, що призводить до генерації напружень, обумовлених термопружним ефектом. Абляція розплавленої речовини створює реактивний імпульс віддачі. Визначено особливості мікроструктур мішені в області плавильного ефекту пучка та в області теплового впливу.