Journal of Physics: Conference Series **652** (2015) 012005 doi:10.1088/1742-6596/652/1/012005

The change in the surface topography of magnesium under high-flux C ion irradiation

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Abstract. The topography of the surface of the magnesium sample after irradiation by the high-intensity pulsed ion beam of a TEMP-4M accelerator was studied. The irradiation causes the formation of a regular comb structure and the creation of craters, their depth reaches 1-1.5 μm.

1. Introduction
The structural phase transformations which occur in metals and alloys under the action of high-intensity pulsed beams (HIPB) of the charged and neutral particles (electrons and ions), as well as the plasma and laser irradiation have been studied for over thirty years. Nevertheless, the mechanism of formation of topography on the surface and of the defects in the near-surface layer of fusible nonferrous materials after the HIPB action is still incomprehensible [1-5]. It especially concerns such metals as aluminum and magnesium. In this connection, the study of the high-intensity ion beam action on a beam surface layer is of a scientific interest.

2. Experimental setup and characterization techniques

The object of research was samples (30x15x3 mm) of technically pure magnesium which surface was mechanically burnished and polished using abrasive paper and diamond suspensions.
The samples were studied using a TEMP-4M accelerator at an accelerating pulse duration τ =100 ns and an energy density J (J/cm^2) on the surface of the target such as: 0.5 (Δ =100 pulses), 1.5 (Δ = 100 pulses), and 2.5 (Δ =10 pulses), J/cm^2 [6]. The particle flux from a self-magnetically insulated vacuum diode operating in a two-pulse mode consists of carbon ions C_n^{+1} admixed with protons and corresponding neutrals. The topography of the surface was studied using the Nova Nano SEM 650 ultrahigh-resolution field-emission scanning electron microscope (SEM) and the Quanta 200 3D thermal-emission SEM.

3. Results and discussion

The process of HIPB interaction with the matter includes the mode of short-pulse implantation of ions which are constituents of the beam, and high-speed heating (~100 ns) during the action of the beam current pulse. The density of the flux of carbon ions and protons for a pulse is within 10^{13}-10^{14} cm^{-2} depending on the beam current density. A high-rate heating of the target can cause the melting of the surface layer of the target. In the case of the uniform density of the particle flux density, the micro irregularities of the irradiated surface are primarily subjected to melting, because heat removal from the area of the micro irregularities is less than that from the flat surface. The melted parts can create a continuous field of liquid in the region of the beam action, when J is over 1.5 J/cm^2. The lifetime of melt is of an order of the duration of the beam current pulse [4].

When the HIPB action is terminated, the crystallization front in liquid [7] moves towards the surface with a rate determined by time of heat removal from the melting zone. In the case of high-speed cooling of the surface layer of magnesium, two-phase (porridge-like) region near the crystallization front is the place of gas bubble inception. The bubbles with a radius over critical can expand and rising to the surface to tear out the liquid shell forming the cavities in the shape of craters when hardening. When the state of magnesium is changed from liquid to solid [8], magnesium viscosity is increased by over 20 orders, therefore, some of these cavities do not have time to be covered in a quick-hardening matter, forming the cavities identified as craters. To our mind, it is one of the reasons of microcrater formation under the action of HIPB upon the metallic materials [9].

Thus, the action of HIPB on the surface of the sample causes the total or partial (depending on the average density of the power of an ion beam and the degree of homogeneity) melting of the near-surface layer of magnesium. The relief of the modified surface of the target, all other factors being equal, will depend on the density of the particle flux power acting on the surface of magnesium (J/cm^2s).

The crystallization of the melted layer on the surface of magnesium causes the formation of the wave (comb) structure (Figure 1, a). The alternation of the combs and cavities is most pronounced in Figures 1 (c, d). The reason for this alternation can be associated with the formation of shock waves in the layer of the liquid metal and the recoil momentum pressure emerging on the surface of the melting at the pulsed evaporation of the part of the layer of the metallic melting.

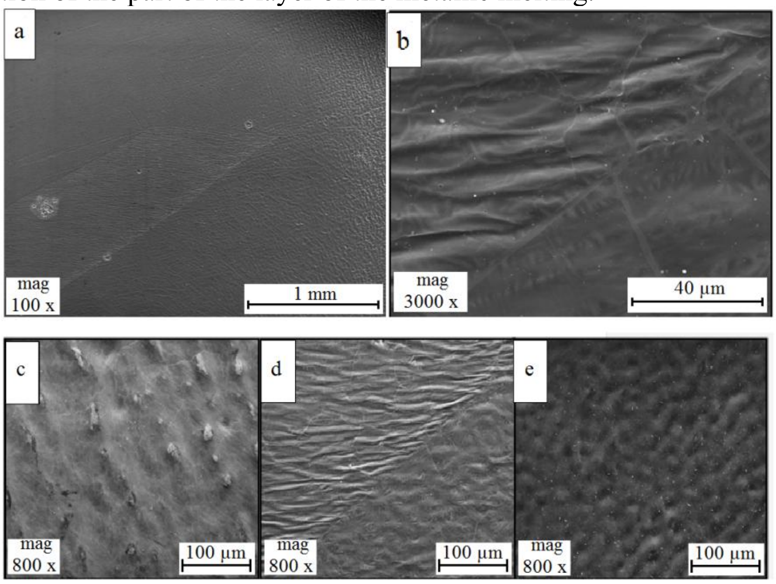

Figure 1. Structure of the surface of magnesium after irradiation (2.5 J/cm^2, 10 pulses) at a different enlargement of one and the same part of the surface under study.

As the structure of magnesium is coarse-grained (4-5 grains at the investigated surface with an area of 1 cm^2), the comb structure is not distorted with grain boundaries. Magnesium workpieces have been produced by a traditional casting technology with a minimum cooling rate. After solidification of liquid magnesium the large grains are formed, which have identical crystallographic structure, but located at various angles from each other. Consequently after the HPIB treatment of the surface of a sample, clipped from a workpiece, the partial ordering of surface occurs by means of the forming of periodic comb structure (Figure 1, b-e). It is especially seen in Figure 1, b, d, where the comb structure differs from grain to grain. In the top left corner of Figure 1, b, the number of combs per unit area of a grain is significantly higher than in the neighbour grain (bottom right corner of Figure 1, b). There are also craters (Figure 2) on the irradiated surface (mainly, on the tops of the combs, Figure 1, c). Two types of craters are formed during irradiation: craters with a cupola in the centre (Figure 2, a) and without a cupola (Figure 2, b).

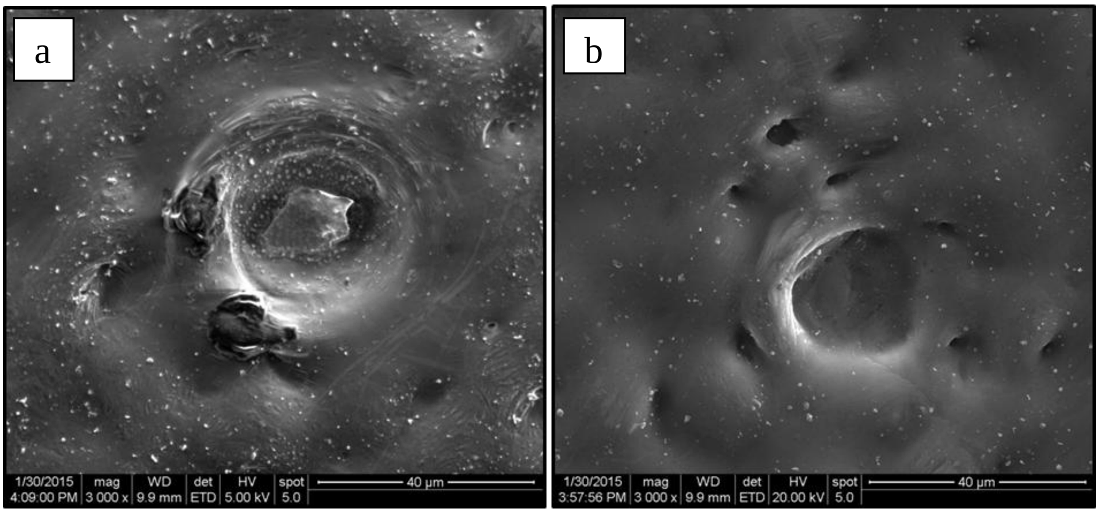

Figure 2. Craters on the surface of magnesium after irradiation (2.5 J/cm^2, 10 pulses).

The mechanism of crater formation under the action of HIPB differs fundamentally from blister formation under the action of the particle flux at a conventional ion implantation [10].

Conclusions

1. Melting the near-surface layer of magnesium with a high-intensity pulsed ion beam causes the formation of a regular wave (comb) structure, which is intermittent.
2. At the same time, round craters are formed on the tops; the formation mechanism requires additional investigation.

Acknowledgments

The work was supported by Russian Foundation for Basic Research (projects nos. 11-08-01165-a, 13-08-98061 and. 14-08-00632-a).

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