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Effect of pulsed soft X-ray radiation on the surface topography of some metals

A E Ligachev[1,6], M V Zhidkov[2], S A Sorokin[3], G V Potemkin[4] and Yu R Kolobov[5]

[1] Prokhorov General Physics Institute of the Russian Academy of Sciences, 38 Vavilova st., 119991, Moscow, Russia
[2] Belgorod State National Research University, 2a Korolyova st., 308015, Belgorod, Russia
[3] Institute of High Current Electronics of Siberia Branch of the Russian Academy of Sciences, 2/3 Akademichesky prospect, 634055, Tomsk, Russia
[4] Institute of Problems of Chemical Physics of the Russian Academy of Sciences, 1 Academician Semenov prospect,142432, Chernogolovka, Moscow region, Russia
[5] Tomsk Polytechnic University, 30 Prospect Lenina, 634050, Tomsk, Russia

[6] E-mail: zhidkov@bsu.edu.ru

Abstract. Effect of the pulsed soft X-ray fluxes (PSXF) on the surface topography of metals (Mg and Cu) has been investigated. Soft pulse X-ray irradiation (energy quanta of 0.1-1.0 keV) were carried out on a high-current MIG generator. The sample of magnesium was located at a distance of 10 cm from the X-ray source. Since the distance to the sample significantly exceeded the size of the X-ray beam, it can be assumed that the density of the X-ray radiation flow to the magnesium sample was uniform. The duration of the radiation pulse was 100 ns, and the radiation energy density in the pulse varied from 13 to 19 J/cm^2. As a result of melting under the action of PSXF of the near-surface layer of metals and subsequent solidification, a wavy relief is formed on their surface. Defects in the form of craters, which usually occur after the impact of a powerful pulsed ion flow on metals, were not detected.

1. Introduction

High-Power Pulsed Ion Beam (HPPIB) have been used for modifying the surface of metals for quite a long time. The first studies on the processing of metals and alloys on the example of tool steel P6M5 with HPPIB of carbon ions (TONUS accelerator) were carried out in 1981 at the Research Institute of Nuclear Physics at the Tomsk Polytechnic Institute [1, 2]. Then experiments were started on irradiation of both pure metals – beryllium, armco-iron, copper of electrolytic purity, titanium, aluminum single crystals, and steels of various grades, hard alloys [3-6]. The purpose of these studies is to study the possibility of using to change not only the structural and phase state of the surface and the near-surface layer, but also the physico-mechanical and physico-chemical properties of metal and alloy products.

Pulsed soft X-ray radiation (PSXR) can also have the same effect on the properties of the surface and near-surface layers of metals. We performed the first experiments on the effect of this type of radiation on metals in 2017-18 using a pulsed soft X-ray radiation source installed in the IHCE SB

RAS [7]. As a target, we selected titanium (T_{melt} = 1679°C), the properties of which are quite well studied after the treatment of HPPIB.

The study of titanium after its treatment by PSXF showed that its surface topography changes significantly [8]. Therefore, to further study the effect of PSXF on the surface properties of metallic materials, we focused on metals with a lower melting point, such as Cu (T_{melt} = 1083°C) and Mg (T_{melt} = 650°C).

2. Experimental details

Before irradiation (high-current MIG generator, quantum energy 0.1-1.0 keV [5]), the surface of technically pure magnesium and electrolytic copper was polished to a mirror shine.

Since the distance from the X-ray source to the irradiated sample, equal to 10 cm, is significantly larger than the size of the X-ray source, the radiation flux density per sample can be considered homogeneous. The duration of the radiation pulse was 60 ns. The energy per pulse was 10-12 (±2) kJ, which corresponded to the radiation energy density on the sample surface of about 10 J/cm^2. The number of IMRI pulses is from 1 to 3.

The topography of the metal surface after irradiation was studied using a Quanta 600 FEG scanning electron microscope (SEM) equipped with an energy dispersion spectrometer.

3. Results and Discussions

As a result of the action of PSXF on the surface of the metal, its near-surface layer melts. After the impact of a single pulse, a relief of a cellular or mesh type is formed on the surface of titanium (figure 1 (a, d)), the width of the grid boundaries is about 10-15 microns.

Treatment with two PSXF pulses only leads to a decrease in the size of the cells and an increase in their number on the treated surface of titanium (figure 1 (b, e)). After exposure to the third PSXF pulse, the mesh relief also does not change significantly, but the cell boundaries are smoothed due to their melting (figure 1 (c, f)), most likely due to melting [8].

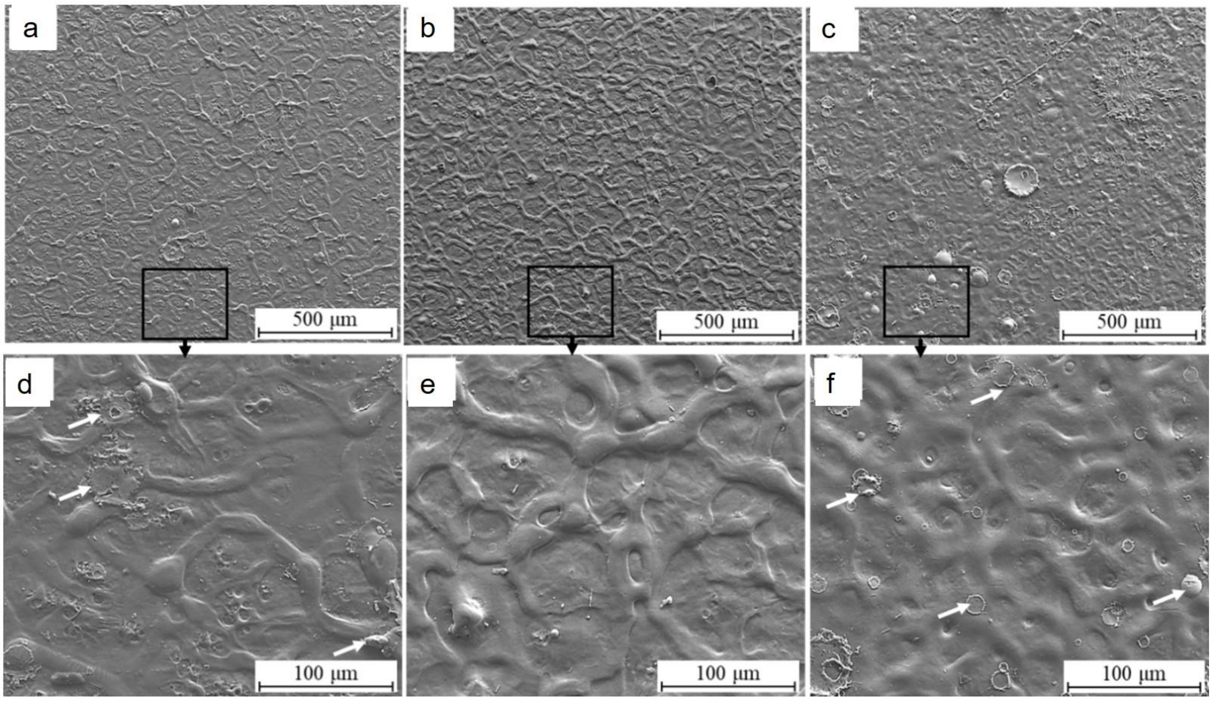

Figure 1. Topography of the surface of titanium after exposure to an X-ray beam: a, d – 1 pulse; b, e-2 pulses; c, f – 3 pulses [8].

A different picture is observed after exposure to PSXF on the surface of copper. The entire irradiated surface is covered with strips of solidified metal, the length of which is 10-15 times greater than their width (figure 2 (a)). The area of these bands occupies at least 90% of the entire area of the irradiated surface. Also, craters were found on the surface of copper after irradiation, on the edge of which there are drops of solidified metal (figure 2 (b)) and pores in the depth of the near-surface layer (figure 2 (c)), formed due to boiling of the near-surface layer.

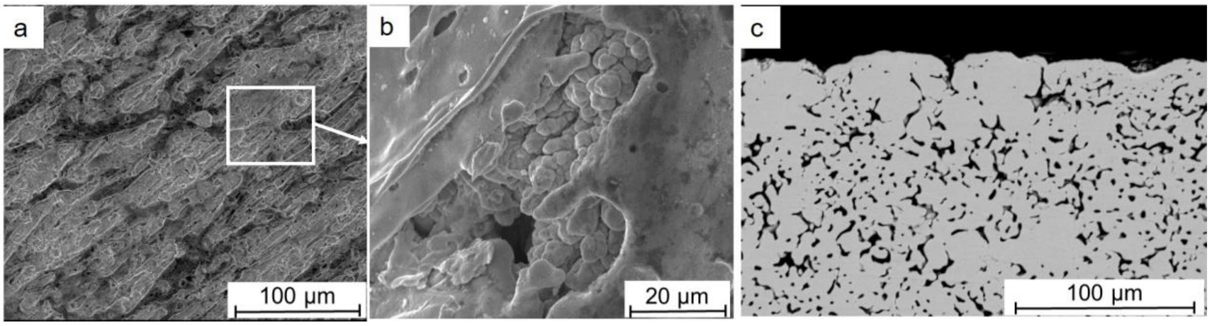

Figure 2. Surface topography (a, b) and structure of the near-surface layer (c) of copper after its PSXF treatment.

As for magnesium, because of irradiation, its entire surface is covered with solidified waves of liquid metal; there are practically no craters on it (figure 3). Moreover, the number of irradiation pulses (from one to three) affects the shape of the surface relief of both copper and magnesium it does not affect.

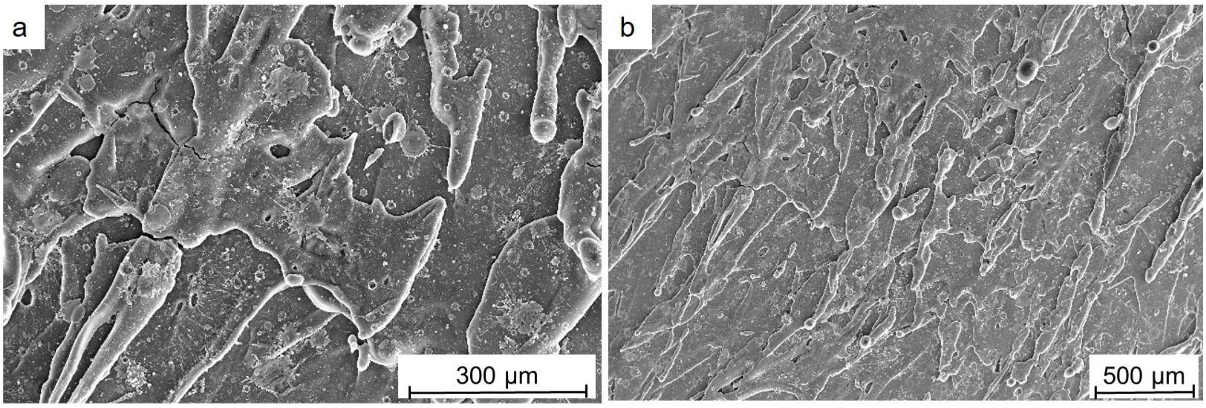

Figure 3. Topography of the magnesium surface after its treatment by PSXF.

4. Conclusions

After exposed to nanosecond pulses of soft X-ray radiation, a wavy structure is formed on the surface of copper and magnesium as a result of melting and subsequent solidification. Defects in the form of craters, which usually occur when pulsed beams of electrons, ions, and plasma are exposed to metals and alloys, were not detected.

The next stage of our research is the study of the structural and phase state of the near-surface layers of copper and magnesium and their physical and chemical properties after this type of surface treatment.

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References

[1] Logachev E I, Remnev G E and Usov Yu P 1980 *Tech. Phys. Lett.* **22** 1404
[2] Didenko A N, Kuznetsov B. I and Remnev G. E 1981 *Tezisy dokladov Vsesoyuznoi konferentsii po primeneniyu elektronno-ionnoi tekhnologii v narodnom khozyaistve* (Tbilisi: NIIET) p 110 [in Russian]
[3] Didenko A N, Remnev G E and Logachev A E 1986 *VI Vsesojuznyj simpozium po silnotochnoj elektronike: tezisy dokladov* (Tomsk: Institute of High-Current Electronics SB of the USSR Academy of Sciences) p 163 [in Russian]
[4] Didenko A N, Remnev G E, Chistjakov S A and Ligachev A E 1986 *Proc. 6-th Int. conf. of high-power particle beams* (Osaka: ILE) p 77
[5] Pogrebnyak A D, Remnev G E, Chistyakov S A and Logachev A E 1987 *Izv. VUZ Phys.* **30** 52 [in Russian]
[6] Pogrebnjak A D, Remnev G E, Kurakin I B and Ligachev A E 1989 *Nucl. Instrum. Meth.* B **36** 286
[7] Kablambaev B A, Luchinsky A V, Petin V K, Ratakhin N A, Sorokin S A, Fedushchak V F, Tchaikovsky S A and Shlyakhtun S V 2001 *Questions of atomic science and technics. Series: Physics of radiation effects on radio-electronic equipment* **3-4** 149 [in Russian]
[8] Ligachev A E, Zhidkov M V, Sorokin S A, Kolobov Yu R and Potemkin G V 2018 *Inorganic Materials: Applied Research* **10** 541