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The impact of a shock-compressed layer on the mass transfer of target material during processing compression plasma flows

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ABSTRACT

The paper describes the results of experimental and numerical research of the thickness of the molten bath and the surface erosion of a substance under the influence of compression plasma flows. It has been demonstrated that the formation of the shock-compressed layer affects the melted depth and the mass erosion from the surface of the treated target.

1. Introduction

High-temperature plasma flows generated by plasma accelerators are some of the most promising energy carriers for use in the field of radiation technologies for production and modification of materials, since they allow a combination of ultra-fast hardening, liquid phase alloying of the surface layer by the elements of the previously applied coating, and saturation of the surface by atoms of the plasma gas. Interaction of an intensive plasma stream with the material surface can be characterized by ultrafast heating processes (10^8 K/s) of the surface layer (to temperatures exceeding the melting temperature) and cooling, resulting in structural and phase changes of the surface layer [1]. Exposure to high temperatures is one of the reasons for the erosion of the material surface that can be used to analyze the behaviour of materials in the first wall of fusion reactors in the event of disruption of the plasma [2–5]. The main mechanisms of erosion can be ablation, including evaporation and boiling of the material [3,6], as well as the melt flow on the surface, accompanied by the formation of hydrodynamic instabilities and ejection of drops of the material [2–6].

A distinctive feature of compression plasma flows (CPF) generated by quasi-stationary plasma accelerators is the relatively large discharge duration (in the order of hundreds of microseconds), while maintaining high plasma parameters (plasma speed is 30–70 km/s, temperature of the plasma is 2–5 eV; the electron density is 10^{16}–10^{18} cm^{-3}) [7]. The shock-compressed plasma layer [7] is formed at the surface of the sample under the influence of supersonic compression stream; the position of its border is determined by the dynamic balance between the pressure of the compression flow and gas-kinetic (heat) expansion of the surface plasma. These high energy plasma parameters of the shock-compressed layer provide high-speed surface heating to temperatures above the melting point of almost any material.

The main parameters that determine the structure, element and phase composition of the surface layer, modified layer thickness, and weight of the material eroded from the surface, is the density of the absorbed energy in the surface layer [8,9]. At the moment, much (more than 10 years of research) empirical material has been collected on the modification of materials by compression plasma flows [8]. The theoretical studies [10,11] have made it possible to explain a number of experimentally observed facts. However, the current approach leaves a significant discrepancy between the results of numerical calculations and experimental data, such as the volume eroded from the treated surface material and the molten depth. For example, as noted at [12], the CPF, in terms of the energy emission, can be considered as a surface energy source and consequently [12] the molten depth is determined by the thermal conductivity and is equal to a few micrometers. Experimental data presented in this work, though, indicate that the molten depth can reach tens of micrometers, depending on the treatment mode. Mass erosion from the target surface, also measured in this work, is, in some cases, below the results of numerical calculations using BETAIN software package [13]. This discrepancy between numerical calculations and experimental data may be explained by the fact that the research [13] did not take into account the effect of plasma pressure on the dynamics of the near-surface layers of material.

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