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Formation model of cathode surface structure in contact with plasma flows of high-current low-inductance vacuum spark

S.A. Sarantsev*

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, 115409, Moscow, Russia

Abstract

This paper presents a model describing formation of a submicron surface structure on electrodes of high-current low-inductance vacuum spark. The model is based on the development of the Kelvin-Helmholtz instability, which occurs at the boundary of tangential discontinuity between plasma and melt. This model has been used to determine the most probable lengths of instability waves, the rate of which conforms to the available sizes of structural elements on electrodes surface.

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Keywords: high-current low-inductance vacuum spark; submicron structure; electrode surface; micropinch; Z-pinch; Kelvin-Helmholtz instability.

1. Introduction

High-current low-inductance vacuum spark (HCLIVS) [Kuznetsov et al. (2014), Beilis et al. (1999), Krasov et al. (2007), Bashutin et al. (2013), Astrakhantsev et al. (1995)] offers high plasma parameters ($n_e > 10^{21}$ cm^{-3}, $T \sim$ keV), long operational life, and a simple and quite inexpensive design, which makes it a promising source of dense

* Corresponding author. Tel.: +7-495-788-5699 add. 9319; fax: +7-499-324-2111.
E-mail address: sasarantsev@mephi.ru

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impulse high-temperature plasma for technological applications and other purposes. This discharge belongs to Z-pinch discharges utilizing electrode material as working substance.

Researches dealing with vacuum spark barely touch upon the processes occurring on electrode surface, although they significantly influence discharge development. Relation between these processes and the processes in interelectrode space is poorly investigated. Therefore, it is impossible fully describe HCLIVS formation and development from the moment of discharge initiation up to the moment of a micropinch disintegration. The same reason explains the absence of HCLIVS mathematical model and scaling principles, which makes it difficult to use the spark in applications requiring high reproducibility of plasma parameters and radiative characteristics discharge by discharge.

This paper describes formation of periodic submicron structure on HCLIVS cathode. This description is based on hydrodynamic model of the Kelvin-Helmholtz instability development occurring upon contact between flowing plasma and melt surface. Processes on electrodes surface were described using the data obtained at the Pion unit [Sarantsev et al. (2015)] of the Plasma Physics Department of the National Nuclear Research University MEPhI.

2. Formation model of submicron structure on metal surface upon the contact with plasma flows

Upon the contact of plasma flows formed during the development of a micropinch in HCLIVS, the electrode surface undergoes significant heat and impact loads, which transform the surface. The raster electronic microscopy of the HCLIVS cathode showed that the periodic submicron structure with ~150 to ~600 nm cells appeared on the cathode surface [Sarantsev et al. (2015)]. The size of cells depends on conditions of discharge development (charge voltage, discharge current, and trigger configuration).

Fig. 1 shows a photo of the HCLIVS cathode with circled area, where the periodic submicron structure is formed. Fig. 2 showcases a photo of this structure.

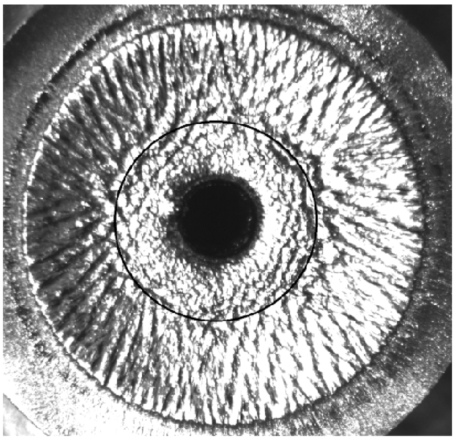

Fig. 1. Cathode Surface photo at the Pion unit after 50 Discharges. Black circled is the area, where periodic submicron structure is formed.

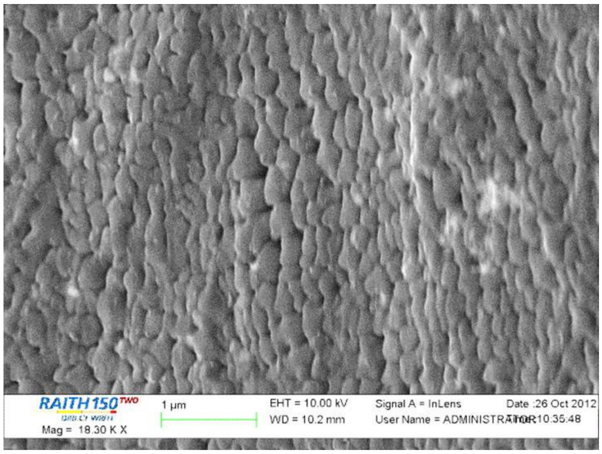

Fig. 2. Periodic Structure on Cathode Surface.

Structures formation can be explained as follows. The melt front in course of plasma action extends to the cathode material together with plasma radial wash along the surface, which results in flowing of the melt top layers. At the same time, the tangential discontinuity of Kelvin-Helmholtz instability occurs in a thin transition layer between recently melted and yet static metal and a moving melt. This process is well known in hydrodynamics. Such fluid dynamics occurs, for instance, when a thin liquid layer is exposed to an airflow moving parallel to the free surface. In general, this type of dynamics develops when two liquid layers with different velocity and density move relative to each other. Instability mechanism results from the Bernoulli effect, i.e. when there is an agitation