Features of the erosion of the surface of carbon materials in the interaction of pulsed plasma flow

M.K. Dosbolayev[1], A.B. Tazhen[1], Zh.R. Rayimkhanov[1], T.S. Ramazanov[1]

[1]IETP, Al-Farabi Kazakh National University, Almaty, Kazakhstan
merlan@physics.kz

This paper presents the results of an experimental investigation of erosion of carbon materials after interaction with a pulsed plasma flow. To generate a pulsed plasma flow, an experimental setup – a pulsed plasma accelerator (IPA-30) was used. Carbon samples were irradiated by 25 pulses of plasma flow. Electron-force microscopy (SEM) was used to analyze the surfaces of carbon samples. As the SEM images show, fractal similar complex structures and blisters were found on the surface of the samples. Some experimental results show that fast dust particles can also appear in the plasma due to the erosion of the insulator material, placed in the inter electrode space of electrodes. Such dust particles are called «projectile particles» that strike to the surface and destroy it. The maximum speed of such dust particles found in our experiment reaches approximately 430 m/s.

1. Introduction

In recent years, the role of dust in plasma has increased dramatically, which is explained by the general understanding of the importance of issues related to the first wall of thermonuclear reactors (TNR) and the development of future thermonuclear reactors [1]. At present, the main problems of the TNR in relation to dust are connected to its safety, that is, the chemical activity of dust, tritium retention and radioactivity, which can complicate the operation of the reactor and possible deterioration of intracameral diagnostics caused by dust [2]. To date, the experimental results on the formation, transportation and mobilization of dust in existing tokamaks, as well as their theoretical substantiation, are still not well understood and require intensive study. Difficulties appear in the diagnostics of dust in hot plasma, more generally, due to poor understanding of plasma-surface interaction processes, evolution, surface morphology, and near-surface physics at high plasma flows, and particle flows. As shown in ref. [3], in modern TNR, working with hydrogen-helium plasma, the formation of tungsten dust particles also occurs by the surface peeling, ejection of grain and melting for carbon-like materials. An intensive dust emission is observed after transient events, such as radiation, the escape of energetic electrons, and most importantly due to plasma instability, for example, ELM events (Edge Localized Modes) [4].

The effects of dust formed due to erosion on the plasma are accompanied by an influx of impurities into the plasma. In TNR for ELM events and reactions failures, thermal loads on the protective wall are expected, which are difficult to achieve in existing tokamaks. In this regard, plasma accelerators are more suitable installations that allow simulating these events in the TNR in terms of some key parameters for both testing materials and studying the characteristics of erosion products [5]. In addition, the use of pulsed accelerators is more extensive than it seems, accelerators can be used in industry for surface treatment of materials for pulsed plasma deposition.

2. Experimental setup

The experimental setup – pulsed plasma accelerator IPA-30 consists of a vacuum chamber, inside which there are coaxially arranged electrodes. The diameter of the inner electrode is 55 mm, the outer one is 108 mm, and the length, respectively, is 330 mm and 350 mm [6]. High voltage from capacitor banks is applied to the electrodes through a vacuum gap. Using a cone-shaped calorimeter, the energy density of pulsed plasma was measured; the maximum energy density is 65 J/ cm^2. To determine the speed and dynamics of the plasma flow, a high-speed camera Phantom VEO710S was used. As the results show, the plasma can accelerate to 27 km/s. The densities and temperatures of charges in the plasma flow were determined using an electric probe "Impedans plasma measurement – Langmuir Probe".

3. Results and Discussion

In the experiments, graphite plates were irradiated by 25 pulses of plasma flow. An analysis of the surfaces of graphite plates was done using the electron force microscopy.

The results of the SEM analysis show that the surfaces of graphite were subjected to erosion, which is a consequence of the heat load of the pulsed plasma flow on the surface of the plates. As can be seen in Figure 1, the surface of a sample of a graphite target is branched, and fractal similar structures are observed in some places. Also in some areas, you can see the traces of blisters.

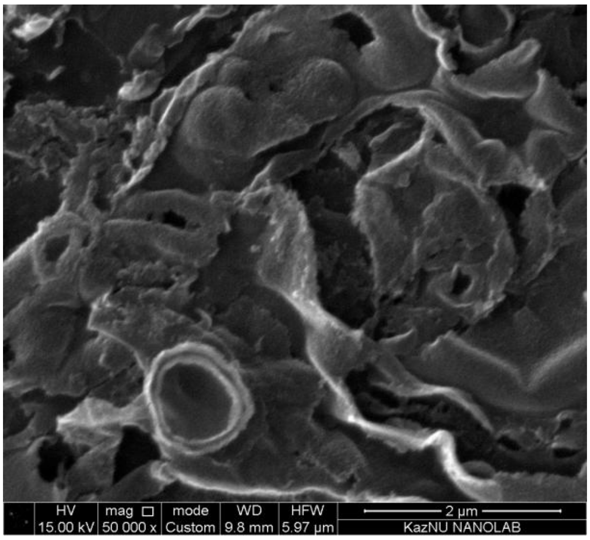

Fig. 1. Erosion and blistering on the graphite target surface.

Blisters are blown bubbles at the surface layer of the material where the molecules of the working gas accumulate. With further accumulation of molecules, surface tension appears at the surface layer, due to which they collapse and leave trails in the form of craters.

In addition, the erosion of the surface occurs because of bombardment by streams of fast dust particles that are present in the plasma as impurities. In Figure 2, you can clearly see that such dust particles are capable of destroying the surface. The maximum speed of such dust particles found by us reaches approximately 430 m/s.

Fig. 2. Single images of the dust "projectile" appearing during the arc discharge and the destruction of the surface with a dust.

The chemical composition of the dust particles in Figure 2 shows that the dust particle appeared due to the erosion of the insulator material placed between the electrodes. Similar fast particles were observed in [2]. It was shown that the drag force caused by the plasma flow plays a decisive role in the dynamics of such particles. In some cases, the behavior and trajectories of some dust particles observed by high-speed cameras during normal operation was a simple picture of toroidal acceleration by the plasma flow.

Acknowledgments

This work was supported by the Ministry of Education and Science of Kazakhstan under Grant IRN AP05134671.

References

[1] J.C. Flanagan, M. Sertoli, M. Bacharis et al. Plasma physics and controlled fusion. **57** (2015) 014037.

[2] S.I. Krasheninnikov, R.D. Smirnov and D.L. Rudakov. Plasma Phys. Control. Fusion. **53** (2011) 083001.

[3] D. Nishijima. J. Plasma Fusion Res. **81** (2005) 703.

[4] A.W. Leonard. Phys. Plasmas **21** (2014) 25.

[5] A. Zhitlukhin, N. Klimov, I. Landman et al. J. Nucl. Mater. **363-365** (2007) 301.

[6] M.K. Dosbolayev, A.U. Utegenov, A.B. Tazhen, T.S. Ramazanov. Laser and Particle Beams. **35** (2017) 741-749.