



Electron beam transport in dusty plasma

T. Vaislieva, S. Lysenko, D. Bayandina, M. Vasiliev*

Moscow Institute of Physics and Technology, Institutsky per., 9, Dolgoprudny 141700, Moscow Region, Russia

ARTICLE INFO

Available online 15 December 2010

Keywords:

Electron beams
Dusty plasma

ABSTRACT

The propagation of low-relativistic electron beams through dusty plasmas was studied experimentally within wide ranges of the plasmagenerating gas pressures, dust densities, and beam characteristics. The peculiarities of the transport of focused and defocused beams were revealed for various combinations of the parameters mentioned above. In particular, three various modes of the beam transport were observed and the conditions of the transitions from one mode to another were found. The values characterizing the beam absorption and scattering in dusty media were measured for each mode of the beam transport. The experimental results were compared with the data of the computer simulation, and the developed method of simulation was shown to describe the beam–plasma interaction correctly.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction: the problem statement

The development of a number of power, aerospace, and industrial technologies demands for the analysis of the electron beam transport in dusty media. Plasmachemical reactors, equipments for the material treatment, gas cleaners, fusion reactors, and other industrial or scientific setups contain zones where an electron beam (EB) propagates through dust dispersed in a vacuum or gaseous volume. Typically, the dust fills a container and complicated interactions between the beam, gas, dust, and container wall occur. To simplify the analysis the EB transport can be considered in an unbounded dusty volume when the wall influence on the above processes is negligible.

Fig. 1 illustrates the statement of the physical problem the developers of research and technological beam–plasma systems usually face. A thin low-relativistic EB is supposed to be injected into the gas along the z -axis and a flat layer of the dust is formed at some distance, z_0 from the point of the EB injection. The layer plane is perpendicular to z , i.e. at the intervals $z < z_0$ and $z > (z_0 + d)$, where d is the layer thickness, the EB propagates in the pure electron beam–plasma (EBP) whereas within the segment $[z_0, (z_0 + d)]$ the electrons move through the dusty EBP. Thus, the plasmas are generated due to the beam–gas interaction only or due to the combination of the beam–gas and beam–dust interactions. Table 1 presents the main physical processes occurring in these plasmas; the intensities of these processes depend on numerous parameters characterizing the beam, gas, and dust. In the present paper the influence of some of these parameters on the EB transport is experimentally studied. The results of the computer simulation of

the EB propagation and the EBP generation under various conditions, including the conditions of the experiments carried out, are presented.

2. Experimental setup and techniques of the investigation

The generator of the aerosol EBP described in detail in Ref. [1] was used to carry out the experiments under consideration. The generator was specially adjusted to the experiments on the EB transport in plasmas and Fig. 2 illustrates the peculiarities of the modified setup. Thin EB 2 is formed by electron gun 1 in the high-vacuum chamber 3 equipped with the pump 10. The beam is injected into the working chamber 5 via the gas-dynamic window 4. The working chamber has its own vacuum pump 8 and the feeding system 7 that fills the chamber with the plasmagenerating gas and keeps the required value of the gas pressure in spite of the gas leakage through the injection window and the pump 8 continuous operations. The mechanical sprayer 6 is placed inside the working chamber to form the dust layer, as shown in Fig. 1, and to vary the density of the dust particles n_d . The chamber 5 is equipped with special holders for the diagnostic facilities, glass windows for optical measurements, and sealed connectors for electric circuits, optical fibers, pressure meters, and some other units.

The diagnostic system of the experimental setup includes the electric and optical probes, calorimeters, and temperature sensors. The following values are measured during the experiments carried out:

- initial electron energy E_b and beam current I_b ;
- gas pressure P ;
- radial profiles of the fast electrons current density in various cross-sections of the plasma cloud beyond the dusty layer;

* Corresponding author. Tel./fax: +7 495 408 6798.
E-mail address: cs1@mail.mipt.ru (M. Vasiliev).

- the potential U_p of a micro-probe placed at various points of the plasma cloud both inside and beyond the dust layer; the potential U_p is similar to the floating potential of gas-discharge plasmas;
- radial profiles of optical radiation intensity at various cross-sections of the plasma cloud;
- heat flows absorbed by a micro-body inserted at various zones of the plasma cloud; in particular, the radial profiles of the EB power input in the dust particles are measured within the dust layer.

The initial energy of the electrons at the injection window outlet was determined as the accelerating voltage of the electron gun adjusted in accordance with the EB deceleration in the injection window channel. The EB energy loss in the injection window and angular spread $\delta\theta$ of the fast electrons trajectories at the window outlet were calculated (see section 4). The value of $\delta\theta$ could be additionally adjusted by electromagnetic lens 9 (Fig. 1) placed at the injection window outlet.

The integral beam current was measured by the Faraday cup at the lowest gas pressure that could be obtained in the working chamber ($P \sim 10^{-2}$ Torr). The potential U_p was supposed to be equal to the potential of the micro-probe inserted at a given point of the EBP cloud.

To study radial profiles of the fast electrons current density at a certain cross-section of the plasma cloud the conventional technique of rotating probe was applied (see Ref. [2]). Two probes were placed in the working chamber so that the planes of their rotation were perpendicular to the z -axis and were at the distance of about 5 mm from the front and rear planes of the dust layer.

The optical measurements were used to study the spatial distribution of the EB power input $Q(r,z)$ into the gas. The intensity of the radiation emitted by any local volume of the plasma cloud beyond the dust layer was supposed to be proportional to the local power input of the beam into this volume. Fig. 3a illustrates the technique applied. The optical fiber 1 with the collimating tube 2 on

one of its end was the receiver of the radiation; the other fiber end was connected to the spectrometer. The receiver moved in a radial direction at the given cross-section 3 of the EBP cloud as shown in Fig. 2, the axis of the collimating tube being perpendicular to the direction of the motion. When the receiver transverses the plasma cloud from one boundary to the other the distribution of the radiation intensity $B_\lambda(x)$ integrated along the chords was obtained as the ratio of the intensity of the selected line of the EBP radiation spectrum to the maximum value $(B_\lambda)_{\max} = B_\lambda(x=0)$. One of the chords mentioned above is designated as chord 4 in Fig. 3a, and the spectrum of the dusty air-EBP is presented in Fig. 3b. The Abel transformation was applied to the original distributions $B_\lambda(x)$ to transform them into the radial distributions $B_\lambda(r)$. Obviously $B_\lambda(x=0) = B_\lambda(r=0)$. When a wide-band photo-sensor was connected to the optical fiber instead of the spectrometer the profiles of the integral radiation intensity $B(r)$ were obtained. The experiments showed the profiles $B(r)/B(r)_{\max}$ to be similar to the profiles $B_\lambda(r)/B_\lambda(r)_{\max}$.

The heat flows absorbed by a micro-body inserted into the EBP were measured

- to estimate the fraction of the EB power absorbed by the dust,
- to evaluate the temperatures of the dust particles bombarded by fast electrons,
- to verify the results of the optical measurements of the EB power input $Q(r,z)$.

Miniature thermo-sensors (2×2 mm in size and 0.5 mm thick) were used as calorimeters. The calorimeters were able to operate in both stationary and non-stationary regimes. In the first case the exposition time τ (τ is the time interval during which the calorimeter was in a contact with the EBP) was sufficiently long to obtain thermodynamic equilibrium between the thermo-sensor and surrounding plasma. In the latter case the sensor temperature T_s was monitored as a function of time t . If the function $T_s(t)$ is known the heat flows absorbed by the calorimeter can be calculated assuming that the heat transfer between the thermo-sensor

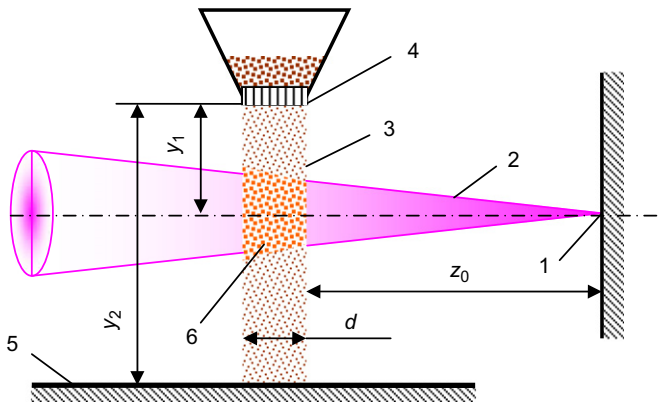


Fig. 1. Statement of the physical problem of the EB transport in dusty plasmas, 1—electron gun, 2—electron beam, 3—high-vacuum chamber, 4—powder sprayer, 5—working chamber, 6—powder sprayer, 7—feeding system, 8, 10—vacuum pumps, and 9—electromagnetic lens.

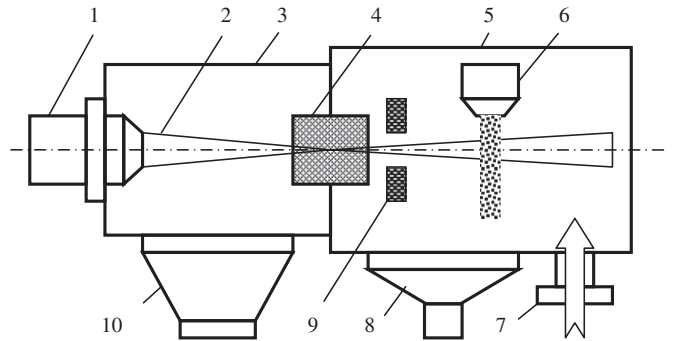


Fig. 2. Scheme of the experimental setup, 1—electron gun, 2—electron beam, 3—high-vacuum chamber, 4—powder sprayer, 5—working chamber, 6—powder sprayer, 7—feeding system, 8, 10—vacuum pumps, and 9—electromagnetic lens.

Table 1
Main processes in electron beam plasmas of pure and dusty gases.

Beam–gas interaction	Beam–dust interaction
EB scattering and deceleration	Scattering and capture of high-energy electrons by the dust
Gas ionization	Heating of the dust and the radiation from the surface of the dust particles
Gas heating	Electric charging of the dust
Electron–ion recombination and electron attachment to the gas molecules	Electron–ion recombination on the dust surface
Plasmachemical reactions	Electron emission from the surface of the dust particles

Download English Version:

<https://daneshyari.com/en/article/1824977>

Download Persian Version:

<https://daneshyari.com/article/1824977>

[Daneshyari.com](https://daneshyari.com)