DISINTEGRATION OF PLASMOGENIC DIELECTRIC WORKING MATERIALS IN PULSED PLASMA ACCELERATORS

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The mechanism is studied by which dielectric (Teflon) inserts in pulsed plasma accelerators disintegrate. The local-bulk character of this disintegration, which is revealed here, indicates that thermal radiation fluxes play a predominant role in this process.

Various dielectrics (Teflon, Plexiglas, polypropylene, etc) comprise an indispensable component of pulsed plasma accelerators. They are used as the plasmogenic working material and, at the same time, as the insulation material in the discharge chamber of erosion-type pulsed plasma accelerators. The surface of a dielectric insert in contact with the electrodes of an accelerator is subject to thermal fluxes generated as a result of discharge and these thermal fluxes destroy the surface while generating the plasma. The physical processes associated with the disintegration of dielectrics determine the performance of erosion-type pulsed plasma accelerators.

Studies were made on pulsed plasma accelerators of cylindrical geometry approximating the one which had been described in [1, 2]. Teflon was used as the plasmogenic working material. The Teflon discharge chamber was cylindrical in shape (inside diameter 20 mm, length 80 mm and 100 mm). The center electrode was a hollow copper cylinder with an outside diameter 20 mm and with the firing electrode placed inside. Ignition was effected by means of a high-voltage pulse from an SFR control panel or from a special firing device. The generated plasma was discharging into vacuum ($\sim 10^{-5}$ mm Hg).

A 24-μF capacitor bank was used for energy storage. The working voltage was varied from 3 to 8 kV. The inductance of the discharge circuit was $1.4 \cdot 10^{-7}$ Hz. The half-period of a discharge was approximately 7.5 μsec and the discharge current during the first half-period reached 50 kA (at $U_0 = 5$ kV).

It is a surface discharge in this particular type of accelerator and, according to spectroscopic test data, the discharge occurs essentially due to the erosion of the dielectric insert in contact with the electrodes [3, 4]. According to [5], a particular feature of surface discharge is that its path "spreads" over the substrate, causing it to heat up and to evaporate. In a cylindrical pulsed plasma accelerator under certain conditions, apparently, at the surface of the dielectric immediately after breakdown there forms a current conducting boundary layer. Evidence of this is a luminescent ring which appeared immediately after ignition and was observed on the moving picture frames showing the process photographed from the end view (Fig. 1a). The current density in this region becomes high and, consequently, so does the temperature. This results in a more intensive heating and violent evaporation of the dielectric accompanied by a spouting of separate clusters (Fig. 1c). Finally, after about 2-3 μsec the discharge chamber of the accelerator is filled (Fig. 1b).

The violent character of dielectric evaporation is an indicator of rather intensive heating at the surface. On the basis of experimental and theoretical data recently obtained in [1, 3, 6, 7], radiation is the predominant mode of heat transfer in erosion-type cylindrical pulsed plasma accelerators. Indeed, according to estimates, thermal fluxes of up to approximately 1000 W/cm^2 can be generated by electron heat conduction under the stated conditions [the thermal flux which impinges on the dielectric surface by electron heat conduction is determined by the equation $Q = \varkappa$ grad T. The thermal conductivity $\varkappa$ is found from test values of electrical conductivity ($\sigma \sim 2 \cdot 10^2\ \Omega^{-1} \cdot \mathrm{cm}^{-1}$) according to the Wiedemann–Frantz Law (0.13 W/°K · cm) and also by calculation according to L. Spitzer [8] (0.115 W/°K · cm). The temperature gradient under our test conditions was approximately $2 \cdot 10^4$ °K/cm]; at the same time, a thermal flux density of

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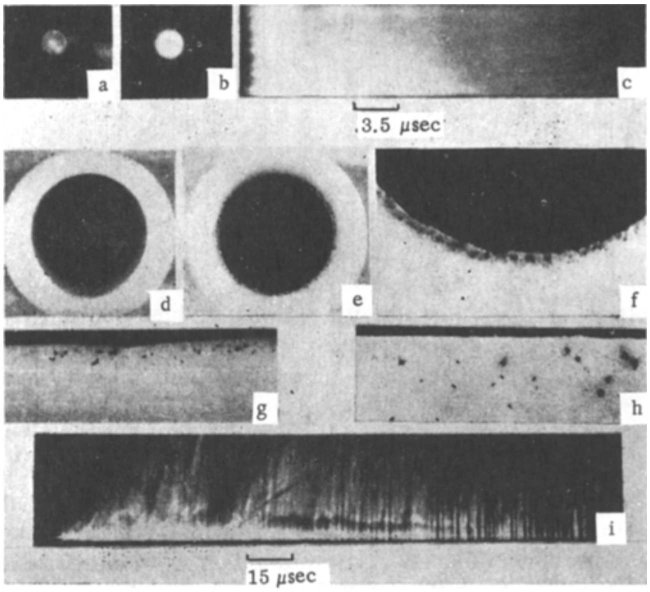

Fig. 1. Photographs of a dielectric insert subjected to a pulse discharge and to a laser beam, also of the luminescence inside a pulsed plasma accelerator: (a) and (b) are moving picture frames of the luminescence process photographed from the end view; (c) is a lengthwise photoscan of the luminescence process inside the accelerator; (d), (e), and (f) are photographs of a Teflon insert section in the accelerator, (d) before activation (×2 magnification), (e) and (f) after repeated activation (×2 magnification respectively); (g) and (h) are photographs of a cut through Teflon subjected to a pulse discharge and to a laser beam respectively (×6 magnification); (i) photoscan of a laser plasma jet.

approximately $5 \cdot 10^4$ W/cm^2 is required for just dislocating the molecules of a dielectric from its surface per one discharge.* Consequently, the thermal flux available from electron heat conduction is not sufficiently large to disintegrate the dielectric. An adequate thermal flux density can be supplied only by radiation. Estimates have shown that radiation fluxes under the conditions in a pulsed accelerator as the one studied here ($W_0 = 300$ J) are well in excess of $5 \cdot 10^4$ W/cm^2.

The radiative mechanism of heat transfer is also indicated by the manner in which the dielectric inserts disintegrate. Microscopic examination of dielectric surfaces has shown that, after activation by a pulse discharge, the Teflon surface appears covered with a mesh of fine cracks. An examination of a section cut 1-1.5 mm deep reveals a multitude of local black 0.1-0.3 mm large spots (cavities) (Fig. 1e, f, g). It is interesting to note that, during activation by a laser beam with a radiation flux density less than 10^6 W/cm^2, the disintegration has the same character as in the case of activation by a pulse discharge, except the black spots are now relatively deep: 3 mm in some places (Fig. 1h). In both cases these cavities are probably formed as a result of radiation energy being released at structural inhomogeneities. The cracks, according to the concepts developed in [9,10], may form as a result of bursting caused by hot gases trapped in

*The average quantity of evaporating dielectric material (Plexiglas) per one discharge was determined by weighing to be approximately 2 mg. A complete dislocation of Plexiglas molecules requires an energy of $W \simeq 60$ J (the C–H bond energy is 30–32 J/mg), which constitutes 23% of the energy put into a discharge. Therefore, the thermal flux density at the inner surface of a dielectric having an area $S = 50$ cm^2 will be $Q = W/\tau_{\text{eff}}S \sim 5 \cdot 10^4$ W/cm^2, where $\tau_{\text{eff}} \sim 20$ μsec is the effective period of discharge.

cavities under high pressure. Apparently, the decomposition products during exudation rather than the local spots (cavities) which have reached the surface (mainly carbon) form the individual plasma clusters which can be seen on the photographs of luminescence inside the discharge device (Fig. 1c).

On the photoscans of plasma formations in a pulsed plasma accelerator one can see the tracks of individual solid particles moving along the plasma clusters. These particles have been produced by the mechanical disintegration of the dielectric, as a result of radiation energy being released from the entire bulk of the material and of the local explosions probably caused by it.

The effect of mechanical disintegration is particularly obvious in the case of activation by laser with radiation fluxes exceeding 10^6 W/cm^2. This is indicated by the presence of many solid Teflon particles in the laser plasma jet (Fig. 1i), which makes for an intensive absorption of laser rays at relatively far distances from the active zone.

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