Microwave coaxial plasma source – "Microwave Arc" (MA)

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I. Introduction

Investigations of fundamental problems of a high-pressure microwave (MW) discharges have performed in GPI (see [1]) made it possible to create a new plasma source – coaxial microwave plasmatron "microwave arc" type (MA).

The following physical phenomena revealed and investigated in GPI provided the basis for this plasma source:

-Low-threshold microwave discharges (sparks) on a metal-dielectric interface [2-4] and

-Peculiar ionizing-thermal instability getting of a strong nonlinear phase [5,6].

Construction of MA permits to realize both these phenomena and to generate dense and relatively hot thermal nonequilibrium plasmoids radiating of intense UV. Among different applications of MA such as combustible gases flow ignition has to be emphasized.

II. Physical bases of "Microwave Arc" device.

During the last years in the General Physics Institute of RAS the microwave plasma sources based on metal-dielectric compositions providing, under microwave (MW) radiation, very low level of plasma formation were developed [2-4]. Most often used variant of metal-dielectric target is shown in Fig. 1. Into the dielectric plate, faced to MW radiation, metal particles of dimensions less than 1 mm are intruded. The surface density of these particles (quantity on 1 cm^2) is chosen under the conditions that a target is transparent when it is radiated by small power MW. Being for some rather large level of power density $\Psi \geq 10 – 100$ W/cm^2, a number of micro-plasma formations (micro-sparks) connected to points of contacts between metal particles and dielectric are created. These formations change the level of transpiration of MW radiation through the target caused by the absorption MW power by these sparks.

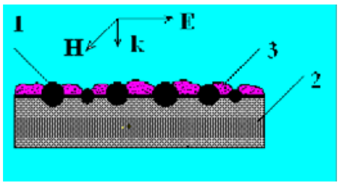


Fig.1.

Metal-dielectric target.

1-metallic particles (grains); 2-dielectric substrate; 3-micro-plasma formations (micro-sparks).

Experimental data [2-4] shows that the appearance of plasma formations on metal/dielectric surface is realized when the relation $\Psi \times \tau \geq 0{,}1$ is valid, where Ψ is intensity of MW (in watts per square centimeter) and τ is duration of microwave flux action.

Analyzing possible explanation of plasma formation on appearance mechanism, the authors of [2-4] made a supposition that the emission of electrons from metal to zone of dielectric conductivity in contact points is a main reason. Electron emission could be increased, owing to the following two effects: 1) decreasing of escape work energy from metal and 2) increasing of local electromagnetic field intensity in the vicinity of metal particles.

At operation in dense gas, the UV radiation created by micro-discharges results in photoionized layer near the metal/dielectric surface, which absorbs MW radiation. The features of processes supporting this layer give arguments to conclude that there is a non-self-sustained MW discharge in which MW energy is transformed into heating of near surface gaseous medium with high efficiency [1,3,7].

Microwave non-self-sustained discharge is characterized by possibility development in it instabilities known like “ionizing-thermal” instabilities. The distinguishing feature of such a type of instability exciting by microwave electric fields is possibility to get strong nonlinear phase [5,6] in which discharge looks like system of plasma “threads” with extremely high electron density, electron and gas temperature. Furthermore these threads are sources of intense UV radiation.

Reasoning from peculiarities of two above noted physical phenomena a new microwave coaxial plasma source – “microwave arc” (MA) – has been proposed and realized in GPI.

III. “Microwave arc” system design and operation features.

The scheme and photograph of operating MA plasma generator is shown on the Figs. 2, 3. The device is fed from a common (applied in domestic microwave ovens) magnetron (f = 2,45 GHz) through the rod antenna. The magnetron is powered by a voltage source using a half-wave rectification circuit, so that MW energy is launched in waveguide in the pulse mode. The pulse

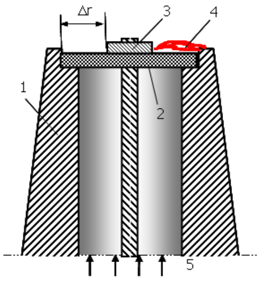


Fig. 2.

Scheme of MA

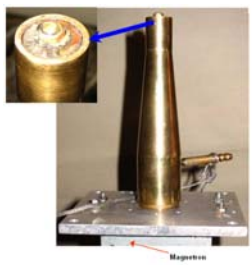


Fig. 3.

Photograph of MA.

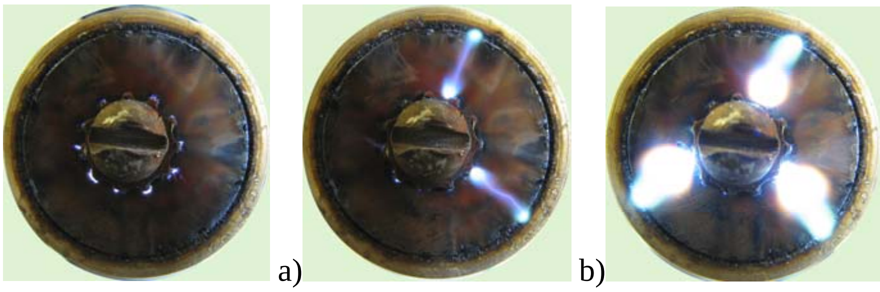
1-outer electrode; 2-quartz disc; 3-inner electrode;

4-near-surface discharge; 5-microwave radiation.

duration is τ ≈ 8-9 ms, whereas the interval between pulses is equal ≈ 11-12 ms. The average input MW power is as high as 2 kW.

With help of coaxial waveguide MW energy is transported to the discharger located at the output of waveguide. Outer section was designed as a quartz disc with a central orifice for displacement central metal electrode. Special construction provides a good connection between the central electrode end and a quartz disc surface.

The MW energy goes 6v a radial one and directed along the dielectric disc. In the points of quartz and metal disc contacts the levels of MW electric field is ~ 1 kV/cm and thus enough to realize spark discharge on the metal-dielectric interface during some microseconds. If the discharge is not realized, then MW energy is partly radiated into an external space and is partly reflected back to coaxial tube-resonator. The electric field intensity at the end of resonator even at low Q-factor is sometimes increased by a factor, and a probability of breakdown is increased significantly.



a) b) c)

Fig. 4.

Photographs of operating MA.

a) τ=10μs; b) 50μs; c) 100 μs

Typical photographs of MA discharge in air at atmospheric pressure for different MW pulse duration are shown on the Fig. 4. After the appearance of sparks (see Fig. 4a), the discharge is developing along the dielectric surface from the central electrode to the external one (see Fig. 4b). The discharge looks like streamers by the surrounded diffused lighting, which was formed due to the hard ionized UV radiation from these streamers. After some time a discharge is passed over to ambient gas, and therefore, a phase of very stratified gaseous discharge is realized. The peculiarity of such discharge is that its development has conditioned both electrodes (variable voltage between them) and the interference with MW flux affected the discharge from the coaxial waveguide.

At rather long discharge operation (see Fig. 4c), the streamers close the electrodes, and the discharge is transformed to arc mode. As distinct from common arc, when an increase of plasma concentration causes the displacement of electric field from plasma and the main electric field is concentrated in the vicinity of cathode area, MW radiation can penetrate into rather dense plasma and significantly increase an energy input into gas, i.e. efficiency of its heating. The last fact, in turn, can significantly increase the temperature of gas in arc for a very short time.

With help of optical spectroscopy parameters of developed “microwave arc” have been determinate. Measurement of H_α Stark broadening gives such a high electron density as ~ 5 10^{16} cm^{-3}, that is close to the values predicted by theory [6]. Measured through the CN radiation band gas temperature T_g is close to ~ 5000 K.

IV. “Microwave arc” as kerosene/air mixture igniter.

MA plasma source has been investigated for kerosene/air mixture combustion initiation as an alternative in reference to standard spark plug. Results of experiment performed on the CIAM installations according to scheme presented in Fig. 5 have been published in [8]. This experiment has demonstrated compelling advantages of MA system.

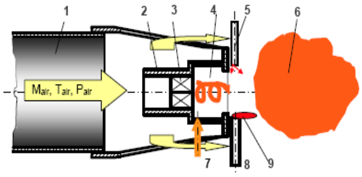


Fig.5.

Schematic of model frontal device with annular cavity flame holder and MA installation in CIAM test rig.
1-air nozzle; 2-model frontal device; 3-swirler device; 4-whirling air flux; 5-standard spark plug; 6-combustion zone; 7-tangential kerosene supply; 8-MA; 9-plasma jet.

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