Thermocouple and electric probe measurements in a cold atmospheric-pressure microwave plasma jet

V M Chepelev, A V Chistolinov, M A Khromov, S N Antipov and M Kh Gadzhiev
Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
E-mail: chepelev@ihed.ras.ru

Abstract. A cold atmospheric-pressure plasma jet was studied using the novel microwave plasmatron recently developed. Cold plasma jet was generated in Ar flow by electrode 2.45 GHz discharge of up to 200 W power in the portable plasmatron burner (torch) with 2.5 cm diameter outlet. Oscillograms and floating potential dependences on distance from the torch outlet were measured by planar electric probe. Axial and radial distributions of gas temperature in a cold plasma jet were obtained by means of thermocouple method.

1. Introduction
At present, the possibility of using atmospheric pressure plasma jets is being actively studied in applications for plasma-chemical surface treatment of various materials in such fields as practical medicine, microbiology, agriculture and the food industry [1–3]. The interest is due to the fact that in plasma jets so-called “streaming-afterglow plasma” is generated and excited particles and radicals with high reactivity are produced. At that, the temperature of the gas flow in the jet can be reduced to almost room temperature, which does not have a destructive effect on a material during processing. This combination of low temperatures and a high reactivity of plasma particles makes cold plasma jets technologically advantageous and effective tool in the above-mentioned industries.

From this point of view, a cold plasma jet based on a microwave discharge has a much higher charge density and, as a result, a greater reactivity compared to other types of discharges at the same energy load. It should be noted that for many plasma technologies, such as plasma cleaning, plasma surface activation, plasma deposition and plasma etching, an important characteristic of a plasma source device is the area of the surface to be treated. The size of the outlets of most existing plasmatron burners is less than 1 cm. For wide-area surface treatment, various tricks are used, such as surface scanning or using of array of several burners. However, such approaches can hardly be attributed to technological advantages. In this work, we present the prototype of the multi-purpose 2.45-GHz-microwave plasmatron developed, which has a portable cold plasma jet torch with the electrode discharge chamber outlet of 2.5 cm in diameter. Parameters of a cold plasma jet based on atmospheric-pressure electrode discharge in Ar were studied.
Figure 1. The atmospheric-pressure microwave plasmatron: (a) view and (b) schematic.

2. Experimental installation and measurements

The prototype microwave plasmatron was made on the basis of a low-power microwave plasma source by the AgroEcoTech Scientific and Production Enterprise (Obninsk, Russia) [4]. The microwave plasmatron allows initiating atmospheric-pressure microwave discharges with a frequency of 2.45 GHz both in a rectangular metal waveguide with a power range from 0 to 2.5 kW (electrodeless discharge) and in a portable torch with a power of up to 200 W (figure 1). The plasmatron waveguide has three-sections providing the possibility of replacing the middle section (splitter) [figure 2(a, b)]. The electrode torch developed was used to study cold plasma jets of non-destructive (“soft”) action. The microwave power to the torch is withdrawn from the waveguide via a coaxial cable connected to the splitter. Nozzles of various forms, geometry and materials (polytetrafluoroethylene, quartz, etc) can be mounted on the torch for stabilizing electrode discharge and optimizing plasma jet parameters. Figure 2(c) shows an example of atmospheric-pressure microwave discharge in the torch with the straight cylindrical nozzle of 2 cm height. Discharge channels arise between the cylindrical discharge chamber with diameter of 2.5 cm and six steel rod-like electrodes inside it. The centers of electrodes form a regular hexagon. The torch is supplied by high purity Ar (99.998%). Gas flow rate is about 7.5 standard liters per minute.

It should be noted that the closest analogue of the developed plasma torch is the MicroPlaSter low-temperature argon plasma generator from Adtec Plasma Technology Co Ltd [5]. However,
Figure 2. The electrode discharge torch (a) without nozzle and (b) with straight nozzle; (c) microwave discharge in Ar flow in the torch with straight nozzle (view from the outlet).

Figure 3. Planar probe floating potential $\varphi_f$: (a) oscillogram; (b) dependence on distance from the torch outlet $z$.

The latter is an expensive highly specialized device produced for bio-medical applications. In contrast, plasmatron by AgroEcoTech is suitable for laboratory investigations and combines many advantages, such as relatively small size and weight, easy handling and low cost. It has flexible open architecture design friendly for maintenance and modernization.

The planar probe formed of a thin metal disk of 1.6 cm diameter oriented perpendicular to the torch axis towards a gas flow was used for probe measurements. The probe was mounted on an adjustable holder for vertical positioning. Figure 3(a) shows oscillograms of probe floating potential near the torch outlet. One can see that the generation of plasma in the gas flow is periodic with a frequency of 50 Hz. We believe that such periodicity is due to the magnetron power supply feature, because of which the magnetron operates in a pulse mode (50 pulses per second). In each pulse magnetron outputs a 2.45 GHz wave packet (50 Hz modulated 2.45 GHz microwaves). Dependences of the floating potential $\varphi_f$ (root mean square values) on the distance
Figure 4. Gas temperature $t_g$ (a) axial and (b) radial profiles in cold plasma jet.

from the torch were measured for 80 and 160 W microwave power [figure 3(b)]. As can be seen, the streaming-afterglow plasma exists at distances up to 3.5–4 cm from the torch.

The spatial distribution of the gas temperature in the plasma jet (figure 4) was measured with an L-type thermocouple consisting of a twisted pair of chromel-kopel wires with a length of about 30 cm. Such a length makes it possible to keep the thermocouple free ends far apart from the plasma jet and, therefore, to maintain the room temperature of the cold junction during the measurements. The thermocouple hot junction was mounted on a holder with adjustable $XZ$-position. The thermocouple was shielded to eliminate electromagnetic field and plasma effects.

The temperature profile measurements show that the gas temperature $t_g$ near the nozzle is relatively high (about 80–110 °C) and increases with $r$ increase. It is explained by the presence of the hot electrodes at a distance of 8 mm from the torch central axis. In contrast, at a distance from the torch outlet $z = 4$ cm there is no maximum above the electrodes—gas temperature gradually decreases from the center to the torch chamber wall.

3. Conclusions
Electric probe and thermocouple measurements were carried out in wide-area cold plasma jet based on Ar atmospheric-pressure electrode 2.45 GHz discharge. For the plasmatron developed, periodic character of plasma generation (50 Hz frequency pulses) was revealed by means of oscilloscope measurements of probe floating potential. Dependences of floating potential on the distance from the torch outlet were obtained. Axial and radial gas temperature profiles outside the torch were measured.

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