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PLASMA PHYSICS

HIGH VOLTAGE PULSED, COLD ATMOSPHERIC PLASMA JETS: ELECTRICAL CHARACTERIZATION

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Abstract. Three types of cold atmospheric plasma jet generators are described. The plasma jet generators are supplied with repetitive high voltage pulses: maximum 20 kV amplitude, hundreds of ns width, up to 100 pulses per second. The obtained cold atmospheric plasma jets have lengths of up to 50 mm. For the first time, the plasma jet current has been measured along the plasma jet length.

Key words: cold atmospheric plasma, repetitive high voltage pulser, current measurement.

1. INTRODUCTION

In the last ten years, the variety of the possible applications of atmospheric pressure cold plasmas highly increased the research in this field. These types of plasma are nonequilibrium systems, where electronic temperature is much higher than ionic temperature. At macroscopic level, plasma is “cold” (non-thermal), its temperature is more or less that of the surrounding environment. Obtaining atmospheric pressure cold plasmas is much simpler and cost-effective as compared to plasmas obtained under low pressure, in special devices.

Among the various applications of the atmospheric pressure cold plasmas, there are (all the papers have been published in 2005–2008): microorganisms destruction (decontamination of biological, food-related etc. mediums) [1–4]; biological tissue treatment [5–8]; *in vitro* and *in vivo* cell treatment [9, 10]; depollution of gaseous or liquid environments [11–14] ; thin layers deposition [15–17]; modifying the properties of certain surfaces [18]; physical and chemical modifications of polymers [19, 20]; nanotechnologies [21, 22].

Cold plasma is produced by electrical discharges in gas at atmospheric pressure. To maximize efficiency, the most suitable gases are inert gases, such as helium and argon. Unfortunately, this goes against the fact that plasma needs to be chemically active to be used in various applications. Solving this problem constitutes the key of success of this research.

In the last few years, spherical-shaped ("plasma needle") or micro-jets ("plasma pencil", "plasma plume") atmospheric pressure cold plasmas have been obtained in alternative electromagnetic fields. Although the research had great achievements [5, 7, 23–25], the biggest problem was to maintain the macroscopic temperature of the plasma within tolerable limits. A small deviation of the plasma impedance from its optimal value (due to the distance to the treated object, the state of the treated surface, etc.) modifies the tuning of the alternative voltage generator and leads to overheating of the plasma.

This problem can be avoided using a new technique [6, 26], which is the core of this paper. To produce atmospheric pressure cold plasmas we use high voltage pulses (tens of kV) which have limited duration (tens, hundreds of nanoseconds) and are repeated (tens, hundreds of pulses per second). The pulses are applied to two metallic electrodes of various shapes which may or may not be separated by a dielectric barrier. An electrical discharge takes place in a cavity through which an inert gas flows at normal atmosphere. The cavity has an aperture through which discharge plasma is pushed out. Under optimal conditions, plasma is emitted as centimeter-long jets, just millimeters in diameter or even smaller. Because the plasma area is spatially separated from the treatment area, the electrical load for the high voltage pulses generator is practically constant, the energetic matching and transfer being the best possible.

The use of short repetitive high voltage pulses has more advantages than alternative electromagnetic fields stimulation because:

- It can be obtained in short (tens, hundreds of nanoseconds) "packs" of highly energetic electrons which have a great efficiency in obtaining chemically active species. Because the high voltage pulse is very short, it is not possible for an undesired discharge such as the electric arc to appear, as it would happen if the same amplitude had been applied alternatively.
- The power and temperature of the plasma jets can be finely tuned using both the amplitude of the high voltage pulses and their frequency of repetition.
- The energy consumption, within the same parameters of the plasma, is smaller by a factor of 5 for pulsating stimulation than alternative stimulation [27].

2. EXPERIMENTAL SET-UP

Our experimental system is composed of: high-voltage repetitive pulser; plasma jet generator; gas flow circuit.

The high-voltage repetitive pulser discharges a capacitor in the primary of a pulse transformer. The high voltage switch is a TGI1000/25 thyratron (25 kV, 1 kA maximum, 1 A average), or a rotary spark gap. The pulse transformer is the key component of this subsystem. It must assure a very good magnetic coupling between the primary and the secondary winding. Many constructive solutions have been tested. The best solution is a transformer with coaxial cable, wound on a toroidal magnetic core. The magnetic material is of amorphous type: Metglas 2605CO – Allied Signal Inc. – USA. The voltage rise-time depends of the winding connection structure, and also of the transformer ratio (1:2, or 1:3). By using this pulser, electrical pulses with tens of kV amplitude, tens up to hundreds of ns width, tens up to hundreds of A load current are obtained. The repetition frequency can be varied between 0–1000 pps.

The voltage pulses are measured with a capacitive-resistive divider (Tektronix, P6015), with division ratio 1/1000. Rise times in excess of 10 ns are correctly measured. For current pulses, Tektronix P6021 probe with passive termination is used. In this case, the bandwidth is 120 Hz – 60 MHz. The voltage and current probes are both connected to a digital oscilloscope: Tektronix TDS 1012 (100 MHz bandwidth).

Various geometrical configurations have been tested for plasma jet generator: point-plate; multiple points-plate; wire-plate.

In the first configuration (Fig. 1a), we used a simple medical syringe (internal diameter (ID) = 14 mm), whose piston was fitted with a metallic needle. The gas (helium, argon), which is the medium of the discharge is introduced through the syringe piston. The gas flows were in the range 1–4 l/min. The discharge takes place between the metallic needle top and a metallic ring fit on the outer surface of the syringe. The piston allows for the inter-electrodes distance to be easily modified, up to 50 mm.

The second configuration (Fig. 1b) is similar with the first one, but there are three high voltage electrodes, working in parallel. The three discharges (instead of one) substantially increase the chemical activity of the plasma jet.

The third configuration (Fig. 1c) uses the wire-plate geometry. A 0.5 mm diameter metallic wire is coaxially mounted inside a dielectric cylinder (ID = 38 mm). A slit (30 mm long, 1 mm width) is cut out along one generatrix of the cylinder. The working gas, introduced through one end of the cylinder, goes out through the slit. By using high-voltage pulsing, a plasma “curtain” is generated along the slit (Fig. 1c). This configuration is more suitable than the first ones to treat rather large surfaces with cold atmospheric plasma.

The working gases are supplied by high-pressure cylinders. Gas pressure regulators are used to reduce the pressure of gases to a workable level. Then, gas flow controllers deliver the gases with the desired flow. For the inert gases (He, Ar), flows of up to 10 l/min can be controlled and measured. The gases (such as oxygen) used to chemically activate the plasma jet, go through flow controllers of 0–500 ml/min.

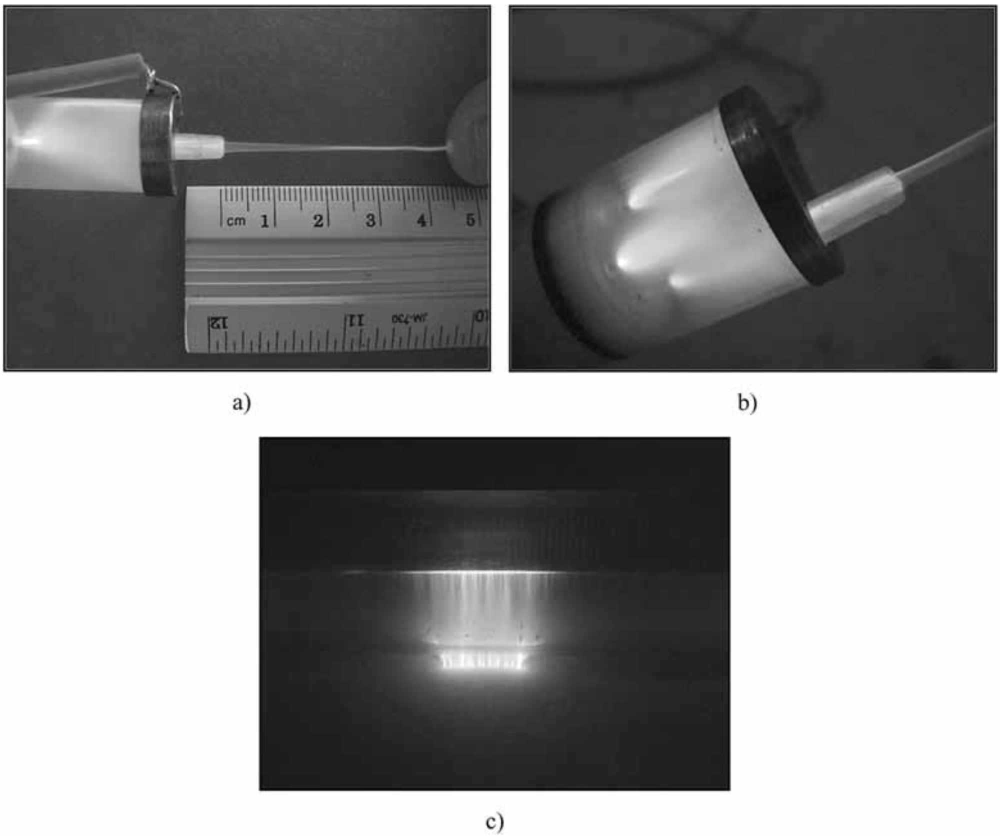

Fig. 1 – The geometrical configurations which have been tested for plasma jet generator: a) point-plate; b) multiple points-plate; c) wire-plate.

3. EXPERIMENTAL RESULTS

In Fig. 2, the high voltage pulses, obtained with the high voltage repetitive pulser, are presented. The two pulses correspond to different values of the primary capacitor: 5 nF, and 20 nF, respectively.

The high voltage pulses are applied between the electrodes of the plasma jet generators. The maximum applied voltage can be up to 30 kV. For the realized plasma jet generators we need maximum 20 kV. Consequently, there is enough voltage reserve to develop in the future plasma jet generators with higher working voltages. With the first two geometrical configurations (Fig. 1 a, b), plasma jets of 40–50 mm length have been obtained. The maximum length corresponds to 20 mm inter-electrodes distance, and to 20 kV amplitude of the applied voltage. For voltage amplitudes of 12–15 kV, the plasma jet is very weak. The plasma jet disappears for voltage amplitudes lower than 12 kV.

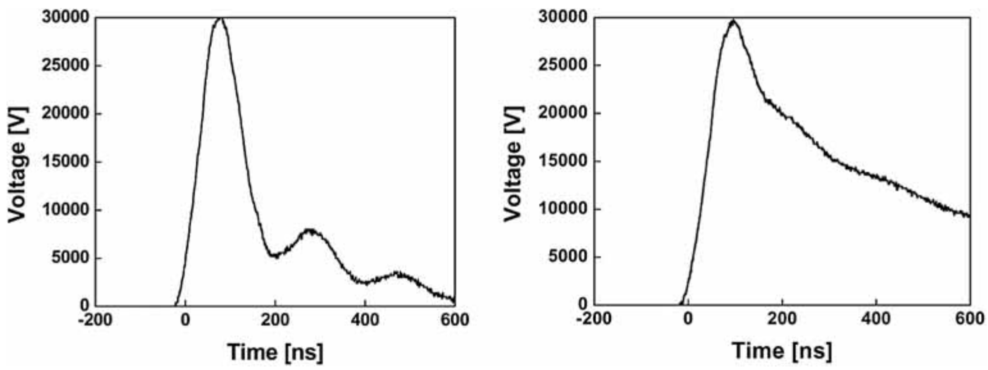

Fig. 2 – The high voltage pulses, obtained with the high voltage repetitive pulser: the primary capacitor = 5 nF (left), and 20 nF (right).

With the wire-plate configuration (Fig. 1c), the maximum length of the plasma "curtain" is of 10 mm. In this case, the high voltage pulses with 20 kV amplitudes are applied between the axial metallic wire and an external surface, capacitively coupled to ground.

The electrical current varies along the plasma jet length. Up to now, this fact has not been taken into consideration. In order to measure this parameter, the plasma jet is "captured" by a little copper plate, at different distances from the plasma exit hole. A metallic wire connects the copper plate with the experimenter's fingers. In this way, the plasma jet is electrically coupled to ground through the human body capacitance. From electrical point of view, the human body is a parallel RC circuit, with $R \sim 1$ MΩ, and $C \sim 60$–120 pF [5]. The current through the metallic wire, equal with the plasma jet current, is measured with a current probe (Tektronix P6021).

In Fig. 3, the plasma jet currents of the first generator configuration (Fig. 1a) are presented, for different distances from the plasma exit hole. For the first 30 mm,

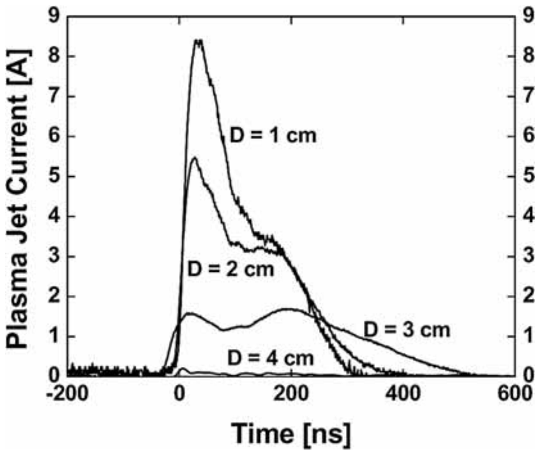

Fig. 3 – The plasma jet currents of the first generator configuration (Fig. 1a), for different distances (*D*) from the plasma exit hole.

the currents have significant values (greater than 1 A). Therefore, the treated objects can be situated at 10–20 mm distance from the plasma exit hole.

Similar measurements have been carried out for the wire-plate configuration (Fig. 1c). In Fig. 4, the plasma "curtain" currents are presented, for different distances from the exit slit. It is found that this configuration allows that the treated object to be placed at most 10 mm from the plasma exit slit.

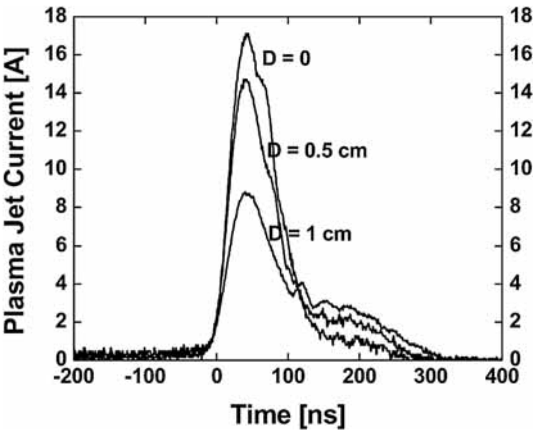

Fig. 4 – The plasma "curtain" currents of the wire-plate configuration (Fig. 1c), for different distances (*D*) from the exit slit.

4. CONCLUSIONS

Three types of cold atmospheric plasma jet generators, supplied with repetitive high voltage pulses, have been carried out. Cold atmospheric plasma jets, having lengths of up to 50 mm have been obtained.

The inter-electrodes high voltage pulses were of maximum 20 kV amplitude, and hundreds of ns width.

The plasma jet currents have been measured along the plasma jet length, for the first time. These currents are of 1–20 A amplitude, depending of the distance from the plasma exit hole.

The research will continue with the chemical activation of the plasma jets, taking into consideration future applications in the food industry and in the biology-medicine field.

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