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Radiofrequency plasma torches al low and atmospheric pressure for surface treatments

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Abstract

We present a radiofrequency plasma torch appropriate for deposition and surface treatments, at low and atmospheric pressure. The source is based on the expansion of a radiofrequency discharge outside the inter-electrodes space and is dimensionally scalable. By free expansion in vacuum one may obtain extended plasma beams, while at high pressure the phenomenon of discharge constriction offers the key to decrease the size of the source body and atmospheric plasma jets can be generated.

Introduction

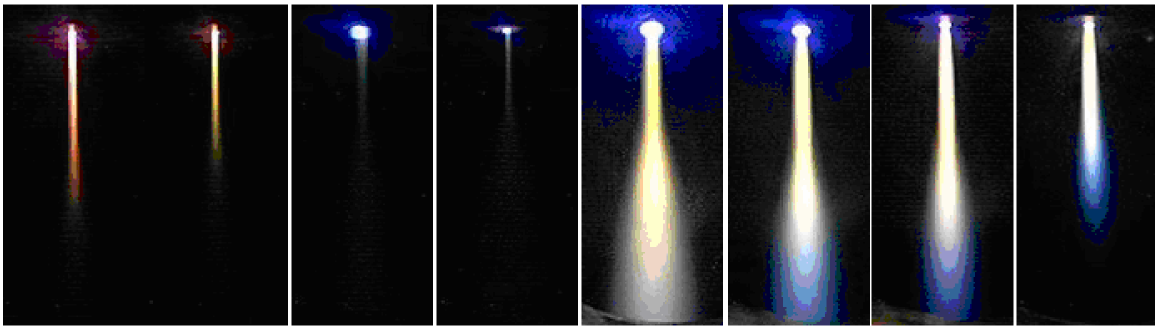
The design of plasma sources for processing is strongly dependent on the envisaged application and the sources aspect and characteristics varies very much as concerning the dimension, injected power, plasma space distribution, plasma parameters. In terms of pressure, operation at atmospheric pressure is desirable: nevertheless in this case large area processing is difficult due to discharge constriction. The temperature at substrate is another important processing parameter, and last decade is strongly marked by researches to develop barrier discharge cold atmospheric plasma sources. In principle, a different type of low temperature non-equilibrium reactive medium at atmospheric pressure can be obtained from expanding plasma. By expansion out of the discharge zone, along the flow axis the plasma cools out and the gas temperature decreases. The non-equilibrium character is supported by the different relaxation lengths of the plasma species. The plasma torches discussed here are based on expansion of a radiofrequency (13.56 MHz) discharge. They can be operated continuously from low pressure to atmospheric pressure. At low pressure they are suitable for Plasma Enhanced Chemical Vapour Deposition, as example of nanostructured carbon layers [1], or for increasing the reactivity during Pulsed Laser Deposition of functional oxide thin films [2]. At atmospheric pressure they can be used for local deposition and modification of surfaces via scanning procedures [3]. In the following are discussed: i) plasma source geometry ii) operation at low to atmospheric pressure iii) breakdown and temperature attained at atmospheric pressure iv) application related aspects.

Plasma source geometry

The expanding discharge geometry was described previously [4]. The source has axial symmetry: the discharge is housed by a quartz tube covered by a metallic water jacket; inside the tube two parallel plate disk shaped electrodes are separated by a few mm distance. The upper disk is RF powered and has smaller diameter than the internal diameter of the tube. The lower disk, provided with a hole in its center, closes the discharge chamber and is grounded to the metallic water jacket which surrounds the system. The disk with the hole plays the role of nozzle and separates the plasma generation space from the outer space. The discharge is supplied by a 13.56 MHz RF generator with automatic matching box. The gas (argon, nitrogen) is forced to flow in the interelectrodic space where it is ionized and the formed plasma expands out as a directional beam.

Operation at low and intermediate pressures

An easy breakdown is observed at low pressure (10^{-1}-1 mbar, the source being mounted on a vacuum chamber) both in argon and nitrogen. The breakdown studies in nitrogen in absence of gas flow [4] showed that at low pressure the discharge extends from the RF powered electrode through the hole nozzle to the grounded chamber walls; this is valid for argon, as well. In presence of gas flow the sheath presence at wall shows that also in this case the chamber is actively involved in sustaining the discharge. The obtained plasma beam occupies large volume, the size and shape depending on the mass flow input (which gives the flow velocity) and pressure (decrease size due to collisional quenching processes). The beam size do not decrease monotonically with the pressure increase: after a tendency to extinction, a sudden change leading to plasma beam increase and intensification is noticed at an intermediate pressure (~400 mbar, see Figure 1); after passing this threshold the source can be operated stable up to atmospheric pressure.



66 mbar 133 mbar 266 mbar 400 mbar 440 mbar 640 mbar 850 mbar 1000 mbar

Figure 1. Images of the plasma beam ij nitrogen during pressure increase

The examination of discharge appearance in the inter-electrodic space offers the key to explain this behavior. Image and OES studies were possible through the quartz tube, after removing the external water jacket. By increasing the pressure up to the threshold plasma evolve for a volumetric distribution of α and γ type regimes to a filamentary regime (caused by thermal induced instabilities), with a movable bright thin plasma column moving all around. During the movable filamentary regime there is little contribution to expansion, as the main part of the discharge is concentrated in the interelectrodic space: outside, the plasma beam looks like extinguishing. Further, the pressure increase leads to sudden column stabilization with one of the ends on the nozzle hole. From this moment all the gas flows practically through the strongly ionizing filament region producing an intensified plasma beam in expansion, observed around 400 mbar. The reducing of the excitation region to the narrow zone stabilized on the nozzle makes unnecessary a large area inter-electrodic space for plasma sustaining; this opens the way to design small size plasma sources for working at high and atmospheric pressures.

Operation at atmospheric pressure

Breakdown at low pressure, with subsequent pressure increase is inconvenient. Experiments were conducted to obtain breakdown directly at atmospheric pressure. In presence of appropriate gas flows and power levels this is possible both for argon and nitrogen. A current-power characteristic curve, describing the discharge regions for argon at atmospheric pressure is shown in Figure 2. It was obtained by gradual increase and decrease of power.

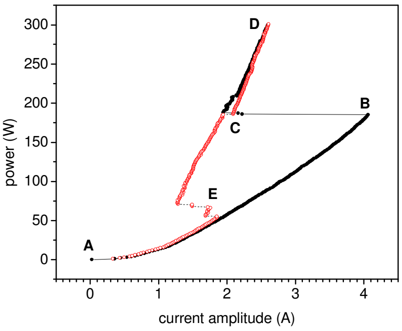


Figure 2. Current-power characteristics curve

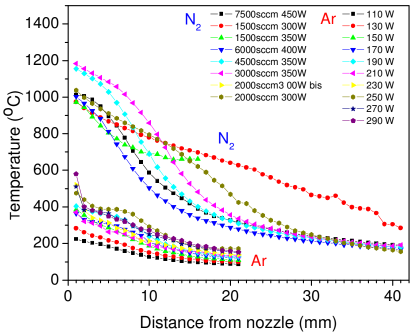


Figure 3. Temperatures along the plasma flow

The A to B portion of the curves describes the behavior up to breakdown; after the breakdown (point B) the discharge parameters jump to point C in filamentary regime. The behavior of the discharge for further increase of power is described by the portion C to D. From D where the power turns to decrease, the discharge passes through the extinction point E and the cycle is closed by the not-existing discharge portion, from E to A. The discharge hysteresis is obvious. The gas temperature is important for processing; it was evaluated by a small thermocouple head introduced in the plasma jet. A comparative view of temperature distribution along the plasma axis for nitrogen and argon, in different conditions, is given in Figure. This shows that argon is appropriate for temperature sensitive substrates, while nitrogen is indicated for processing at higher temperatures.

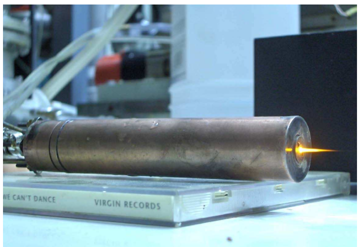


Figure 4. Plasma torch in operation at atmospheric pressure

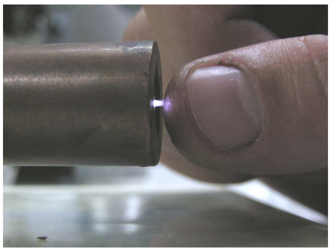


Figure 5. Cold plasma in contact with skin

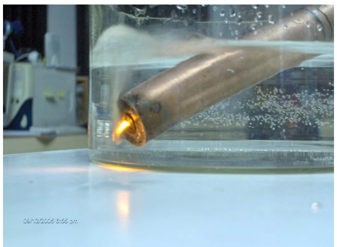


Figure 6. Underwater operation of plasma torch

Application related aspects

An image of one of the small size plasma sources, of 22 mm diameter, is shown in Figure 4. By handling the source parameters cold plasmas, able to come in contact with the human tissues without voltage danger and burning effects are generated, which may be of interest for medical applications (Figure5). The source can work also under water, opening conditions for depollution applications (Figure 6). Other applications, as example detritiation of Tokamak walls are possible, as was proved by removal of material from tile surfaces.

Conclusions

I was shown that small size plasma beam torches, based on the expansion of radiofrequency discharges, can be operated continuously from low to atmospheric pressure. Direct breakdown at atmospheric pressure was proved, with operation stabilized by flow. A large range of temperature values can be obtained, making the sources appropriate for surface functionalization, cleaning, and material removal.

References

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