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ATMOSPHERIC PRESSURE PLASMA JET FOR BIO-MEDICAL APPLICATIONS

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Recently, atmospheric pressure plasmas have emerged as a promising new tool in medicine. Compared to application of conventional direct thermal plasma, direct treatment using non-thermal plasmas or indirect application of thermal discharges ("cold" plasmas) are selective in its treatment and is safe since no thermal tissue damage is observed.

There are several different mechanisms of plasma influence on bio-objects:

1) Thermal heating;
2) Shock and pressure waves generation;
3) Oxidation by radicals (so-called "reactive oxygen species", ROS, production);
4) Stimulation by radicals (example - NO production);
5) Ionic oxidation (O_2^-, OH^-, H_3O^+, O_4^+, etc);
6) UV radiation.

These different mechanisms may be used for targeted chemical modification and catalysis or just employ high temperature that causes significant thermal tissue desiccation, burning, and scar formation. An example of thermal plasma is the Argon Beam or Argon Plasma Coagulator (APC) developed mainly to cauterize wounds [1]. On the other hand, cold plasma discharges have many potential medical applications that include sterilization of living tissue without damage, blood coagulation, induction of apoptosis in cancer and other cells, and control of cell attachment [2].

Spark discharge ignited in a special electrode configuration (pin-to-hole, where needle anode is fixed coaxially with hollowed cathode, Figure 1) was shown to be effective in inactivation of bacteria both *in vitro* and *in vivo* [14-18]. A series of experiments on rabbit eyes [17, 18] showed that spark discharge has strong bactericidal action while no or minimal and reversible changes of biological tissue are caused, even of such delicate tissue as an eye cornea. First human trial reported by Gostev and colleagues [15] on treatment of phlegmonous eyelid defeat using spark plasma in pin-to-hole configuration (when traditional medical approaches did not result in any positive effects) allowed fast and effective cure, and essentially saved patient's life.

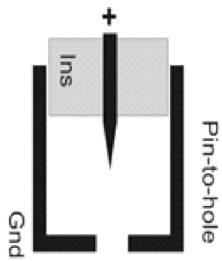
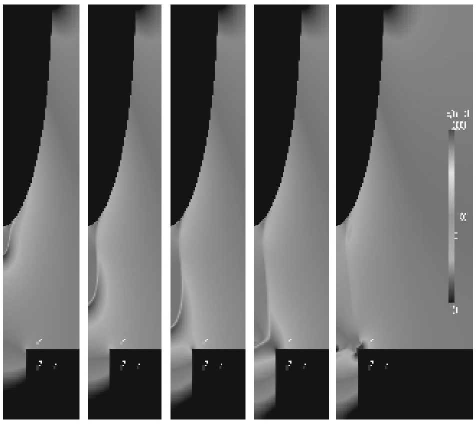


Figure 1. Spark gap configuration.
Gap: 1.6 mm;
Wall thickness: 0.8 mm;
Breakdown voltage: ~8 kV;
Peak current: ~130 A;
Pulse duration: ~140 ns

Despite of these very impressive results the discharge itself remains almost unknown from the point of view of mechanisms of influence. In the present work dynamics of discharge development and plasma jet formation are investigated both numerically and experimentally. The measurements were performed with the help of 4Picos ICCD camera and quartz lens with focal distance 16 mm. Camera spectral response range was 220-750 nm. Camera gate was equal to 5 ns and was synchronized with the high-voltage current pulse with the accuracy of about 10 ns. These measurements allow us to trace the spark stage of the discharge while the streamer stage with a typical duration ~ 2-3 ns under conditions considered remains unresolved. To analyze the initial phase of the discharge we used 2D numerical simulation. Streamer discharge dynamics was calculated in the local hydrodynamic approximation. Adaptive mesh generation technique was used to improve the solution. Minimal cell size was 5×10^{-4} cm.

The results are shown in Figure 2. Typical time of streamer propagation from high-voltage to low-voltage electrode is ~2 ns. Then the streamer channel connects to the hole edge and return stroke appears. Discharge converts into the developed spark form in 1 µs from the beginning of the process (Figure 2, right). Hot gas from the spark channel expands through the hole and forms the plasma jet (time scale 20-50 µs). After that there is a suction stage and the discharge cavity fills with a fresh portion of air. Detailed measurements of the discharge dynamics allow to improve the plasma jet parameters and to produce the plasma with required characteristics – temperature, velocity, composition.



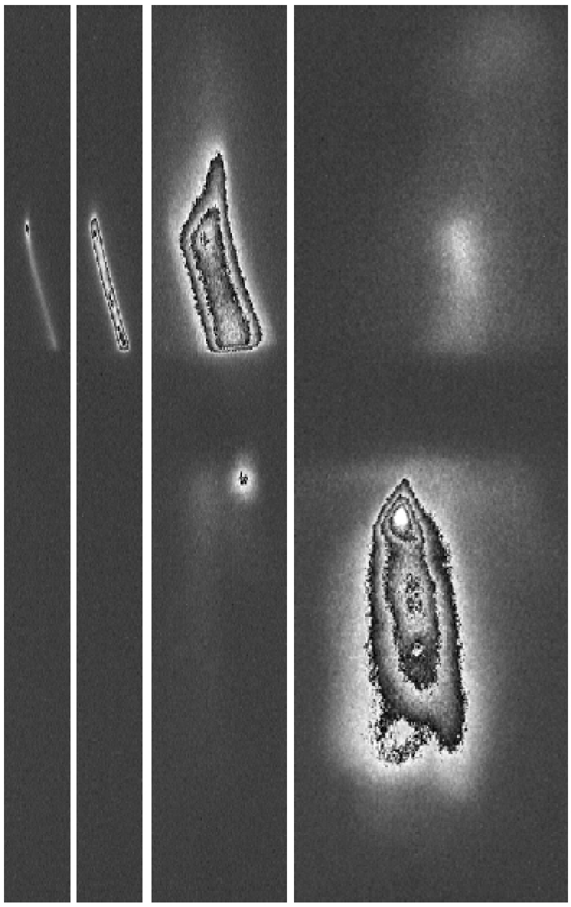


Figure 2. Plasma jet development.
Air, P = 1 atm. U = 8 kV.

Streamer stage of discharge (left):
τ = 1, 1.5, 1.7, 1.9 and 2.0 ns.

Spark phase (right):
τ = 0.01, 0.03, 1.1 and 35.5 μs.

References

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