Low-Cost High-Frequency Power Supply for Cold Atmospheric Plasma Sterilization
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Abstract: Cold atmospheric plasmas represent a promising technique for the descontamination of surfaces. This work aims to describe a low-cost cold atmospheric plasma device for the sterilization of surfaces, objects and environments. An atmospheric plasma source has been built using different circuit topologies that work with high frequencies, on the order of KHz, utilizing AC or DC-Pulsed signals.

Keywords: Cold Atmospheric Plasma, High Voltage Power Supply, Plasma Sterilization, ZVS circuit, DC-Pulsed circuit.

1. Introduction

Surface treatment using plasmas is a process widely used in industry. Examples of technological applications include deposition of thin films, removal of material through the sputtering (etching), welding of metals, doping of semiconductors, electric thrusters, fabrication of nanomaterials and elimination of biological contaminants.

There are different ways to sterilize medical equipment, for example, using ovens, antiseptics, disinfectants, autoclave, ultraviolet, among others [1,4]. Surface treatment using plasmas is a promising technique for the sterilization of medical equipment.

We can classify the possible uses of plasmas for the elimination of contaminants into two groups, namely, vacuum processes and atmospheric processes. Vacuum processes use a closed chamber and a low-pressure environment to ionize a specific gas, such as hydrogen peroxide. The resulting plasma fills the entire internal space of the chamber, through diffusion, and the constituent ions of the plasma react with biological contaminants, resulting in their sterilization.

Atmospheric processes, which are the focus of this paper, can be applied in open and closed environments, at atmospheric pressure, ionizing the atmospheric air, producing a cold plasma and thus reactive ions that are capable of eliminating viruses, bacteria, fungi, depending on the duration of exposure to the ionized gas [8]. This plasma generated from atmospheric air, and at pressures close to 1 atm, is known as cold atmospheric plasma (CAP).

The ongoing COVID-19 pandemic led to the development of different and affordable ways to sterilize surfaces, objects and environments in a safe and reliable way. In recent years, several applications for atmospheric plasmas have been studied and developed, with a focus on eliminating the SARS-CoV-2 virus. This concept has been applied to the treatment of surfaces [12] such as PFFF3 masks [5], in the sterilization of environments, wounds, dressings and medical equipment [3,8]. This scientific effort also brought other applications for CAPs, such as in food preservation processes [6] and in the manufacturing process of medical materials [12].

Plasmas can inactivate and eliminate biological contaminants through different mechanisms, such as the production of free radicals, reactive nitrogen species (RNS), reactive oxygen species (ROS), electric fields, charged particles and ultraviolet (UV) photons [3, 13]. These mechanisms can act directly or indirectly on sterilization, for example, the production of free radicals and reactive species can act directly on biological contaminants (through the diffusion of gas around the object to be sterilized), or by dissolving these chemical compounds in a liquid solution to be used as an antiseptic cleaning material [3,13].

2. Cold Atmospheric Plasma Sources

Cold atmospheric plasmas sources can be obtained with different electrical discharges such as corona discharge, dielectric barrier discharge and glow discharge. These types of plasma can contain electrons, UV photons, ions, neutral atoms and molecules [3].

The glow discharge can be used to obtain a cold plasma jet. This jet is an extension of the plasma density decay from the generation point [3]. Thus, by regulating the electrical parameters of the discharge and the flow of the gas, we can control the parameters of the jet, such as density, intensity, and plume size. These devices are usually pen-shaped, with a dielectric material serving as the structural body, an electrode on the inside of the tube, and an electrode on the outside of the tube. When the gas passes through this electric field, ionization occurs and we have a plasma plume at the exit of the tube. A schematic of this construction can be seen in figures 3 and 4.

Corona-type plasma discharges use electric fields capable of ionizing the gas around an electrode, but without allowing arcing or dielectric breakdown to occur [3]. These electric fields can be continuous (DC) or alternating (AC).

Atmospheric corona and glow discharges require high voltage and low current. The electric arc in these systems uses a low voltage and high current. The electric arc also has applications in the generation of CAPs and in different industrial processes, such as the generation of ultra-fine particles, cutting, welding, waste treatment, plasma spraying, among others.

3. High Voltage DC Pulsed Circuit

Different topologies of electronic circuits can be used to carry out the ionization of atmospheric air, and thus promote the elimination of biological contaminants from surfaces, environments and objects. Among them we will highlight two topologies, namely, Zero Volt Switching and DC Pulsed.

Zero Volt Switching (ZVS) consists of an oscillating circuit where the activation of a transistor causes the deactivation of the other, thus generating an oscillation of voltage and current in the inductor, which may be the primary of a transformer. The frequency in which this circuit oscillates is determined by the relationship between the inductance (primary of the transformer) and the capacitance in parallel. This circuit is able to supply current pulses of tens, and even hundreds, of amperes to the primary of the transformer, making possible to work with higher powers of hundreds, even thousands, of watts. One application of these high current pulses is seen in induction heaters. A differential of this circuit for the ionization of atmospheric air, in addition to the possibility of working with higher powers, is the AC nature of the output signal, alternating polarity each time the oscillator passes through zero volts.

DC Pulsed is a circuit that uses pulses from a DC signal on the primary of the transformer to create high voltage pulses on the secondary. These pulses are in the form of a PWM signal (square wave) and make it possible to control the frequency and pulse width of the generated signal. A possible example of this topology consists of a PWM signal generator circuit, which in turn controls a power stage, made up of transistors. These, in turn, are responsible for switching the primary of the transformer, creating voltage and current pulses in it. In addition to signal adjustment, these circuits make it possible to control the power delivered to the transformer (and in turn to the plasma), allowing operation with varying levels of power and avoiding the transition to electric arc.

In this work a test circuit was developed using the DC Pulsed philosophy. A PWM signal generator, using a 555 IC and an LM741 operational amplifier, was coupled to a MOSFET, IRF540N, in order to create pulses in the primary of a FLYBACK transformer, model OV20762F, taken from a CRT television. With this circuit we can control the DUTY-CYCLE of the PWM signal, and its frequency, thus adjusting the consumed power of the source and the intensity of the corona discharge. The plasma wand was built with a 5 mL hypodermic syringe, which was modified to allow air to enter through the upper part, and the positive electrode to pass through. The purpose of this initial circuit, in addition to making it possible to adjust the discharge in order to find the optimum operating point for the system, was to develop a low-cost system (approximately 20 dollars).

Figure 1 shows the prototype mounted on a universal perforated board. The power supply for this circuit was carried out with a bench source, model PS-1502DD, supplying 13 V and 1.2 A approximately, which is equivalent to 15,6W. This circuit can also be operated with a 12V battery.

Figure 2 displays the corona discharge between the plasma wand and the ground plane connected to the ground of the high voltage transformer. The body of the plasma pencil consists of an hypodermic syringe. Figure 3 shows the discharge being applied to the substrate on a petri dish. The biocide action against biological contaminants is currently ongoing work.

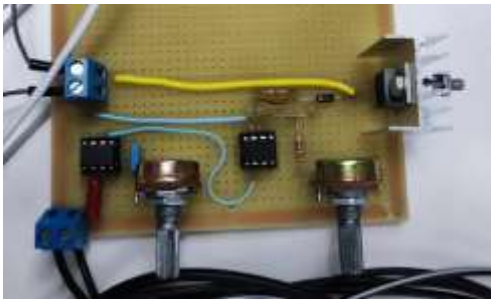

Figure 1. Electronic circuit of the prototype of the low-cost plasma pencil.

Figure 2. Corona discharge between the plasma pencil and the ground plane.

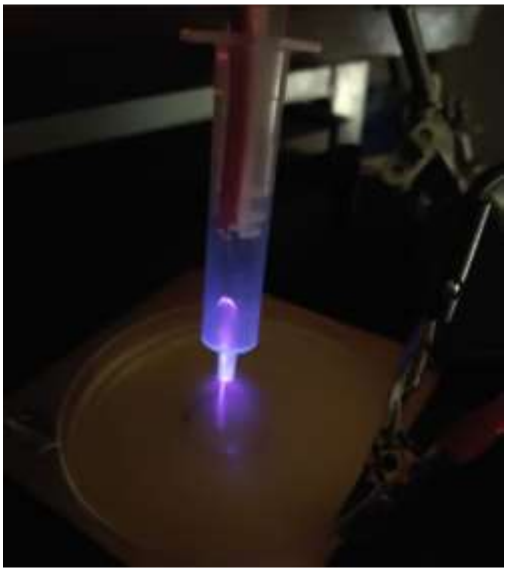

Figure 3. Cold Atmospheric Plasma discharge applied to the substrate of a petri dish.

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5. References

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