Research Inventy: International Journal of Engineering And Science
Vol.6, Issue 2 (February 2016), PP -15-20
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Cold Plasma: Emerging As the New Standard in Food Safety

Ritesh Mishra*, Sunny Bhatia, Ramesh Pal, Amit Visen and Himanshu Trivedi
Department of Agricultural Sciences and Engineering, IFTM University, Moradabad- 244102 UP INDIA

ABSTRACT: *Cold plasma is an emerging non-thermal technology for the improvement of food safety. This technique becomes a subject of high interest for a wide variety of technologies including the food industry. Cold plasma is a novel non thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. The atmospheric cold plasma is proposed for decontamination of fruits and vegetables, especially, without changes in sensory attributes. Growing demand for fresh produce poses the challenge to the food industry of supplying safe food with minimal processing. It is crucial that foods are supplied without any microbial contamination as many products are eaten raw. Cold atmospheric plasma has potential in the food manufacturing sector to inactivate microorganisms, thereby improving food safety without loss of physicochemical or sensory properties.*

Keywords: *Food preservation, food safety, micro-organisms, non thermal plasma, sensory attributes.*

I. INTRODUCTION

The name "plasma" was first used by Irving Langmuir in 1926 who described this state of matter as: "... near the electrodes, where there are sheaths containing very few electrons, the ionized gas contains ions and electrons in about equal numbers so that the resultant space charge is very small. We shall use the name plasma to describe this region containing balanced charges of ions and electrons..." [11]. Later, the definition was broadened to define a state of matter in which a significant number of atom and/or molecules are electrically charged or ionized. Plasma is considered as a distinct state of matter due to its properties; it does not have a regular shape or volume and it can form filaments and/or beams under magnetic fields. Depending on the method of generation used, the plasma can display a broad spectrum of states ranging from extreme no equilibrium to almost complete thermal equilibrium. Plasma can be found in the form of natural phenomena such stars and lightening or man-made as in the production of fluorescent and neon lights, plasma television etc. The research areas of plasma technology is fast growing and has been particularly studied for its use on bio-medical materials and devices [9,18], surface modification of textiles [14], removal of chemicals on surfaces of devices manufactured from heat sensitive materials [3], water sterilization [10] and more recently wound healing and food decontamination [5,15]. Non Thermal Atmospheric Plasma can be divided into two groups depending on the method of generation as non-thermal plasma (NTP), and thermal plasma (TP). NTP consists of gas molecules with moderate temperatures and electrons with higher temperatures whereas in TP the electrons and gas temperatures are several thousands of Kelvin and these species are found in equilibrium. NTP is also known as cold and non-equilibrium plasma with regards to the energy level, temperature and ionic density. An important aspect in the use of NTP for decontamination is the ability to be effective, without affecting the material being decontaminated. This is possible due to the weakly ionized nature of the cold plasma discharge. The antimicrobial efficacy of NTP has been related to the specific type of plasma technology used including; the power level used to generate the plasma, the gas mixture in the plasma emitter, the intensity and length of exposure, design of the system, flow rate and pressure.

Cold atmospheric plasma has potential in the food manufacturing sector to inactivate microorganisms, thereby improving food safety. Growing demand for fresh produce poses the challenge to the food industry of supplying safe food with minimal processing. It is crucial that foods are supplied without any microbial contamination as many products are eaten raw. As a result, there is much interest in novel ways of preserving food and destroying micro-organisms without affecting its quality. One such emerging technology that has shown promise is the use of cold atmospheric plasma (CAP) treatment. An overview of the cold plasma technology is presented with its potential applications in food processing sector.

Plasma is considered as the fourth state of matter. The concept of the fourth state of matter results from the idea that phase transitions occur by progressively providing energy to the matter, such as the one from the solid state to liquid up to the gas state. A further phase transition may be thought as the one from the gas state to plasma state, even if these states is reached gradually by providing more and more energy to the system. Plasma can be seen as a particular ionized gas, which retains some unique features which distinguish it from an (ideal) gas.

Plasma Science and Technology

Plasma is ionized gas that consists of a large number of different species such as electrons, positive and negative ions, free radicals, and gas atoms, molecules in the ground or excited state and quanta of electromagnetic radiation (photons). It is considered to be the forth state of matter in the world. It can be generated in the large range of temperature and pressure by means of coupling energy to gaseous medium. This energy can be mechanical, thermal, nuclear, radian or carried by an electric current. These energies dissociate the gaseous molecules into collection of ions, electrons, charge – neutral gas molecules and other species [18]. Depending on the type of energy supply and amount of energy transferred to the plasma, density and temperature of the electrons are changed. These lead Plasma to be distinguished into two groups, high temperature plasma and low temperature plasma [18]. High temperature plasma implies that electron, ions and neutral species are in a thermal equilibrium state. Low temperature plasma is subdivided to thermal plasma, also called local thermodynamic equilibrium plasmas (LTE) and non thermal plasma (NTP), also called non-local thermodynamic equilibrium plasmas (non-LTE). An equilibrium or near equality between electrons, ions and neutrals is the main characterization of thermal plasmas (TP). Frequently employed thermal plasma generating devices are those produced by plasma torches, and microwave devices. In generation of cold plasma most of the coupled electrical energy is channeled to electron component instead of heating entire gas stream so the temperature of heavy particle remains near the room temperature, these characteristics make it suitable to be used in processes which high temperature is not desirable [18].

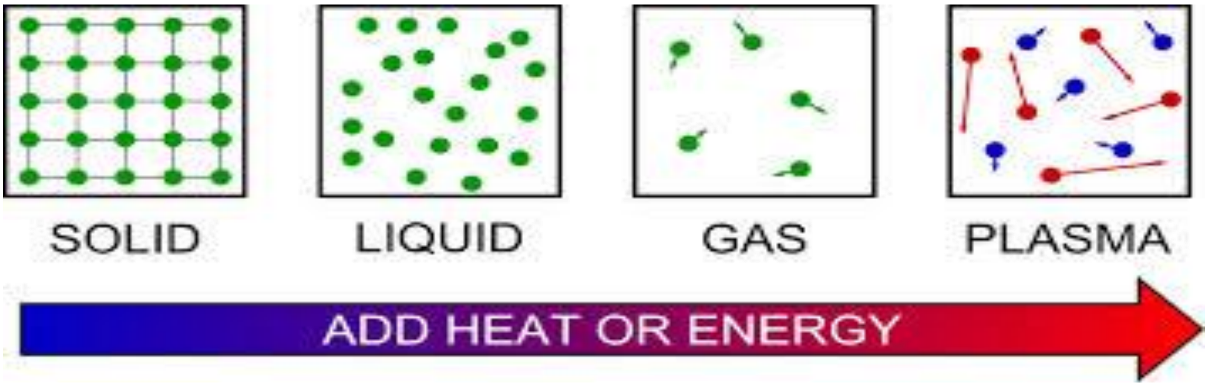

Figure: Plasma as fourth state of matter

Cold plasma is a novel non thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. [4] This flexible sanitizing method uses electricity and a carrier gas, such as air, oxygen, nitrogen, or helium; antimicrobial chemical agents are not required. The primary modes of action are due to UV light and reactive chemical products of the cold plasma ionization process. A wide array of cold plasma systems that operate at atmospheric pressures or in low pressure treatment chambers are under development. [3]

Methods to Generate Plasma

There are various ways to supply the necessary energy for plasma generation to a neutral gas as shown in the figure below. One possibility is to supply thermal energy, for example in flames, where exothermic chemical reactions of the molecules are used as the prime energy source. Adiabatic compression of the gas is also capable of gas heating up to the point of plasma generation. Yet another way to supply energy to a gas reservoir is via energetic beams that moderate in a gas volume. Beams of neutral particles have the added advantage of being unperturbed by electric and magnetic fields. Neutral beams are primarily used for sustaining plasmas or for plasma heating in fusion devices. The most commonly used method of generating and sustaining a low-temperature plasma for technological and technical application is by applying an electric field to a neutral gas. [5]

Generation of Plasma

Plasmas are generated by supplying energy to a neutral gas causing the formation of charge carriers [5]. Electrons and ions are produced in the gas phase when electrons or photons with sufficient energy collide with the neutral atoms and molecules in the feed gas (electron-impact ionization or photo ionization). There are various ways to supply the necessary energy for plasma generation to a neutral gas. One possibility is to supply thermal energy, for example in flames, where exothermic chemical reactions of the molecules are used as the prime energy source. Adiabatic compression of the gas is also capable of gas heating up to the point of plasma generation. Yet another way to supply energy to a gas reservoir is via energetic beams that moderate in a gas volume. Beams of neutral particles have the added advantage of being unperturbed by electric and magnetic fields. Neutral beams are primarily used for sustaining plasmas or for plasma heating in fusion devices. The most commonly used method of generating and sustaining a low-temperature plasma for technological and technical application is by applying an electric field to a neutral gas. Any volume of a neutral gas always contains a few electrons and ions that are formed, for example, as the result of the interaction of cosmic rays or radioactive radiation with the gas. These free charge carriers are accelerated by the electric field and new charged particles may be created when these charge carriers collide with atoms and molecules in the gas or with the surfaces of the electrodes. This leads to an avalanche of charged particles that is eventually balanced by charge carrier losses, so that steady-state plasma develops.

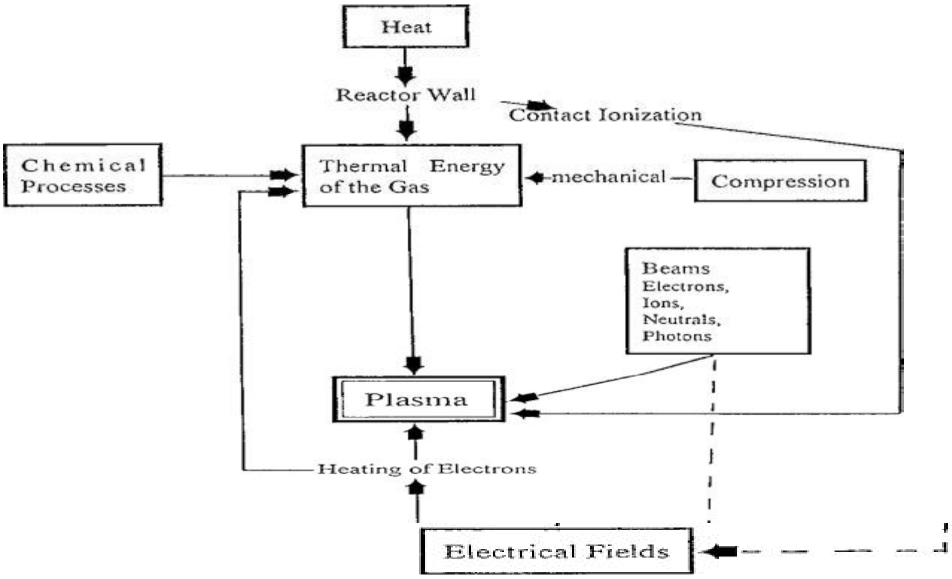

Figure: Various ways of supplying the necessary energy for plasma generation

Here is a schematic representation of plasma formation (Figure). The primary purpose of the first RF coupler is to convert gas into plasma by ionizing it, or knocking an electron loose from each gas atom. It is known as the helicon section, because its coupler is shaped in such a way that it can ionize gas by launching helical waves through the gas. A Helicon antenna is commonly used for generating plasma. After the helicon section, the gas is now “cold plasma. The soup of electrons and the atoms is primed for acceleration in the second stage. Where there were neutral gas atoms, there are now ions and electrons, which are charged, and such moving charged particles interact with magnetic fields. The magnetic field can be visualized as lines passing with ions orbiting around each line. The second RF coupler is called the Ion Cyclotron Heating (ICH) section. ICH is a technique used in fusion experiments to heat plasma to temperatures on the order of those in the Sun's core. [19]

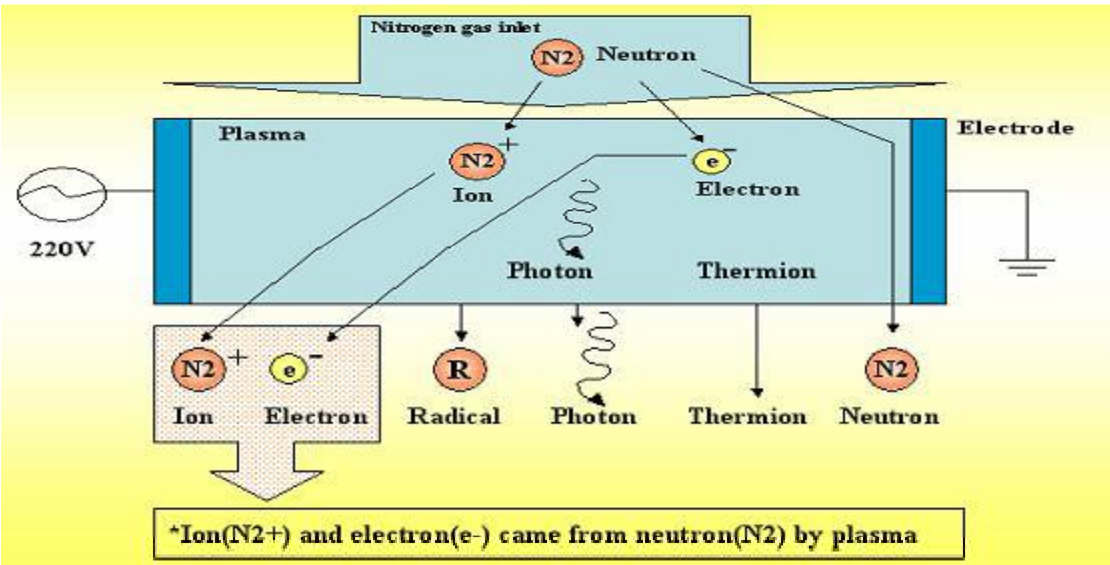

Figure: Generation of Plasma

Benefits of Cold Plasma over Other Food Safety Technologies

Cold plasma can be used for decontamination of products where micro-organisms are externally located. Unlike light (e.g. ultraviolet light decontamination), plasma flows around objects which means "shadow effects" do not occur ensuring all parts of a product are treated. For products such as cut vegetables and fresh meat, there is no mild surface decontamination technology available currently; cold plasma could be used for this purpose. Cold plasma could also be used to disinfect surfaces before packaging or included as part of the packaging process. Energy consumption would be similar to existing UV-C systems and the treatment of foods would be highly cost-effective; the electronics and lifetime of plasma technologies are comparable to UV-C systems even with the additional need for a carrier gas. [7]

Atmospheric plasmas containing high levels of bactericidal molecules (> 100 ppm ozone, nitric oxides, peroxides, etc.) are generated with minimal power under room-temperature conditions in seconds to minutes, with little or no product heating. Atmospheric plasma technology (APT) requires a few hundred watts of power and a supply of compressed air or other gas; sometimes, a gas blend is used depending on the reactive gas species being generated. APT can generate bactericidal molecules in situ very efficiently solely from air with product temperature increases less than 5 °C. This flexibility and unique processing capabilities are driving the technology into new markets and applications. Atmospheric plasma offers a number of advantages over existing food safety technologies, including the following: 1) it is a dry process; 2) it is readily adaptable to a food manufacturing environment; 3) it requires very little energy; 4) reactive gas species revert back to original gas within minutes to hours after treatment and 5) it requires short treatment times.

- **Advantages:**
- Novel, ultra-fast sterilization/preservation process (sterilization takes only few minutes)
- Surface treatment process doesn't affect nutrients and vitamins within the food
- Process operates at ambient temperatures (ideal for thermo labile products)
- Depending on the plasma type, it is possible to inactivate all types of pathogens
- Low running cost (cost of natural gases and electricity)
- Environmentally friendly (uses natural gases including nitrogen, argon, air, hydrogen and oxygen)

Cold plasma as a novel food processing technology

Potential application in food NTP has been applied in the food industry including decontamination of raw agricultural products (Golden Delicious apple, lettuce, almond, mangoes, and melon), egg surface and real food system (cooked meat, cheese,). In one study on E. coli 12955 a non-pathogenic surrogate for Salmonella spp. inoculated onto almonds, Deng et al. [5] reported a reduction of more than 4 log CFU/ml after 30 s treatment at 30 kV and 2000 Hz.

Cold plasma used to kill bacteria on raw chicken

Pathogens such as *Campylobacter* and *Salmonella* contaminate over 70 percent of the raw chicken meat tested [17]. Recent research from a food safety team at Pennsylvania's Drexel University made use of high-energy, low temperature plasma to eliminate unwanted bacteria while leaving the food basically unchanged.[17

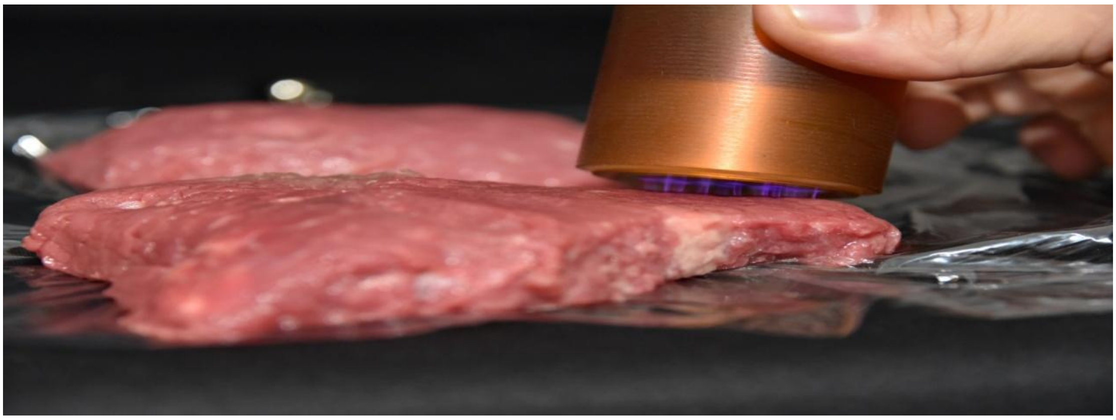

Figure: A plasma torch applied to uncooked chicken

Cold plasma in food packaging

Whether labeling jam jars, printing on glass containers, or sealing liquid packaging, a key factor in the packaging industry is the ability to process materials reliably and at low cost. Pretreatment with atmospheric-pressure plasma makes it possible to process different materials and coatings that are sometimes very thin, for example, in the production of composite packaging. [2]

Where packs are processed at high speed and an adhesive bond is required, recesses in the area of the bonding surfaces usually have to be taken into account, especially in the case of high-gloss plastic-coated surfaces. By using Open-air plasma technology, such high-gloss gluing points are directly and selectively pretreated inline so that reliable bonding is ensured. In labeling glass bottles, atmospheric-pressure plasma is employed for pretreating glass. This allows the use of a universal and low-cost water-based adhesive. [2]

One of the most common applications of plasma in packaging is in the area of labeling. For advertising stickers, information labels or tamper evidence, there's always one key requirement: the glue must be water based and the adhesive joint must not loosen by itself. When it's torf off a clear fiber tear should be evident. To ensure adhesion of such label, companies such as Kraft and other leading food and beverage manufacturers make use of plasma technology. [2]

Modification of food packaging polymers

Polyethylene (PE)

Structurally PE is one of the simplest polymers used in food packaging. PE of varying densities, characterized by different WVTR (water vapor transmission rate), GTR (gas transmission rate), tensile strength, heat sealing and other properties are commercially available. This provides freedom to food manufacturers to choose the package type optimum for their [22]. However, the low surface energy of PE, has driven most of the research in cold plasma towards surface modifications of PE. Surface characterization of PE with CO2, H2O and CO2/H2O plasma has been reported [12].

Poly (ethylene terphthalate) (PET)

PET has many desirable properties, including good strength, rigidity, high strength-toweight ratio, transparency, thermal stability, gas barrier property, chemical resistance and formability which make it a packaging material of choice for a wide range of food [16]. However, PET, like other synthetic polymers has lower surface energy, which necessitates surface modification for good adhesion, printing and dyeing properties. The crystalline of PET film is an important factor which determines the changes in surface energy upon CP treatments [8]. Surface characterization studies for plasma treated PET film using oxygen, carbon dioxide, nitrogen and helium plasma have been reported [1,6].

Food Packaging Surface Sterilization

Most regulatory guidelines specify microbiological requirements for food packaging materials and in many cases the packaging process is an important critical control point in a hazard analysis critical control point (HACCP) system [13]. Food packaging materials are intended to preserve food quality along the distribution and storage chain and also to protect it from deterioration, damage or outside contamination. Schneider, et al. (2005) investigated the scalability of a plasma array system (Duo-Plasmaline®) for industrial applications, and compared the performance to a laboratory scale system (Plasmodul®) using PET foil substrates and common treatment times of 5 s. The spore reduction kinetics for both systems suggests scalability of the approach.

Printing

Surface activation and functionalisation by atmospheric-pressure plasma enables the processing of different materials and coatings that are very thin; as for example in the production of composite packaging. Whether labeling jam jars, printing on glass containers, or sealing liquid packages, a key concern in the packaging industry is the ability to process materials reliably and at low cost [4].

II. CONCLUDING REMARKS

In conclusion, we could recommend that there is an urgent need for regulation of safety of foods by effectively sanitizing without compromising food quality. This has led to an increased interest in cold plasma processing for meat, poultry, and dairy products. Cold Plasma is now being investigated for application to foods as a sanitizing and/or conditioning step. The atmospheric cold plasma, by far, is one of the newest technologies used in food industry for microbial inactivation. Future studies should be directed towards assessment of the efficacy of cold plasma on the processing of different food products.

REFERENCE

[1] Almazan-Almazan, M. C., Paredes, J. I., Perez-Mendoza, M., Domingo-Garcia, M., Lopez-Garzon, F. J., Martinez-Alonso, A., & Tascon, J. M. (2005). Effects of oxygen and carbon dioxide plasmas on the surface of poly(ethylene terphthalate). J Colloid Interface Sci, 287,57-66.

[2] André Schlenk *Innovative Plasma Technology Resolves Problems In Package Manufacturing*

[3] Annual Review of Food Science and Technology *Cold Plasma Decontamination of Foods* Review in Advance first posted online, 2011.

[4] Banu, M. S. (2012). Cold Plasma as a Novel Food Processing Technology. International Journal of Emerging Trends in Engineering and Developments.

[5] H Conrads and M Schmidt, *Plasma generation and plasma Sources*, 441 454. UK PII, (2000).

[6] Inagaki, N., Narushim, K., Tuchida, N., & Miyazaki, K. (2004). Surface characterization of plasmamodified poly(ethylene terephthalate) film surfaces. Journal of Polymer Science Part B: Polymer Physics, 42, 3727-3740.

[7] Ir. Ariette Matser, *Cold plasma processing Food & Biobased Research* http://www.novelq.org

[8] Jacobs, T., De Geyter, N., Morent, R., Van Vlierberghe, S., Dubruel, P., & Leys, C. (2011). Plasma modification of PET foils with different crystallinity. Surface and Coatings Technology, 205, Supplement 2, S511-S515.

[9] Kogelschatz U. Twenty years of Hakone symposia: From basic plasma chemistry to billion dollar markets. Plasma Processes and Polymers. 2007; 4: 678-681.

[10] Korachi M, Turan Z, Senturk K, Sahin F, Aslan N. An investigation into the biocidal effect of high voltage AC/DC atmospheric corona discharges on bacteria, yeasts, fungi and algae. Journal of Electrostatics. 2009; 67:678-685.

[11] Langmuir I. Oscillations in ionized gases. Proceedings of the National Academy of Science of US. 1928; 14: 628.

[12] Médard, N., Soutif, J.-C., & Poncin-Epaillard, F. (2002). CO2, H2O, and CO2/H2O Plasma Chemistry for Polyethylene Surface Modification. Langmuir, 18, 2246-2253.

[13] Mittendorfer, J., Bierbaumer, H., Gratzl, F., & Kellauer, E. (2002). Decontamination of food packaging using electron beam—status and prospects. Radiation Physics and Chemistry, 63, 833-836.

[14] Morent R, De Geyter N, Verschuren J, De Clerck K, Kiekens P, Leys C. Non-thermal plasma treatment of textiles. Surface & Coatings Technology. 2008; 202:3427-3449. [6]

[15] Nastuta AV, Topala I, Grigoras C, Pohoata V, Popa G. Stimulation of wound healing by helium atmospheric pressure plasma treatment. Journal of Physics D: Applied Physics. 2011; 44: 105-204.

[16] Pankaj, S. K., Kadam, S. U., & Misra, N. N. (2011). Trends in food packaging. Germany: VDM Publishing House.

[17] Randolph Jonsson Cold plasma used to kill bacteria on raw chicken, *2012*

[18] Rossi F, Kylian O, Hasiwa M. Decontamination of surfaces by low pressure plasma discharges. Plasma Processes and Polymers. 2006; 3: 431-442.

[19] Technology, VASIMR http://www.adastrarocket.com/aarc/Technology