Development of plasma-generating devices and history of plasma utilization

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Abstract. *This paper is focused on the main milestones of the plasma-generating devices, the development of the technologies, being used in those generators. The history of plasma research from the discovery of the phenomena (1879) till nowadays is mentioned. The second part of the paper describes the development of plasma devices and research on this field. In the third part the modern devices of the 21-st centuries are discussed, utilization of this devices, such as water purification, plasma medicine, agriculture, plasma chemistry and space applications, are described.*

Keywords

Plasma, history of plasma, plasma devices, plasma utilizations.

Discovery of plasma and devices of 19-th century

Discovery of the phenomena.

The plasma is known as the fourth state of matter, it is an ionized gas. Plasma contains free electrons, positive and negative ions. It was discovered by W. Crookes in 1879, but coined with the word “plasma” only in 1928 by I. Langmuir. It is worth mentioning, that the word “plasma” itself was proposed by Czech medical scientist Jan Evangelista Purkyně (1787-1869) to name a part of blood, free from corpuscles [1]. Until the middle of the 19th century, it was believed that plasma was a secondary part of the cell compared to the membrane. In the XIX - early XX century, the word “plasma” was widely used, but in modern scientific literature almost never occurs, if speaking about blood and cells. The reason for such a substitution might be the popularization of usage the word “plasma”, describing the ionized gas. By the middle of the 18-th century, it was known that a negative electrode emits an emanation of an unknown nature, which the German physicist Eugen Goldstein in 1876 called cathode rays. After many experiments, W.Crooks decided that these rays are nothing but gas particles, which after a collision with the cathode acquired a negative charge and began to move toward the anode. These charged particles he called "radiant matter". The results of his experiments with cathode rays led Crookes to a very deep thought: the environment in which they propagate is no longer gas, but something completely different. On Aug. 22, 1879, at a session of the British Association for Science, Crookes stated that discharges in rarefied gases "are so unlike anything that happens in the air or any gas at ordinary pressure, that in this case we are dealing with matter in the fourth state, which by properties differs from ordinary gas in the same degree as the gas from the liquid."

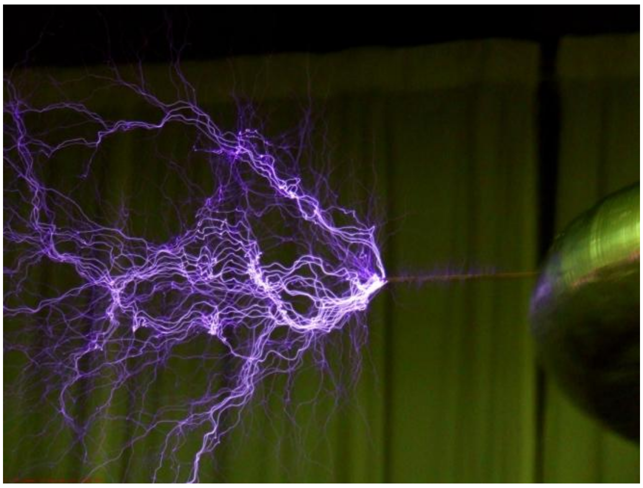

Fig. 1. *Formed Plasma in atmospheric Air*

In many scientific papers it is written, that it was Crookes who first thought up the fourth state of matter. In fact, this thought was much earlier than that of Michael Faraday. In 1819, 60 years before Crookes, Faraday suggested that matter can be in solid, liquid, gaseous and radiant states, radiant state of matter. In his report, Crookes explicitly said that he uses terms borrowed from Faraday, but the descendants forgot about it for some reason. However, Faraday's idea was still a speculative hypothesis, and Crookes justified it with experimental data. [2]

In the second half of the 1920s, the future Nobel Prize laureate in chemistry Irving Langmuir, who worked in the laboratory of the corporation General Electric, was closely involved in the study of gas discharges. Then we already knew that in the space between the anode and the cathode, the atoms of the gas lose electrons and become positively charged ions. Realizing that such a gas has many special properties, Langmuir decided to give it his own name. In its new quality, the term "plasma" first appeared in Langmuir's article "Oscillations in ionized gases", published in 1928. For thirty years, this term was used by very few people, but then he became firmly established in scientific usage. [3]

Devices of the 19-th century.

Around 1808 Humphry Davy invented the carbon-arc lamp, using an arc between two carbon electrodes, which later found applications in movie projection lamps, in searchlights and as a radiation standard for spectroscopy. Davy used arcs for melting (1815) and investigated the effects of magnetic fields on arcs (1821). In France this technology was investigated by Moissan (1892, 1897) and by Heroult. [5]

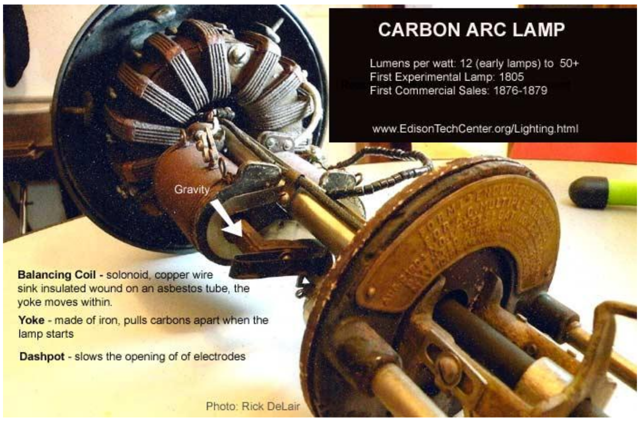

Fig. 2. *Carbon Arc Lamp, 1876 year*

The generators based on the dielectric barrier discharge (DBD) date back to 1857 and to the discovery described by the German electrical engineer Werner von Siemens. Studies, that describe the application of the surface dielectric barrier discharge (SDBD) not only for ozone generation, but also for numerous industrial applications (such as plasma displays, CO2 lasers, planar excimer ultraviolet lamps and air control), in medicine and for surface treatment of materials including the application of thin layers. [4]

Development in the 20-th century.

Thermal Plasma.

A hot plasma in one which approaches a state of local thermodynamic equilibrium (LTE). A hot plasma is also called a thermal plasma, such plasmas can be produced by atmospheric arcs, sparks and flames. [10]

More refined experiments with rarefied plasma started at the beginning of the 20th century. For a long time the transport of electricity through gases had been treated like the flow of charges in electrolytes. Only about 1900, mainly due to the work of Wilson (1901) and Townsend (1904), it was established that conductivity in electrical gas discharges was due to ionization of gas atoms or molecules by collisions with electrons. In most gas discharges the current is mainly carried by electrons.

From the very beginning it was obvious that cold glow discharge plasmas had different properties than the hot arc discharges. For a long time, it was believed that glow discharges which are characterized by hot electrons and essentially cold heavy particles (atoms, molecules, ions) could exist only at low pressure.

Much of the early work on electric arcs, producing plasma, is summarized in the monograph of Ayrton (1902). In 1901 Marconi used an electric arc for radio transmission across the Atlantic, and around 1910 already 120 arc furnaces of the Schonherr and Birkeland—Eyde design were installed in Southern Norway for nitrogen fixation. In this electric-arc process, proposed by Birkeland and Eyde in 1903, nitrogen and oxygen in air were combined to form nitrogen oxides, nitric acid, and finally artificial fertilizer (Norge salpeter, i.e. calcium nitrate). By 1917 the plant had been extended to use up to 250 MW of cheap hydro power. Arc welding was first demonstrated around 1910, and in its various forms is now responsible for the bulk of fusion welds. Schenherr (1909) was the first to use a forced gas flow to stabilize long carbon arcs.

Also various kinds of flow and vortex arc stabilization techniques are used in plasma torches. Many technological developments are described in a book edited by Dresvin (1977), and in reviews by Pfender (1978) and Pfender et al (1987). The fundamentals and applications of thermal plasmas are discussed in Boulos a al (1994), in Heberlein and Voshall (1997) and in Pfender (1999).

The most important applications include circuit breakers, lamps, plasma spraying, welding and cutting, metallurgical processing and waste disposal. Most arcs are approaching the state of local thermal equilibrium (LTE) and require high temperatures to maintain sufficient electrical conductivity by thermal ionization. [5].

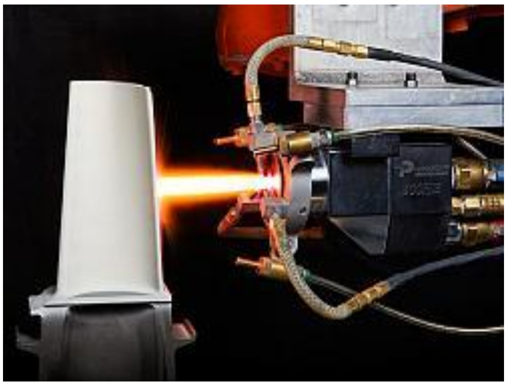

Fig. 3. *100HE™ Plasma Spray System*

Dielectric barrier discharges were used to generate relatively large volume diffuse plasmas at atmospheric pressure and applied to inactivate bacteria in the mid 1990’s. This eventually led to the development of a new field of applications, the biomedical applications of plasmas. This field is now known as plasma medicine. [8]

Non-thermal plasma.

The nomenclature for nonthermal plasma found in the scientific literature is varied. In some cases, the plasma is referred to by the specific technology used to generate it ("gliding arc", "plasma pencil", "plasma needle", "plasma jet", "dielectric barrier discharge", "Piezoelectric direct discharge plasma", etc.), while other names are more generally descriptive, based on the characteristics of the plasma generated ("one atmosphere uniform glow discharge plasma", "atmospheric plasma", "ambient pressure nonthermal discharges", "non-equilibrium atmospheric pressure plasmas", etc.). The two features which distinguish NTP from other mature, industrially applied plasma technologies, is that they are 1) nonthermal and 2) operate at or near atmospheric pressure. [9]

A cold plasma is one in which the thermal motion of the ions can be ignored. Consequently, there is no pressure force, the magnetic force can be ignored, and only the electric force is considered to act on the particles. Examples of cold plasmas include the Earth's ionopshere (about 1000K compared to the Earth's ring current temperature of about 10^8K), the flow discharge in a fluorescent tube. [11]

Non-equilibrium plasmas are mainly used to generate chemically reactive species and for their electromagnetic properties. Their applications include the synthesis of thermally unstable compounds like ozone and the generation of intermediate free radicals for pollution control. Surface modification of polymer foils, thin film deposition and plasma etching in the electronic industry are further applications.

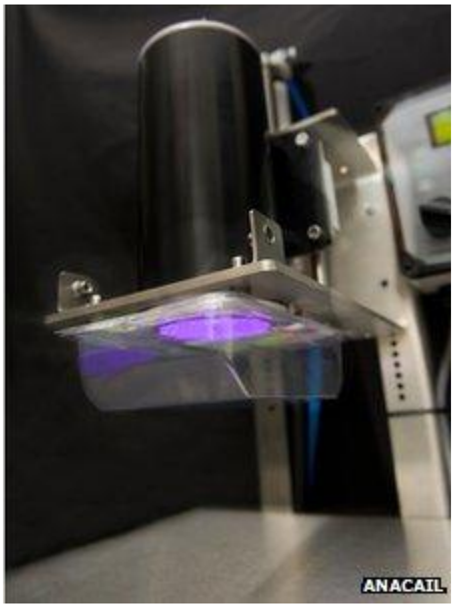

Fig. 4. *Plasma Ozone generator for food sterilizing utilization.*

Progress in the under-standing and control of atmospheric pressure non-equilibrium discharges has led to increased activity in recent years which is manifested in several monographs and review papers devoted to this special subject (Capitelli and Bardsley 1990, Eliasson and Kogelschatz 1991, Lelevkin et al 1992, Penetrante and Schultheis 1993, Manheimer et al 1997, Capitelli et al 2000. Kunhardt 2000, Protasevich 2000, van Veldhuizen 2000, Hippler et a! 2001, Kruger et a! 2002).[5]

Nowadays applications.

Nowadays, plasma is used in a great variety of technologies. Some of them are known to everyone (gas lamps, plasma displays), others are of interest to narrow specialists (the production of heavy-duty protective film coatings, the manufacture of microchips, disinfection). However, the greatest hopes for plasma are assigned about the work on the implementation of controlled thermonuclear reactions. [6]

Plasma is widely used in a variety of gas-discharge devices: voltage stabilizers, rectifiers of electric current, generators of ultrahigh frequencies and others. In addition, the development of plasma engines designed to replace reactive ones is continuously carried out, and there are also several ready-made plasma power plant projects that will be much more productive and safer than nuclear ones. Plasma cutting, which has several different types, used in certain areas depending on the main gas, is also becoming more widespread. Thus, plasma using deoxidizing gas (for example, a mixture of nitrogen and hydrogen) is well suited for cutting stainless steel and non-ferrous metals, based on argon-hydrogen - is used only for manual cutting. [7]

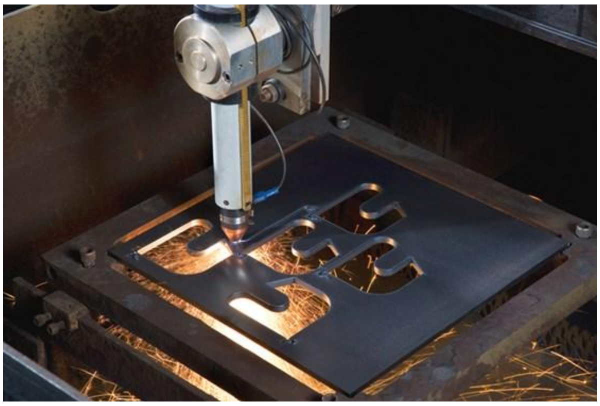

Fig. 5. *3D plasma cutting device*

A dielectric barrier discharge is one method of plasma treatment of textiles at atmospheric pressure and room temperature. The treatment can be used to modify the surface properties of the textile to improve wettability, improve the absorption of dyes, and for sterilization. DBD plasma provides a dry treatment that doesn't generate waste water or require drying of the fabric after treatment. For textile treatment, a DBD system requires a few kilovolts of alternating current, at between 1 and 100 kilohertz. Voltage is applied to insulated electrodes with a millimeter-size gap through which the textile passes.

An excimer lamp can be used as a powerful source of short-wavelength ultraviolet light, useful in chemical processes such as surface cleaning of semiconductor wafers. The lamp relies on a dielectric barrier discharge in an atmosphere of xenon and other gases to produce the excimers. [8]

The use of plasma processes is an environmentally friendly and cost effective alternative. By applying an electrical current, ions, highly-reactive short-lived radicals and short-wave radiation are generated in the plasma from the ambient air and atmospheric oxygen, and break down the wastewater constituents. Hence, the use of additional chemicals and their disposal is not required because the reactive particles are generated only during discharge and react rapidly with pollutants dissolved in water due to their high reactivity. [12]

Fig. 5. *Water purification device, working on plasma-generated ozone*

Plasma treatment is also used in decontamination of foods and minimization of food spoilage are critical issues to ensure food safety and sustainability. Cold plasma technology has brought a new dimension to the concept of decontamination under ambient conditions, in that it truly is an ensemble of both physical and chemical decontamination methods. The recent developments in cold plasma sources, the confirmation of strong antimicrobial action and the ability to "plasma treat" foods with the retention of their quality has led to the emergence of a new subject area within food science. [13]. Among other usages in agriculture there is also using the plasma treatments to control plant growth and identify the mechanism, to control fish growth and identify the mechanism to destroy the pathogenic bacteria that infect crops and marine resources.[14]

A positive effect in non-healing wounds, treated with cold plasma was also reported [15]. Such skin diseases as Atopic dermatitis, psoriasis and chronic venous leg ulcers (usually caused by diabetes), that were impossible to cure with traditional method in medicineб now has a chance to be totally cured with treatment of innovative cold-plasma technologies.

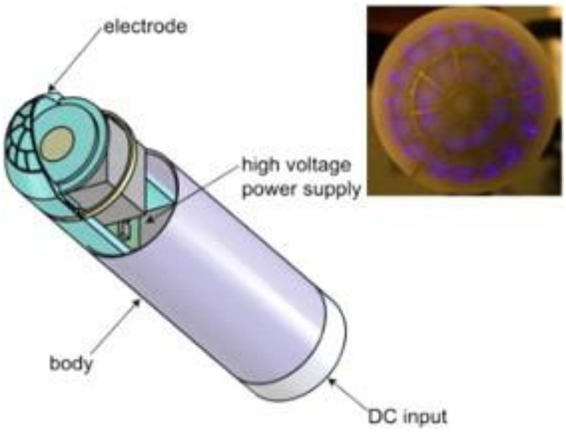

Fig. 6. *Plasma pen for skin treatment*

There is also a possibility to utilize plasma technologies in space-engines engineering. Currently, the most widespread - as engines to maintain the points of standing of geostationary communication satellites - have received stationary plasma engines, the idea of which was proposed by A.I. Morozov in the 1960s and the first flight tests took place in 1972 [16]. From that time the technologies improved a lot and, theoretically, plasma-engines of future could decrease the amount of rocket fuel, consumed in more, than 1000 times.

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About Authors...

Kirill CHUKHLANTSEV was born in Moscow, moved to Czech Republic in 2014, from 2015 year studying in CTU University, at FEL faculty on Electrical Engineering and Computer Science program.

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