Plasma and photon technologies against bio-factors, dangerous to human being

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Abstract. Possible plasma and photonic methods and devices for monitoring and preventing dangerous infections and human diseases are presented. In experiments with different types of atmospheric pressure discharges in different gases, the significant bactericidal effect was found. The prototype of device based on the method of absorption spectroscopy for detecting human diseases by biomarkers in the exhaled air has been proposed and tested. The importance of the plasma technology of deposition of coatings by magnetron sputtering for the creation of anti-covid masks and high-quality optics (mirrors) for photon monitoring devices is emphasized.

1. Introduction
Since biological hazards (as bio-factors) constantly lie in wait for humans, an example of which is the global pandemic COVID-19, scientists and engineers are constantly looking for ways to combat biohazards, proposing new approaches and creating new devices. Plasma and photonic (optical) technologies have great potential along this path [1–3]. Plasma methods are attractive from several sides: firstly, they make it possible to generate highly effective germicidal agents with fairly simple and relatively cheap devices, and secondly, plasma production technologies make it possible to manufacture effective devices for combating bio-hazards by other methods, in particular, using photonics. Photonic and optical technologies are at the heart of prevention, monitoring and detection of diseases, as well as disinfection and sterilization. Photon measurements are used in devices for remote molecular analysis and thermometry of people. Examples of such devices are multispectral cameras with high quantum efficiency, laser diodes and LEDs in visible and ultraviolet light, infrared bolometric arrays, narrowband optical filters, and broadband multispectral optical spectrometers. This work is devoted to the consideration of the aspects of plasma and photonic technologies that we are developing.
2. Investigation of the bactericidal effect of atmospheric pressure discharges

In recent decades, much attention has been paid to the study of the effect of gas discharges and plasma generated in them on biological objects [1, 2]. This effect is due to the physical and chemical properties of plasma, which are determined by the fact that the plasma contains a variety of active particles (reactive oxygen and nitrogen species (RONS), hydrogen peroxide additives, free radicals, excited atoms and molecules, electrons, various ions, even active species of inert gases and radiation of photons from UV to IR wavelength range) in a wide energy range (0.05–0.1 eV for atomic particles, for ions and electrons - up to 10 keV). Moreover, to influence biological objects, as a rule, non-equilibrium non-thermal plasma is used, in which the role of high-energy electrons is important. Reaction plasma is used in biomedical equipment for the treatment of various diseases, preparation of liquid and gaseous medicinal media, disinfection and sterilization, as well as for purification, deodorization and disinfection of air. This direction in plasma technology is called as “Plasma in Medicine”. The proof of its relevance is the creation of the new journal “IEEE Transactions on Radiation and Plasma Medicine” [1]. The ozone treatment of various biological objects, including agricultural products, as well as drinking water and waste water, is close to this direction. In these technologies, plasma discharges are used to generate ozone.

![Image](https://example.com/image1)

**Figure 1.** Survival of bacteria spores Bac. Stearothermophilus in 30 min. The atmospheric pressure discharges are sustained in different gaseous media, which were created in a glass chamber with a diameter and height of 20 cm. Discharge power related to the volume of the chamber (W/cm³): for corona – 1·10^-4, for spark discharge – 6.3·10^-3, dielectric barrier discharge (pulse mode) – 4·10^-3, barrier discharge (power supply is by alternating voltage 50 Hz) – 1.5·10^-3. The initial number of spores is 8.6·10^5.

Our studies of atmospheric pressure discharges have shown that the chemical and germicidal effects of exposure to biological objects are inherent in all types of the discharges. See figure 1 with data for such discharges as silent (streamerless) corona, spark discharge and dielectric barrier ones. After exposition of Bac. Stearothermophilus spores in the discharge chamber, the number of the survivors is
very small. Moistening gases diminishes the number of the survivors due to acids generation. The maximum effect is reached with barrier discharge in air.

The coronavirus (COVID-19) pandemic has sparked a surge of interest in the research and development of plasma devices to target this virus [1]. The positive results of studies with other viruses are encouraging. The exact mechanism of the virucidal effect is still being investigated, but there is the reason to assume that the activity of viruses is suppressed as a result of the oxidation by the active species of its outer spines. Currently, the most realistic plasma technology is the fight against the spread of viruses in the atmosphere of confined spaces with people by equipping ventilation systems with plasma devices while taking all measures of safe operation.

3. Plasma for the production of materials and devices for fighting infections

The second aspect of the application of plasma technologies against coronavirus is the use of plasma methods, in particular, magnetron sputtering [4, 5] for applying active antiviral materials to the surface of masks to prolong their sterile action. It is known that coronaviruses quickly die on the surface of copper alloys, in particular, of the composition Cu-Zn. There is also data on the antiviral activity of Ag films and nanoparticles and TiO$_2$ photolytic films, which are effectively applied to roll materials by the high-productivity magnetron method. The same method with the reactive plasma assistance [4, 5] is promising for the manufacture of high-quality narrow-band multilayer filters for fluorescent systems for molecular diagnostics of coronavirus infection using a technique called as real-time reverse transcription polymerase chain reaction [3]. It is based on very sensitive spectroscopic detection of extremely small amounts of viral material in a swab from a patient's nose or throat.

4. Photonic device for monitoring human diseases by gas biomarkers

For effective treatment of patients, early detection of signs of disease is desirable, for example, by biomarkers (BM) in the exhaled air [6, 7]. We are developing an optical device prototype that allows determining the presence of low concentrations of BM molecules in the exhaled air, which are derivatives of pathologies in the human organism and indicate diseases in initial stages in the absence of other signs. It is assumed that the reliability of the diagnosis of the disease in the early stages by BM must be sufficiently high. The operation of the device may be based on the method of gas analytical spectroscopy by light absorption in a high-Q optical resonator after wave excitation by external light (may be pulsed one) [7]. Figures 2a depicts the variant of scheme of such device. The device contains a gas cuvette through which the air with BM additive is passed. If BM is detected one makes the conclusion about the decease presence. In the given work the gas CO was taken as a model of BM. Clinical studies have shown, as it is known from literature, for example in [7], the increase in the concentration of exhaled CO is observed in the next diseases: the infection with Helicobacter pylori bacteria, liver dysfunction, including cirrhosis, bacterial overgrowth, pancreatic dysfunction, malabsorption, bile metabolism, glucose metabolism, anemia, hemoglobinuria, respiratory tract infection, asthma, etc.

![Figure 2. Scheme of gas spectroscopy (a) based on the light absorption and decay of a light wave in the high-Q resonator and the photo of experimental spectroscopic set-up (b).](image-url)
The experimental device prototype has been built in the accordance with the scheme of figure 2a and its photo is shown in figure 2b. The resonator has been adjusted for the chosen type of BM, namely CO, and for registration of the first overtone of vibration spectra at 2.33 μm. Testing the device showed the minimal detectable CO content in Ar medium was about 1 ppm with error of order of 20%. The further experiments with the device are continued.

To carry out the diagnosis of COVID-19, the search for a complex of BM is carried out for providing the diagnostic reliability of over 90%, as well as commercial device designs for stationary and mobile applications are to be developed. Preclinical and clinical trials must be fulfilled, too.

Note, the device must use high quality, very low loss, narrow band mirrors to ensure high Q of the optical cavity and sensitivity of gas analysis. For the manufacture of such mirrors with a precision multilayer nanostructure, the most suitable coating method is on the base of magnetron sputtering with reactive plasma assistance [4]. The technological facilities for such coating method are described in our paper [5].

5. Conclusions
The results obtained in this work and the literature data confirm the great potential of plasma and photonic technologies in the fight against infections and diseases that are dangerous to humans. In particular, various types of atmospheric pressure discharges in atmospheric air and other gases can be recommended for disinfecting air in ventilation systems, but subject to measures to protect a person from exposure to harmful products of plasma processing. Plasma methods in the magnetron sputtering form and with reactive plasma assisting are recommended for applying various coatings with a germicidal effect on objects used by humans, and for producing high-quality optics for devices that detect early signs of human diseases using gas biomarkers. Experiments have confirmed the possibility of creating the quick non-contact method for diagnosing human diseases based on the presence of biomarkers in the exhaled air, but it is necessary to search for suitable biomarkers for diagnosing diseases such as COVID-19.

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