Excilamps and atmospheric pressure plasma and their applications in biology and medicine

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Résumé

In the present paper the review of the results obtained at the Laboratory of Optical Radiation at High Current Electronics Institute SB RAS during 2008-2010 years is presented. Main attention pays to applications the excilamps and atmospheric plasma in biology and medicine.

Excilamps [1]

Efficient radiation of Ar_2, Kr_2, Xe_2, KrBr*, KrCl*, XeI*, XeBr*, XeCl*, Cl_2* molecules and I atoms was obtained in rare gas or in rare gas-Br_2(Cl_2, I_2) mixtures. Study of radiation parameters and lifetime period of the manufactured barrier discharge excilamp has been performed. Radiant power for the just sealed off KrCl ($\lambda \sim 222$ nm) excilamp exceeded 100 W was obtained. Maximal radiation power density was of 50 mW/cm^2. UV output power of ~75 W and efficiency up to 10 %, respectively, at $\lambda \sim 308$ nm (XeCl* excilamp) were obtained under excitation by pulses with frequency of 100 kHz. Application of water cooling allows increasing the radiant power of DBD coaxial excilamps. VUV radiant power of ~ 120 W at $\lambda \sim 172$ nm was obtained under excitation by pulses with frequency of ~ 100 kHz. The lifetime of gas mixtures in small-size XeCl and KrCl barrier discharge excilamps over 12000 and 8000 h was demonstrated. Dynamics of discharge formation in KrCl excilamp was studied. The extraordinary characteristics of excilamps led to a lot of applications, which had been demonstrated in a number of recent studies.

Atmospheric pressure plasma [2]

Breakdown of the gaps with a non-uniform electric field filled with air and nitrogen as well as with other gases under high-voltage nanosecond pulses was investigated. It is shown that conditions of obtaining a diffuse discharge without a source of additional ionization are extended at the voltage pulse duration decreasing. A volume discharge is formed due to the gap pre-ionization by runaway electrons and X-ray quanta. A runaway electrons preionized diffuse discharge (REP DD) has two characteristic stages. In the first stage, the ionization wave overlaps the gap during a fraction of a second. The second stage of the discharge can be related to the anomalous glow discharge with a high specific input power. At a negative polarity of the electrode with a small radius of curvature, a volume (diffuse) discharge formation is determined by pre-ionization with runaway electrons which are generated due to the electric field amplification near the cathode and in the gap. At a positive polarity of the electrode with a small radius of curvature, the X-ray radiation, generated at the runaway electrons braking at the anode and in the gap, is of great importance in a volume discharge formation. At the REP DD, the anode is influenced by the plasma of a dense nanosecond discharge with the specific input power up to hundreds of megawatt per a cubic centimeter, by the electrons beam, shock wave and optical radiation from discharge plasma of various spectral ranges, including UV and VUV. A REP DD is easily realized in various gases and at different pressures. This allows forecasting the REP DD application for disinfection, for producing ozone, for modification and cleaning of dielectric and metal surfaces.

Applications [3, 4]

UV inactivation of biological systems by excilamps. VUV or UV excilamps appear as an interesting option to conventional light sources for UV disinfection. Thus, one should distinguish between two different disinfection methods: the inactivation of microorganisms by UV irradiation (e.g. by KrCl*, XeBr*, KrBr* excilamps) or their total VUV-induced photomineralization (by Xe_2* excilamp). The comparative analysis of inactivation by excilamps and other means (plasma processing, laser irradiation, LP Hg lamps) has demonstrated that excilamps are the competitive technical systems. Excilamps based on XeBr* (283 nm), XeCl* (308 nm), KrCl* (222 nm), and Xe_2* (172 nm) molecules were used for bactericide purposes. Recently, the inactivation effect of excilamps was demonstrated for a number of microbiological objects. In [4] it has been carried out a comparison of the bactericide properties of CD- and DBD-driven XeCl*, XeBr*, and KrCl* excilamps and has shown that a XeBr* excilamp (electric input power P_{el} of 60 W, UV radiant exitance 10 mW cm^{-2}) is the most efficient light source for inactivation of bacteria in this series. Concluding this chapter, let us note that some microorganisms and cells possess UVA/VIS repair mechanisms (photoreactivation) that substitute or dissociate thymine dimers. Under these circumstances, excilamps as narrow-band emission sources should be more efficient than wide-band MP Hg lamps. Sure, this problem needs further studies to be done.

UV phototherapy of skin diseases. One of the most effective methods of psoriasis curing is UVB phototherapy. Radiation is absorbed by endogenous chromophores, especially by DNA nucleotides, which lead to suppression of DNA synthesis in epidermal cells, for example in psoriatic plaques. Photochemical reactions of these molecules result in alterations of skin and then lead to the curing effect. Apparently, the DNA damage is the general mechanism at UV curing of skin diseases. Particularly, UV radiation affects the production of soluble mediators, the expression of cell-surface receptors, to induce apoptosis in pathogenetic relevant cells. More than 90% of the DBD XeCl* excilamp radiant energy is within the anti-psoriasis action spectrum. Thus, this excilamp is also a good variant for psoriasis curing, which was proposed for the first time in 1994 by Oppenlaender [3]. An example of UVB curing of psoriasis by the XeCl* excilamp is presented in Figure 1.

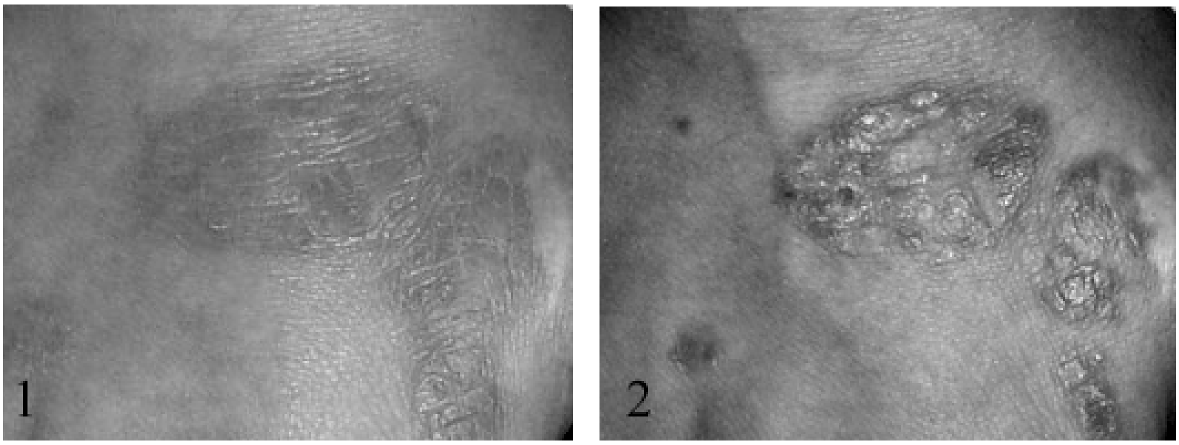

Fig. 1: Example of psoriasis curing by the XeCl* excilamp in Siberian Medical University (BD_compact model, Optical Radiation Laboratory, Russia, output window square 30 cm^2, UV photon exitance of 40 mW·cm^{-2}): after 10 days at suberythermogenic doses treatment (1) and before curing (2).

The merits of such a therapy method are a good tolerance by patients and the use of suberythermogenic doses. In comparison with a XeCl* laser, the excilamp is cheaper and simpler in use. There are no principal restrictions for XeCl* excilamp radiant area increase that allows to create major set-ups both for local and total-body irradiation.

*Narrow-band UVB/UVC photoregulation of plants***.** The conditions of plants cultivation is appreciably influenced by plant biochemistry. The light factor (radiant exitance, spectra) has a very strong regulatory impact on plants. The new facts about a regulatory action of UVB and UVC on coniferous plants, particularly, on accumulation of photosynthetic pigments in needles of Siberian cedar seedlings were obtained. It has been shown that narrow-band UVB from XeCl-excilamp is very interesting for study of increasing the productivity of plants.

References

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