Topic number: W1

Flowing plasma-afterglow as a promising sterilization medium

Kinga Kutasi[(1,*)], Carlos D. Pintassilgo[(2,3)], Vasco Guerra[(2)], Paulo A. Sá[(2,3)], Jorge Loureiro[(2)], Michel Moisan[(4)]

[(1)] Res. Inst. for Solid State Physics and Optics of HAS, POB 49, H-1525 Budapest, Hungary
[(2)] Instituto de Plasmas e Fusão Nuclear - Laboratório Associado, Instituto Superior Técnico, 1049-001 Lisboa, Portugal
[(3)] Dep. de Engenharia Física, Fac. de Eng. da Univ. do Porto, 4200-465 Porto, Portugal
[(4)] Groupe de Physique des Plasmas, Université de Montréal, CP 6128, Succursale Centre-Ville, Montréal H3C 3J7, Québec
[(*)] **kutasi@mail.kfki.hu**

In the last decades, the use of polymer-based heat-sensitive tools in the medical praxis has increased the need for efficient and safe low-temperature sterilization methods that would not only ensure complete inactivation of micro-organisms (e.g. vegetative bacteria, spores, viruses), but also remove all potentially infectious residues (e.g. pyrogens (endotoxins), prion proteins) on the processed instruments. To date, the most common low-temperature sterilization methods are either based on chemical treatments, which call for toxic active agents (e.g. ethylene oxide) and generate harmful effluents, or on exposure to gamma radiation, which can alter the bulk properties of the polymers being sterilized. The use of low-temperature plasmas appears as a promising solution to these drawbacks [1, 2]. Two generic plasma configurations are nowadays being investigated: sterilization taking place within the discharge region [3, 4, 5], or in its flowing afterglow [6, 7, 8].

Although the direct exposure to active plasma leads to a fast inactivation of microorganism or etching of the biological contaminants, the active plasma, as also shown by Bretagnol *et al.* [9, 5], causes the etching of surfaces of polymer-based instruments. On the other hand, the flowing afterglow is particularly well adapted to provide a low-temperature gas and is practically free of charged species, thus avoiding ion bombardment damage to the exposed materials. At the same time, the afterglow, depending on operating conditions, can comprise high concentrations of chemically reactive radicals (e.g. O and N atoms or O_3 molecules in the appropriate mixtures), excited atomic and molecular species (e.g. metastable-state atoms and molecules), and/or high UV intensity radiation, all of these having some potential for the inactivation of microorganisms. Nevertheless, the damage to polymer based tools can also occur in the afterglow plasma, as shown by Boudam *et al.* [10], when the samples happen to be subjected to the plasma early-afterglow (due to an improper set of discharge conditions and an odd system configuration), which is still rich in species capable of efficient etching.

The low pressure post-discharge system proposed by Moisan *et al.* [11] and tested on bacterial spores is composed of a surface-wave microwave discharge generated in a few mm diameter tube [12] and a large volume reactor connected to the discharge tube through a tube typically 2-3 cm in diameter. By varying the length of this connecting tube and the gas flow applied, the composition of the afterglow present in the reactor can be controlled [10, 13]. Discharge modelling represents a powerful tool for the characterization of the whole post-discharge system [14, 15] and for the determination of the plasma composition in the processing zone. Post-discharge models allow the calculation of the spatial distribution of species densities in the whole three-dimensional reactor volume (taking also into account the recombination of active species on the reactor walls, whose efficiency varies strongly with the material used) [16]. With the knowledge of the species densities at each position in the reactor the role of different species and reactions in the sterilization processes can be better understood. Furthermore, the validated models can help designing of the optimal system configuration.

The discharge plasmas generated from N_2-O_2 and Ar-O_2 mixtures are thought to be very efficient, dry and non-toxic sterilizing media [5, 6, 11, 17]. The ternary Ar-O_2-N_2 mixture offers the

further possibility of combining the advantageous properties of the binary mixtures [18], namely, the capability of N_2-O_2 plasmas to emit intense UV radiation and the high dissociation degree of Ar-O_2 discharges. We have conducted experimental and modeling investigations in N_2-O_2, Ar-O_2 and Ar-O_2-N_2 post-discharge systems, aiming at determining the density of the species all along the system, i.e. from the discharge zone to the post-discharge reactor, and the density distributions in the processing reactor.

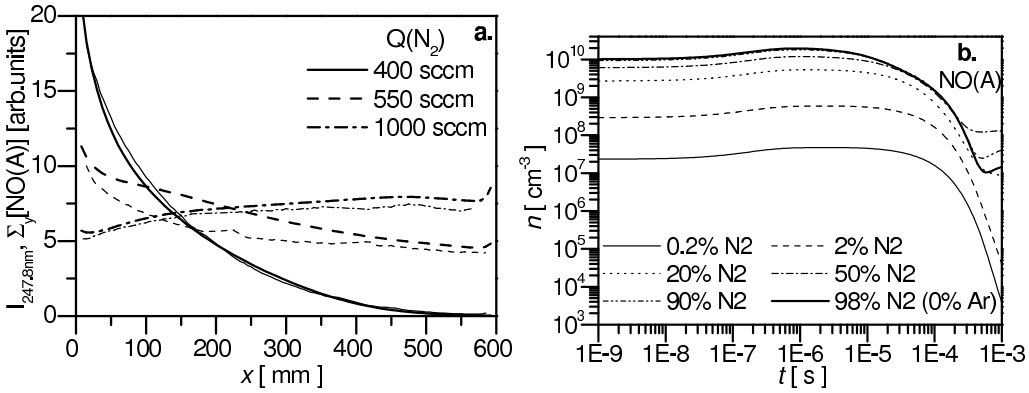

Fig. 1: a.) Measured (given thin line shape) emission intensity at 247.8 nm and (normalized) calculated (same line shape but thicker) density of NO(A) molecules as functions of position x at z = 140 mm (afterglow axis) in the reactor at 2 Torr for three different N_2 gas flow rates Q with O_2 added flow rate set to 8 sccm. b.) NO(A) density as a function of the early afterglow time in the case of an Ar-O_2-N_2 discharge, when the O_2 percentage is set to 2%.

Here we present, as an example, the evolution of the UV emission intensity and the UV radiating species density in the reactor and along the early-afterglow in case of N_2-O_2 and Ar-O_2-N_2 mixtures, respectively, as shown in Fig. 1.

The work has been supported by Hungarian OTKA F-67556 and by Janos Bolyai Scholarship of HAS, and the Portuguese FCT funds to IPFN-LA.

Reference

[1] M. Moisan et al., 2001 Int. J. Pharmaceutics 226 1
[2] O. Kylin et al., 2008 J. Phys. D: Appl. Phys. 41 095201
[3] M. Nagatsu et al., 2005 Appl. Phys. Lett. 86 211502
[4] F. Rossi, O. Kylian, M. Hasiwa, 2006 Plasma Process. Polym. 3 431
[5] F. Rossi, O. Kylian, M. Hasiwa, D Gilliland, 2009 New J. Physics 11 115017
[6] A. Ricard, M. Moisan and S. Moreau, 2001 J. Phys. D: Appl. Phys. 34 1203
[7] M. Moisan et al., 2002 Pure Appl. Chem. 74 349
[8] U. Cvelbar et al., 2009 J. Appl. Phys. 106 103303
[9] F. Bretagnol et al., 2008 Acta Biomater. 4 1745
[10] M. K. Boudam, B. Saoudi, M. Moisan, A. Ricard, 2007 J. Phys. D: Appl. Phys. 40 1694
[11] S. Moreau et al., 2000 J. Appl. Phys. 88 1166
[12] M. Moisan and Z. Zakrzewski, 1991 J. Phys. D: Appl. Phys. 24 10
[13] K. Kutasi et al., 2008 Plasma Process. Polym. 5 840
[14] K. Kutasi, C. D. Pintassilgo and J. Loureiro, 2009 J. Phys.: Conf. Ser. 162 012008
[15] K. Kutasi, V. Guerra, P. Sá "Theoretical insight into Ar-O_2 surface-wave microwave discharges", 2010 J. Phys. D: Appl. Phys. (to be published)
[16] K. Kutasi and J. Loureiro, 2007 J. Phys. D: Appl. Phys. 40 5612
[17] V. Raballand et al., 2008 J. Phys. D: Appl. Phys. 41 115207
[18] K. Stapelmann K, O. Kylián, B. Denis and F. Rossi, 2008 J. Phys. D: Appl. Phys. 41 192005