Biomaterials etching in low pressure inductively coupled discharge

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Résumé

Low-pressure plasma discharges can be applied to remove various biomolecules from surfaces. However, the knowledge of the physical-chemical interaction mechanisms between plasma and biomolecules is still rather poor, which is a major limiting factor for the optimization of this type of plasma treatment.

In the last years several authors presented experimental investigations devoted to isolate potential agents effective in plasma decontamination (UV, radicals, ions, heat) and to identify possible synergic mechanisms between them, but in most cases particle fluxes have been produced outside plasma environments (beam experiments) or the effect on biofilm was studied by physically decoupling the effects of single mechanisms (UV screen, afterglows).

In this work a series of experiments is presented, performed on a double coil planar inductively coupled plasma reactor. Plasma discharge was ignited in oxygen and water vapor containing gas mixtures. These experiments were designed to quantitatively measure the fluxes of different potentially sterilizing species in the plasma phase (ions, radicals, UV and heat) and their interaction effects with a model biofilm (BSA, BrH). Particle fluxes have been calculated using data from Langmuir probe, mass spectrometry, optical emission actinometry and infrared pyrometry measurements.

To understand biofilm removal mechanisms, different experiments have been performed using plasma internal parameters (e.g. fluxes) as independent variables for the decontamination treatments, modyfing one flux component at time while keeping the others constant the influence of synergetic effects between decontamination agents have been measured. Removal rates for biofilms have been measured by means of quartz crystal microbalance used as a quasi-online diagnostic tool in pulsed plasma operation. Profilometry, X-ray photoelectron spectroscopy, atomic force microscope were also used for ex-situ surfaces characterization.

Furthermore the control of the DC bias applied on the sample holder allows changing the energy of the ions (moderate voltages from 10 to 150 V were applied) interacting with the surface.

To understand the interaction, different synergic mechanisms has been postulated and mechanistic model equations for etching rates have been constructed in the well-known context of the Langmuir surface chemical kinetics for plasma-substrate interaction. The results arising from plasma sterilization experiments (ER) have been confronted with the models via linear multiple regression. In order validate a unique model for plasma surface reaction mechanism data fits have been tested rigorously after significant parameter estimates were regressed. A series of non-parametric statistical tests has been applied to determine which model mechanism describes accurately the behavior of the etch rate in our plasma system.

Within the confidence limits of the statistical method implemented for validation, ion assisted chemical etching operating in an ion limited regime proved to be the mechanism which describes more accurately the etching rates for our biological substrates.