PREFACE

Special issue on fundamentals of plasma–surface interactions

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Special issue on fundamentals of plasma–surface interactions

A Bogaerts and E C Neyts
Research group PLASMANT
Department of Chemistry, University of Antwerp, Campus Drie Eiken, Universiteitsplein 1 BE-2610 Wilrijk-Antwerp, Belgium
E-mail: annemie.bogaerts@uantwerpen.be; erik.neyts@uantwerpen.be

A Rousseau
LPP, Ecole Polytechnique, 91 128 Palaiseau, France
E-mail: Antoine.rousseau@lpp.polytechnique.fr

Plasmas are used in a wide range of applications. Often, these applications are related to the interaction of the plasma with a surface. This is most evident for applications in materials technology and the microelectronics industry (including, for instance, coating deposition, surface modification and etching) [1, 2], but it is also the case for environmental applications (where plasma is often combined with a heterogeneous catalyst to improve the selectivity, in so-called plasma catalysis) [3], biomedical applications (where the plasma species can interact with e.g. living tissue) [4] and energy applications (e.g. in fusion reactors) [5].

To improve these various applications, good insight is needed into the underlying plasma–surface interactions. This can be obtained by both experiments and computer modelling. Experimental research often involves a combination of plasma diagnostics on the one hand, such as optical emission spectroscopy (OES), atomic absorption spectroscopy (AAS), mass spectrometry (MS), laser induced fluorescence (LIF), laser scattering techniques (e.g. Thomson or Rayleigh scattering), Langmuir probes and retarding field energy analysers, and surface analysis tools on the other hand, such as Fourier transform infrared spectroscopy (FTIR), x-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Raman spectroscopy, Rutherford backscattering spectroscopy (RBS), elastic recoil detection (ERD), secondary ion mass spectrometry (SIMS), attenuated total reflection (ATR) and x-ray spectroscopy. Indeed, the combination of plasma diagnostics and surface analysis tools allows a connection to be made between the plasma behaviour (e.g. the important plasma species and their fluxes and energies to the substrate) and its effect on the surface.

Computer modelling is also often based on a combination of plasma (chemistry) modelling and plasma–surface interaction modelling, where the output of the plasma chemistry model (i.e. species fluxes and energies towards a substrate) can be used as input for the plasma–surface interaction model. The latter type of model can be on the atomic level, ranging from highly accurate but time consuming ab initio simulations for very small systems to more approximate classical molecular dynamics (MD) simulations for much larger systems, but also on a more phenomenological (macroscopic) level, or a combination of both, where the output of atomistic models can be used as input for phenomenological models. In this special issue, examples of both experiments and modelling for a better understanding of plasma–surface interactions are presented for various applications.

The most straightforward applications are for coating deposition, surface etching and modification, which are widely used processes in materials technology, the microelectronics industry and nanotechnology. This special issue contains examples for coating deposition by both low pressure plasmas [6–9] and atmospheric pressure plasmas [10, 11], surface functionalization [12], etching [13] and nanostructure growth [14]. However, a good insight into the plasma–surface interaction processes is also crucial in other application fields, as is demonstrated in this special issue for plasma catalysis [15–17], plasma medicine [18–20], plasma in liquids [21, 22] and fusion plasmas [23].
First of all, this special issue contains a number of review papers on (experimental or modelling) studies of plasma–surface interactions for the various applications mentioned above. Britun et al [6] give an overview on the various plasma diagnostic techniques used for understanding the plasma–surface interactions in both non-reactive and reactive HiPIMS plasmas. Karahashi and Hamaguchi [13] present a review on ion beam experiments to analyse specific surface reactions, because it is difficult to analyse individual surface reactions separately in a plasma system. To illustrate how such experiments can be used to study fundamental surface reactions, the authors present data for silicon etching. Ostrikov [14] illustrates, for the specific example of the growth of single-walled carbon nanotubes, how a combination of modelling, plasma diagnostics and surface microanalysis can give a better insight into plasma–surface interactions at the nanoscale. Two review papers [15, 16] discuss the state-of-the-art for plasma catalysis. Neyts and Bogaerts [15] present an overview of the various plasma–catalyst interactions that have been reported in the literature, and on the modelling approaches that have been applied for studying these plasma–catalyst interactions. Thevenet et al [16] focus on particular applications such as volatile organic compound (VOC) removal and indoor air treatment, and illustrate that sequential plasma–catalyst coupling is a great step forward for optimizing the process and also for understanding the key scientific issues in plasma catalysis. Belmonte et al [21] discuss the various plasma–surface interactions in liquids. Special attention is paid to nanoparticle synthesis, for which a general sketch on the formation mechanisms is proposed. Finally, Nordlund et al [23] present an overview on different modelling approaches for plasma–surface interactions in fusion plasmas.

The majority of the papers in this special issue deal with experiments. Many different techniques have been applied to obtain better insight into plasma–surface interactions, including both plasma diagnostic tools, such as OES [6–8, 11, 22], AAS [6], MS [6, 7, 13, 18], laser based diagnostics [6, 17], electrical and calorimetric probes [6, 8], a retarding field energy analyser [8] and optical shadowgraphy [22], as well as surface analysis tools, such as FTIR [8, 10, 11, 13, 19, 20], XPS [10, 12, 13], (micro-)Raman [8], RBD [8], ERD [8], dynamic water contact angle measurements [12], SEM [19, 20], ATR [19] and SIMS [20].

In addition to experiments, computer modelling can also contribute to a better understanding of plasma–surface interactions, as is demonstrated by several papers in this special issue. Typical computational methods for describing plasma–surface interactions include ab initio simulations, as outlined in the reviews by Neyts and Bogaerts [15] and by Nordlund et al [23], classical MD simulations [9, 12, 15, 23], Monte Carlo modelling [23], mesoscopic surface models [17] and multiscale modelling, based on rate equations, parametrized from lower-level simulation methods [23].

In general, we can conclude that both experiments and computer modelling are crucial for obtaining a more fundamental insight into plasma–surface interactions. Indeed, computer modelling can yield information that is experimentally very difficult to achieve, due to possible disturbance of the mechanisms. Moreover, it can study processes at the atomic scale, with very high (spatial and temporal) resolution. Finally, it also allows one to separate processes, which are in reality closely interlinked, and hence to study the individual processes. On the other hand, computer modelling always needs to be validated by experiments before it can be used to make valuable predictions. Therefore, we believe that a combination of experiments and modelling is the ultimate approach for obtaining a better understanding of plasma–surface interactions, as is also demonstrated in this special issue by Dufour et al [12], Ostrikov [14] and Guerra et al [17].
Finally, we would like to thank all the contributors to this special issue, as well as the editorial staff, for their support in the preparation of this special issue. We sincerely hope that you will enjoy reading this special issue and that it will be a helpful guide for young researchers who want to contribute to a better understanding of plasma–surface interactions for improving the various applications of plasmas.

References