Final report FP7 Marie-Curie IEF
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Project acronym: "BioFuS"
Project title: *Biofunctionalized surfaces: a multiscale modeling approach*

1 Introduction

The aim of the Marie-Curie project entitled *Biofunctionalized surfaces: a multiscale modeling approach* (in short BioFuS) was to investigate the properties of biologically modified surfaces, surfaces on which biomolecules have been attached. The interest on these biomaterials is high with respect to their potential applications ranging from bio-electronics and bio-sensors to templates for programmable self-assembly. From a theoretical point of view, though, the challenges related to modeling such biomodified materials are complex. In this project, the tools for the investigation should be purely computational utilizing different approaches, spanning different time and length scales and ranging from single- to multiscale schemes. The choice of the scheme used is based on the type of properties under study and the desired accuracy. Different types of biomolecules (from a single nucleotide to a short sequence of double-stranded and single-stranded DNA, and small peptides) attached on a variety of surfaces, metallic (gold) as well as non-metallic (carbon-based and silicon), were to be characterized and studied, while various factors affecting these biomaterials were proposed to be examined. The goal was an in depth understanding of the structure, mechanical stability, and properties of biofunctionalized surfaces and a guide to experiments for potential biotechnological applications. In order to pursue this goal many preliminary tests and a check or update of the necessary computational tools and schemes was essential.

2 Objectives

2.1 Soft-matter part

The project has started by testing and optimizing the tools for the investigation of biofunctionalized surfaces. Since one of the schemes center in the investigation would be Molecular Dynamics, the question of the classical force fields that would be optimum for describing the systems under investigation was tackled. At the large scale the biologically modified surfaces would be surrounded by solvent and/or ionic solution, thus a good description of such solutions would be important for the project. To that end we have continued our previous work on classical ionic force field optimization. Briefly, we have modeled ions in explicit water and have used both single-ion and ion-pair thermodynamic properties as compared to relevant experimental data to obtain well optimized force fields for ions of biological interest. Specifically, by starting with force field parameters that lie on the free energy of solvation curves of single-ions and modified combination rules for the ion-pair, we were able to obtain activity derivatives using the Kirkwood-Buff theory of solutions. Our results match well with the experimental values leading to good force fields for the ions and an additional novel approach in the area of force fields optimization [Fyta & Netz, J. Chem. Phys., **136**(11) (2012)]. In order to obtain an additional understanding of the details in the optimization procedure, we have carefully looked at the structural details of the ionic solutions and the obtained Kirkwood-Buff integrals for different relevant to BioFuS ion-pairs. We have also made a further step in checking the transferability of the derived ionic force fields in a range of ionic concentrations [Fyta, Europ. Phys. J. E **35**, 21 (2012)].

2.2 Condensed-matter (material) part

A key issue in the BioFuS project would be the mechanical stability of different biomaterials, specifically when these are put under mechanical load. This is of fundamental interest in biotechnological applications, as there are different conditions in which the biofunctionalized surfaces might operate that could affect their function and properties. A first step towards this goal was the investigation of how the properties of pure (non-modified) materials are affected by an external load. Surfaces of interest to BioFuS are amorhous and nanocrystalline carbon ones as these materials can also be tuned - by varying their density or inclusion - to obtain desired properties. We have started the investigation with bulk materials, namely diamondlike carbon and diamond nanocomposites. Using tight-binding Molecular Dynamics simulations we have modeled their behavior under tensile strain and looked at their optoelectronic properties. As probes, we used the optical gap and Urbach energy, the latter being a measure of the disorder in these materials. We were able to identify how these properties are affected by the strain up to their fracture point and provide a measure of the inherent disorder as a function of the structural details in the materials [Mathioudakis and Fyta, Diam. and Relat. Mater. **23**, 50 (2012); J. Phys.: Condens. Matter **24**, 205502 (2012)].

3 Additional goals

Apart from the studies that involved the Marie-Curie project, the involvement in other investigations and additional collaborations offered interesting possibilities for a deeper involvement in projects which are complementary to BioFuS. Biologically modified surfaces are of a high interest in the process of DNA translocation through narrow pores, which has a high potential in providing novel ways for an ultra-fast sequencing of human DNA. In order to read-out the DNA bases, though, the surface of the pore should be biofunctionalized. An intensive study towards this goal is being done by various groups. To this end, and moving on with our own theoretical investigation of the translocation process, we have reviewed the most important key studies [Fyta, Melchionna, and Succi, J. Polym. Sci. B **49**, 985 (2011)].

As an additional study on the different properties, mechanical and optoelectronic, of equilibrium amorphous and nanostructured carbon materials (relevant also to the BioFuS project, as mentioned above) we have provided an overview of relevant studies [Fyta *et al*, Surf. & Coat. Techn. (2011); DOI: 10.1016/j.surfcoat.2011.02.026]. This has provided an initial step from which we could continue our investigation on relevant materials under external load.

In a collaboration with another Marie-Curie project in the host group, we have extended our work on the optimization of classical ionic force fields in the case of divalent cations. The outcome would be of a high biological interest as polyvalent, specifically divalent, ions play an essential role in physiological processes such as protein folding, modulation of enzyme activity, signal transduction [Mamatkulov, Fyta, and Netz, in preparation].

Apart from the research aspects of the fellowship, the researcher has taken part in outreach activities organized by the host University and other organizations. These were events having graduate students and junior researchers as target groups. In these events, the researcher presented her experience with a Marie-Curie fellowship and provided insightful hints for preparing and writing a successful scientific proposal.

4 Conclusion/Impact

Overall, during the BioFuS project, a comprehensive work has been carried out towards the utilization of various computational schemes for the investigation of biologically modified surfaces. The results of the project are expected to have an impact on effective atomistic modeling of the solvent environment of these surfaces. It is envisaged that the methods proposed will be useful tools in accelerating discoveries associated with atomistic approaches to various systems in Biophysics as well as Materials Science. The different but complementary investigations of the soft-matter and condensed matter parts of the BioFuS project provide an initial in depth investigation for a further integration of both these parts in forming and introducing the biofunctionalized surfaces. The ultimate goal of the Marie-Curie project, the in-detail study of these surfaces could not be pursued for practical reasons. The actual running-time of the project was about 8 months, as the researcher obtained an academic position at a university in the host country and the BioFuS project had to be terminated quite early. Accordingly, these 8 months were not sufficient for concluding the project, but were important in setting the base for the further exploration of biofunctionalized surfaces in the Marie-Curie fellow's own research group in the near future. This investigation will supplement the outcome of the BioFuS project promising an important impact on the various novel biotechnological applications as the ones mentioned in the introduction.