The challenge of nanostochasticity: Complexity concepts and methods in the characterization and modeling of random-like nanostructured surfaces and materials

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During the last twenty years, we have been witnessing a tremendous advancement of nanotechnology with impact on several scientific and technological areas such as electronics, photonics, tribology, and composite materials to name just a few. The common basis in all cases is the novel properties and functionalities caused by the nanostructuring of surfaces and bulk of materials involved in these applications. However, the benefits of nanostructuring are challenged by the missing of understanding and controlling the stochastic effects which prevail on nanoscale dimensions. The statistical origins of these effects are coming from the small amount of materials involved in nanoprocesses which allows for enhanced fluctuations and variances in material density and compositions as well as in fabrication processes. The latter lead to random-like stochastic nanomorphologies which degrade the repeatability of nanostructured devices and undermine the ability to control and optimize their performance. A first but critical step to face with the challenge of nanostochasticity is to provide the proper mathematical and modelling tools enabling the quantitative characterization of the random-like nanostructure morphologies promoting their understanding and the control of their fabrication and properties. The key idea of this work is that nanostochasicity is coupled with the presence of spatial correlations bringing nanostructure morphologies between fully ordered and fully random extremes. This means that the recent advances in nonlinear dynamics and complexity theory can inspire new approaches to characterize and model nanostructure morphologies and pave the way to ther deeper understanding. In particular, in this work we will try three fundamental concepts of nonlinear and complex systems in nanostructure characterization. First the essential ingredients of a chaotic system (stretching and folding of trajectories in phase space) will be properly used to build a methodology for the characterization of the spatial complexity of rough nanosurfaces which are considered the initial conditions of the chaotic system [1]. Second, we will focus on the information content of nanostructure stochasticity and use the concept of multiscale Shannon entropy to define a measure of spatial nanocomplexity quantified by the deviation from the average spatial symmetry of nanomorphology [2]. Finally, we will highlight a hidden aspect of nanostochasticity playing though a critical role in biomimetic nanotechnology. We mean the embedding of nanostructures in morphologies with larger scales consisting what has been called hierarchical surfaces and materials. A theoretical framework and toolset for the definition, classification, characterization and modeling of hierarchy in surfaces is developed and validated. Special emphasis is given on the nonlinear character of hierarchical surfaces and the new physics of the interaction between hierarchy levels it implies [3]. The above complexity-based tools for nanostructrure modelling and characterization will be applied in a large variety of nanosurfaces produced either by plasma treatment of polymer films or wet etching of metal materials while their added value will be evaluated and discussed.

References

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