Plasma Engineering of Surface Properties by 3D nanostructures

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Abstract: The properties of the bulk materials can be effectively modified by plasma processing of the surface and near-surface structures. In this contribution, we report on low-pressure radiofrequency (RF)-plasma deposition and phase modification of near-surface 3D nanostructures, whose morphology and phase composition depends on the plasma parameters, as well as the type of the substrate modified.

1. Introduction

Plasma treatment of exposed metal surfaces enables non-equilibrium thermos-dynamical interactions, among others realization of thin films or 1D, 2D or 3D nanostructures. Due to the vast parameters space considering the parameters of plasma discharge conditions, such coatings promise practically unlimited possibilities considering phase and chemical composition combinations.

Thin superficial layers are generally accepted solution to effectively cover, modify, and protect the metal surface for various applications. One of the important potential applications emerged in energy sector, where 3D plasma-synthesized superficial carboniferous nanostructures were demonstrated as AC line filtering capacitors [1], as binder-free electrodes for ion batteries [2], and high frequency for AC line-filtering applications [3]. Here, we use in-house developed RF-plasma system to deposit 3D carboniferous nanostructures on the metallic surface. By modifying the plasma parameters, and the type of the metal substrate, we explored the morphology-plasma conditions dependencies.

2. Methods

An RF-driven low-pressure plasma was used to develop different carbon nanostructures, including carbon nanotubes, carbon nano-walls and nanocones, as a result of varying the plasma parameters. Precursor gas methane and gas mixture of methane and nitrogen have been applied to improve the surface properties and adhesion of carbon nanostructures: methane as active gas and nitrogen as buffer gases. The mixture has a critical effect on the morphology of the carbon nanostructures. Out of explored possibilities, methane showed the best results for the deposition of uniform and continuous carboniferous deposits.

The successful deposition of nanostructures by the plasma deposition process was verified by a scanning electron microscope (SEM) used to observe the morphology and analyze the chemical composition of deposited structures, and Raman spectroscopy to determine the phase composition and the quality of the deposits. Where sample preparation was possible without introducing sample-preparation processing artefacts, we analyzed the samples by the transmission electron microscope (TEM) to verify the nature and composition of the carboniferous 2D materials.

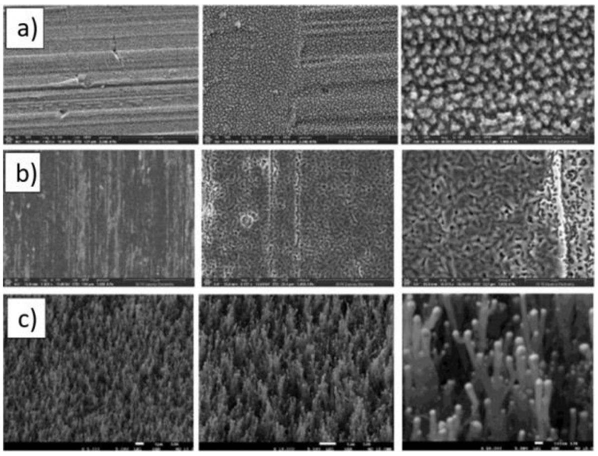

Fig. 1. Examples of 1D, 2D and 3D carbon nanostructures grown on metal substrate: (a) nano-cones grown on stainless steel substrate, (b) carbon sheets deposited on stainless steel substrate, (c) carbon nanowires (NWs) grown on nickel sheet metal.

3. Results and Discussion

The introduction of the buffer gas resulted in the best carbon deposits in the case of nitrogen, while hydrogen, oxygen and ammonia resulted in the etching of the deposited structures and were not considered further. Figure 1 shows examples of continuous layer of 3D carboniferous nanostructures and their morphology, which, besides plasma parameters, depends also on the substrate type. It is worth to mention that the observed results were obtained at laboratory-scale systems, and the scale-up is expected to suffer from reproducibility issues that are sometimes hard to identify.

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