proceedings

Abstract

Electrochemical analysis of rationally designed ZnO nanostructures for biodegradable cellular scaffolds†

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† Presented at the Eurosensors XXXIV, Lecce, Italy, 10-13 September 2023.

Abstract: This work shows a preliminary analysis of a wet-chemistry synthesized platform based on ZnO nanostructures (n-ZnO) for application in regenerative medicine. n-ZnO stability is investigated by electrochemical in-situ sensing of zinc ions released by n-ZnO soaked in simulated biofluids. Impedance analysis allows detecting subtle changes in the bulk solution impedance in the range 1 Hz-50 kHz, which can be ascribed to the release of ionic species in solution, among which Zn^{2+} ions. In parallel, a voltammetry analysis by low-cost mercury-free screen-printed sensors shows the release of Zn^{2+} ions at not harmful concentrations.

Keywords: ZnO nanostructures; metal oxides crystals; solution impedance; zinc ions determination.

1. Introduction

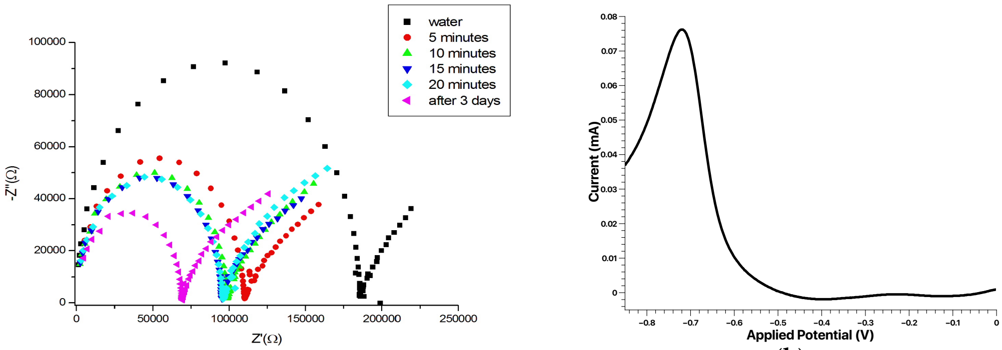
The development of sustainable platforms for biodegradable cellular scaffolds requires to engineer functional materials coupling versatile physicochemical properties, biocompatibility and tunable stability in biofluids. A well-investigated material to this aim is nanostructured ZnO [1]. The ZnO nanostructures (n-ZnO) geometry influences both stability and functionality. For instance, ZnO nanoparticles are toxic toward different kinds of cell lines [2], due to a fast (< 1 hour) dissolution process. On the contrary, 1D n-ZnO are biocompatible, as reported by the Food and Drug Administration (21CFR182.8991) [3]. Nevertheless, dissolution of n-ZnO occurs with a kinetics of the order of some hours [4]. This can modify the zinc homeostasis, and lead to reactive oxygen species, which can trigger apoptosis [5]. In this scenario, there is still a lack in the knowledge of n-ZnO stability when used as is or as filler within biocompatible matrixes. To fill this knowledge gap, this preliminary study leverages electrochemical detection methods, based on impedance and voltammetry, to provide a first glance of the stability of n-ZnO in aqueous solutions.

2. Materials and Methods

n-ZnO growth is carried out with a 250 mL solution in ultra-pure DI water with resistivity at 25 °C > 18.2 MΩ · cm (Direct-Q® 3 UV Water Purification Systems, Merck Millipore). The solution contains 15 mM zinc nitrate hexahydrate (Sigma Aldrich, ≥ 99.0%), 7.5 mM hexamethylenetetramine (Sigma Aldrich, ≥99.0%), 0.10 M ammonia (Alfa Aesar, 28% v/v in water), 2 mM polyethylenimine (Sigma Aldrich, average Mw ≈ 800, average Mn ≈ 600), 5 mM potassium chloride (Fluka, > 99.0%), 15 mM monoethanolamine (Sigma Aldrich, ≥ 99.0%). The precipitates at the bottom of the container are collected, washed by DI-water, dried at 60 °C for 24 h and calcined at 200 °C for 2 h. The electrochemical measurements are carried out by using the Autolab PGSTAT128N (Metrohm AG).

3. Discussion

The synthesized n-ZnO are analyzed by spectroscopic (UV-vis) and electrochemical methods (cyclovoltammetry). Preliminary impedance measurements are conducted on n-ZnO (at 0.2 mg/mL concentration) dispersion in ultra-pure water by using two identical graphite electrodes soaked in the analysis solution. The solution impedance measurement is conducted from 5 minutes until 20 minutes. The resulting decrease in impedance is measured by the reduction of the diameter observed in the Nyquist plot (Figure 1a), which reports the negative value of the imaginary versus the real parts of the complex impedance. On-going experiments aim at the voltammetric determination of zinc ions, using the Britton-Robinson buffer (pH 7.0) as the background electrolyte [6]. To this aim, anodic stripping detection of zinc on a disposable screen-printed gold electrode shows the zinc ions release from the n-ZnO at ppm-levels (Figure 1b). Whereas in principle, zinc ions in biofluids could pose a challenge for cells, this preliminary study shows that the released zinc ions are at concentrations below the limits that would cause dyshomeostasis. On-going studies are looking at the preparation of n-ZnO/cellulose composites for minimizing such Zinc ions leakage into solution.



(**a**) (**b**)

Figure 1. Direct sensing of n-ZnO effect in aqueous fluids: (**a**) Time-dependent analysis of the impedance of solution containing n-ZnO; (**b**) Preliminary voltammetric determination of zinc ions.

Author Contributions: "Conceptualization, G.A. and B.P.; methodology, V.F., G.P.; investigation, G.P., P.G.M., M.S.; resources, G.A. and B.P.; writing—original draft preparation, G.A.; writing—review and editing, V.F., B.P. P.G.M..; funding acquisition, G.A. All authors have read and agreed to the published version of the manuscript."

Funding: This research was funded by the European Union – NextGenerationEU – fondi MUR D.M. 737/2021 – research project "Zoomer", CUP B79J21038330001.

Conflicts of Interest: "The authors declare no conflict of interest."

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