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The fabrication of metal oxide nanostructures using *Deinococcus radiodurans* bacteria for supercapacitor

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ABSTRACT

The metal oxide nanostructures with high surface-to-volume ratio have been achieved using the *Deinococcus radiodurans* bacteria. In particular, the morphological properties of surface-layer proteins make them an ideal type of matrix for biotemplating the direct chemical synthesis of nanostructures. Surface properties of the metal-oxide nanostructures were investigated by electron microscopy. The surface area of that was also studied by Brunauer–Emmett–Teller (BET) analysis method. The materials were used at the construction of supercapacitor as electrode active materials.

1. Introduction

Storing electrical energy using capacitors has been studied intensively in the last thirty years. Depending on the development of technology, the desired electrode materials contain generally nanoparticles with high surface area and high energy density [1–5]. Recently prokaryotic organisms like bacteria have been explored for the templates and nanostructures [5–7]. The metal oxide nanomaterials obtained by bacterium-based templates can provide strong electrochemical performance; potential applications in batteries, catalysts, sensors and supercapacitors [5,6].

D. radiodurans bacteria are known as radiation-resistant organisms, which are easily cultured. *D. radiodurans* cells have eccentric structures. They are electrophiles, chemoorganotrophic and non-pathogenic [8]. *Deinococcus* often stains gram positive [9], although its cell wall is similar to Gram negative bacteria's cell wall. As reported by Kubler and Baumeister [10,11], the cell envelope consists of the plasma and outer membranes, which include six major layers. The first layer is the cytoplasmic membrane; the second layer is a rigid peptidoglycan containing holey layer; the third layer is the compartmentalized layer and this layer appears to be separated into many fragments; the next layer is the outer membrane; the fifth layer is a distinct electrolucent zone. Finally, the sixth layer is the fragile soft layer which consists of regularly packed hexagonal protein subunits (S-layer), containing carotenoids, lipids, proteins, and polysaccharides. Recently, S-layer proteins have been used as mask for metal and semiconductor nanoarrays [12]. It has been shown that producing nanostructures using S-layer proteins has advantages of high surface to volume ratio. High surface area parameter is very important in order to get good performance of supercapacitors. Therefore, in this study, S-layer of *D. radiodurans* bacteria was used to obtain high surface to volume ratio. The method is easy and safe for supercapacitor active electrode material product yield. NiO nanostructured electrode materials were produced by using Gram (+) *Deinococcus radiodurans R1* (ATCC BAA-816). The bacterium is usually between 1.5 and 3.5 μm in diameter. The highest

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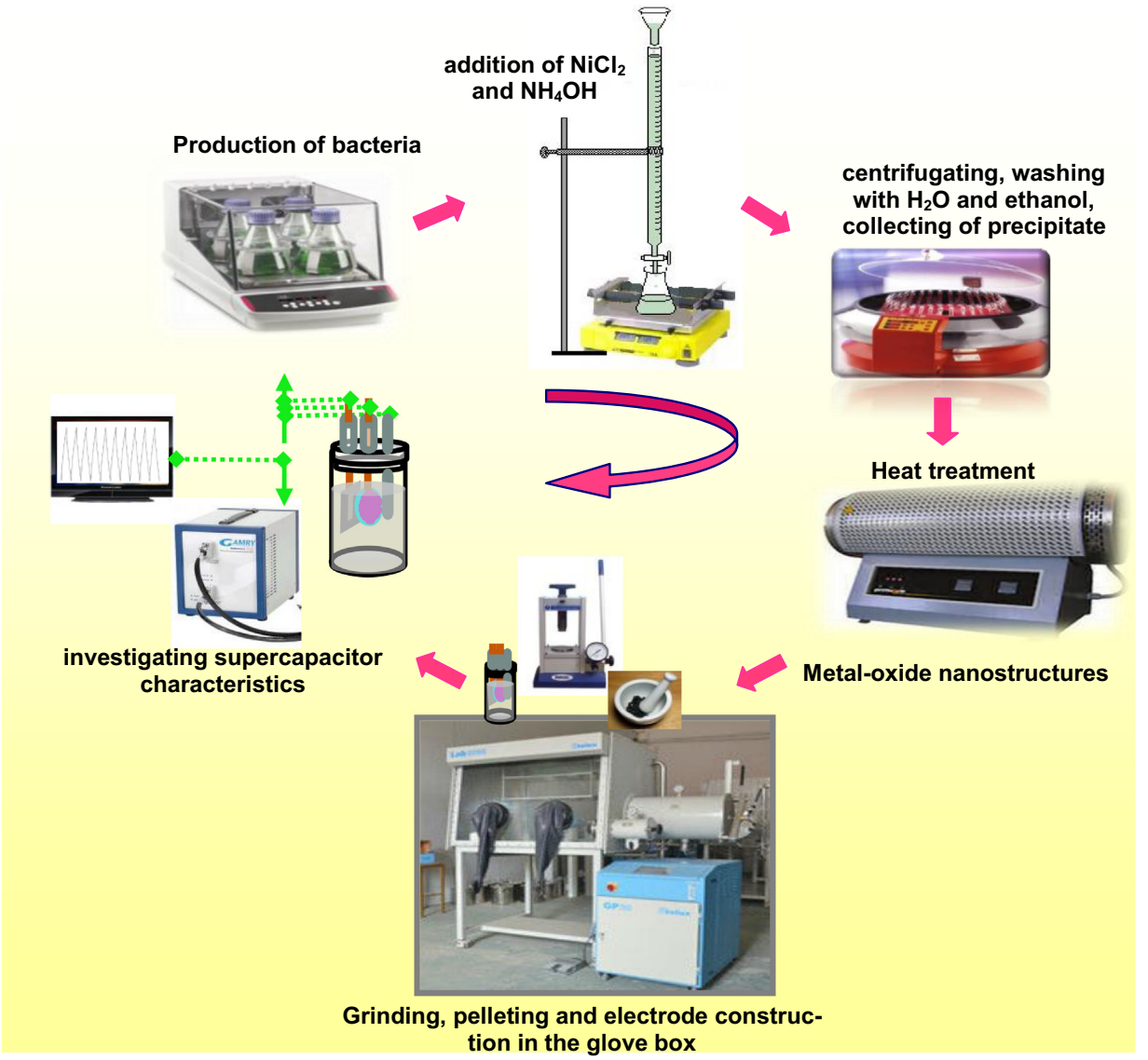

Fig. 1. A representation of supercapacitor fabrication process.

specific capacitance, 237 F/g, was observed at constant current-discharge with a current of 0.8 A/g in 6 M KOH.

2. Experimental

Radiation resistant, Gram positive *D. radiodurans R1* was cultured in a TGY (Tripton Glukoz Yeast) agar and TGY (Tripton Glukoz Yeast) broth at pH 7.5. Media were autoclaved for 30 min at 121 °C under one atmospheric pressure. *D. radiodurans* was grown in shaking incubator at 32 °C and 150 rpm overnight. After incubation, when the optical density of the culture reached to 0.3–0.6 it was transferred into 250 ml flasks containing 50 ml TGY broth. Cultures were agitated on rotary shaker at 150 rpm for 24 hours and then subculture was obtained. Then the bacterial cultures were centrifuged at 9000 rpm for 15 min at 4 °C. The pellets were washed in deionized water twice and finally cells were harvested. Later 200 ml of 200 mM $NiCl_2$ solution was added to the cell suspension of *D. radiodurans* at 10 ml/min by using burette. The mixture was continuously stirred at 800 rpm at room temperature. After the mixture was stirred for 30 minutes, 100 ml of 25 mM NH_4OH solution was added to the mixture at 10 ml/min. NH_4OH was used as a reducing agent. The resulting mixture was continuously stirred at 800 rpm for 36 h. This was followed by centrifugation and collection of precipitate. $Ni(OH)_2$/bacteria precipitate was washed thoroughly with deionized water two times and then with ethanol. Later, the formed $Ni(OH)_2$ ellipsoids precipitate was dried for 12 h in an oven at 60 °C. It was heated from room temperature to 360 °C in air at a rate of 1 °C/min and maintained for 12 h. This was followed by cooling down to room temperature at a rate of 10 °C/min. Later the Ni foam was degreased with acetone, etched with 3 M HCl for