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Nanoporous Silicon Carbide by thermal plasma synthesis for supercapacitors with enhanced storage performance

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Highlights

- Nanoporous structure of silicone carbide
- High power density
- Large surface area
- Electrode materials with enhanced supercapacitors performance

1. Introduction

In response to rapid improvements in renewable energy generation, electrochemical supercapacitors with high power densities have emerged as a promising technology to bridge the energy density storage and variable energy density demands of grid management and hybrid vehicles. Supercapacitors are very appealing for their high power density and long cycle life in a wide range of applications [1]. In this field a notable improvement in performance has been achieved: through recent advances in understanding charge storage mechanisms; and the development of advanced porous structured materials for supercapacitors applications, with high surface area [2]. Carbon materials (carbon nanotubes, carbon nanofibers, hierarchical porous carbons and mesoporous carbons, graphene) are perfect supercapacitor materials because of their good conductivity, excellent cycling stability and large specific surface area [3]. In particular, in recent years silicon carbide (SiC) has received increased attention as a promising electrode material, especially for microsupercapacitor, thanks to its unique electrical, mechanical and thermal properties [4]. However, preparation of high surface area SiC is a major problem. Amongst the various methods used for synthesis of nanoparticles (NPs), the plasma processing appears to be most promising. The thermal plasma technology has several important advantages relative to various other nanopowders synthesis techniques: (i) rapid cooling in the flow direction; (ii) high energy densities in the reaction zone resulting in high precursor flow rates and increased temperatures (it is higher than that in any other method). Both of these cause significant reaction time reduction [5]. The key aspect of this paper is the production of a nanoporous structure of silicon carbide powers prepared using a thermal plasma synthesis (SiC_PL) with high surface area. The SiC_PL exhibits high specific capacitance and excellent cycle stability, making it promising application in energy storage devices, for example including the possibility to implement on-chip supercapacitors by ink printing.

2. Methods

SiC_PL was produced by treating coarse commercially available SiC powder in a pre-pilot plant for the production of nanoparticles. The plant, based on thermal plasma technology, is equipped with a DC torch with a maximum power of 40kW. Tests were conducted in controlled Argon atmosphere, using Helium as secondary gas. Raw SiC powder is continuously fed to the plant through a pneumatic feeding system. Within the plasma the powders undergo to an evaporation/reconditioning reaction with few millisecond residence time and are dragged out from the process gas. The rapid cooling after the reaction zone limits particle

growth. Due to a certain dissociation degree in SiC gas phase, silicon metal could be detected in the product [5]. Different techniques were employed to characterize our nanostructures: transmission (TEM), Raman and FT-IR spectroscopy, X-ray diffraction (XRD), Thermogravimetric analysis (TG-DTG). Electrochemical measurements were performed with screen printed carbon electrodes (SPCEs). The electrochemical cell consists of three-electrodes arrangement with carbon (4 mm-diameter) serving as a working electrode, a carbon used as the counter electrode and a silver as reference electrode that completed the circuit. Cyclic voltammetry (CV) at different scan rates, galvanostatic charge/discharge (GCD) tests and electrochemical impedance spectroscopy (EIS) experiments were performed at room temperature in aqueous electrolyte, using a potentiostat/galvanostat (Autolab PGSTAT 302N).

3. Results and discussion

The nanomaterials show a porous structure (pore size distribution centered at 2.5, 5.6, 9.4 and 22.5 nm- BJH (Barrett–Joyner–Halenda) Desorption pore distribution). A photograph of SPCE, used for electrochemical measurements, is shown in Figure 1(a). The CV curve at 2-10-50-100 mV/s in the potential window of 0-1 V and in aqueous electrolyte are presented in Figure 1(c). The curves subtend a large area and they present a quasi-rectangular shape, supporting a typical double-layer storage mechanism. In addition, the CV curves maintain their shape at each scan rate, revealing a highly reversible charge/discharge response and excellent rate capability. It is worth noting that SiC_PL showed minimal distortion with increasing scan rates. This indicates a fast and efficient kinetics of electron transportation in the electrode materials and excellent ion adsorption–desorption process at the electrode/electrolyte interface.

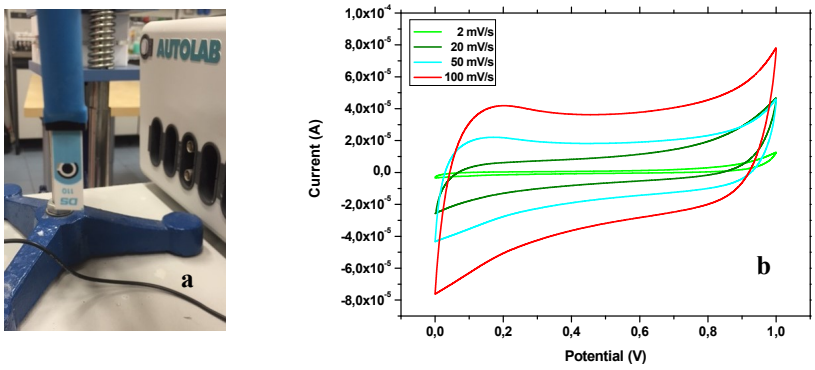

Figure 1. Photograph of SPCE (a); Cyclic voltammogram (CV) SiC_PL at different scan rate, 2,20,50 and 100 mV/s between 0 V and 1V (b).

4. Conclusions

Nanoporous structure of SiC_PL powers were generated on thermal plasma synthesis in a pre-pilot plant. The electrochemical characterization showed for SiC_PL an excellent capacitance performance and high stability in acid media. In particular, SiC_PL electrode exhibits a high energy density of 59 Wh/kg at a power density of 0.52 kW/kg and good cyclability in acid media.

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