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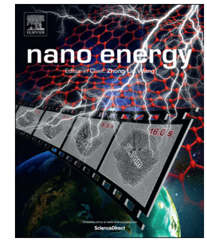

REVIEW

Present and future supercapacitor carbon electrode materials for improved energy storage used in intelligent wireless sensor systems

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Abstract
In this paper we argue that supercapacitors are the best choice for energy storage in an intelligent wireless sensor system. Furthermore we present recent research on carbon allotropes used as electrode. To compare these materials we introduce a theoretical model to estimate the maximum surface area and maximum capacitance obtainable for carbon electrodes. The purpose of the model is to elucidate what material features are crucial for obtaining a higher energy density in electrochemical double layer capacitors which will particularly benefit energy storage in wireless intelligent sensor systems since a supercapacitor will deliver a higher energy density over time and will have a longer lifespan than a battery. The result of the comparison is that composite materials especially nitrogen-doped graphene nanosheets show great promise with their high capacitance compared to other carbon allotropes.

Contents

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Introduction

This review will cover supercapacitors from an intelligent wireless sensor point of view. The basics of supercapacitor operation will be explained and particular attention will be given to electrochemical double layer capacitors (EDLC). Recent research on carbon allotropes as supercapacitor electrode material will be presented and evaluated in relation to a theoretically derived maximum capacitance achievable for carbon electrodes. This will give us a road-map on which materials look most promising today and might give us better supercapacitors tomorrow. The review is structured so that we begin by explaining what an intelligent wireless sensor is and why it is better to be powered by a supercapacitor (see (Intelligent wireless sensors)). We move on to explain the theory of super-capacitors (see (Supercapacitors)), and in Electrode material requirements section we continue by looking at crucial material properties for electrodes. Carbon electrode materials section covers carbon allotropes and their traits as electrode material for EDLC. Maximum theoretical surface area and capacitance for EDLC and Difficulties of comparison of carbon allotropes sections give a theoretical model in comparison with experimental results and a discussion on future electrode materials respectively. Brief conclusions are given in the final part.

Intelligent wireless sensors

An intelligent wireless sensor (IWS) is an autonomous device with internal computing capability and wireless communication which can be combined with energy harvesters that scavenge energy from the environment or which can use stored energy. Today we have battery powered or wired sensors which can provide us different kinds of data from our surrounding. In the near future we want to place several of these sensors in remote places or incorporate them in structures which will make them hard to maintain [1]. The solution for powering these wireless sensors has so far been to rely on batteries, fuel cells or supercapacitors. These solutions give them a limited lifetime and the sensors will mostly send data if it is really necessary to save energy and by that extending their lifetime.

Energy sources with a higher energy density will enable the IWS to perform its task longer. The development of electrode materials that increase the energy density is needed for IWS that need high energy output, like a chemical sensor in the exhaust of a car [2]. Here size and weight is crucial and a rechargeable energy supply with higher energy density will take less space and will weigh less.

A conventional sensor is wired and could be positioned in an airplane, in a car or in a structure like a bridge. In a car you have many sensors and hence a great deal of wires which makes the car more expensive to produce; different sensors also need different wire lengths depending on where they are placed which add up to the pile of cables that is required. The drawbacks of batteries, with limited lifetime, and cable consumption make the idea of a wireless intelligent sensor with a self-preserving power source very attractive from many environmental points of views.

An IWS contains different energy supply parts which are one or several different energy harvesters and energy storage which are connected to a power manager (Figure 1). The power manager either provides the converted energy to the sensor or stores it in a supercapacitor or battery. This setup requires an energy storage which can deliver enough energy directly during the IWS lifetime, which makes a demand for a high accumulated energy density and an energy storage that does not reach end of life due to aging.

Energy harvesting can exploit different energy sources and one has to consider the environment for the IWS in which energy or energies to harvest to get an optimized or at least sufficient output.

Vibration energy harvesting uses vibrations and typically a cantilever optimally tuned for the vibration frequency. Since the frequency is often shifting and unstable, research has been conducted to broaden the bandwidth to obtain a higher power output from these harvesters. The power available for harvesting from ambient vibrations is often relatively low so it has to be accumulated and stored. The advantage of vibration harvesting is that it is available almost everywhere, usually in the low frequency domain [3-7].