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ScienceDirect

Procedia Technology 15 (2014) 248 – 257

Procedia Technology

2nd International Conference on System-Integrated Intelligence: Challenges for Product and Production Engineering

Energy storage options for self-powering devices

Felix Andre[a]*, Frederieke Langer[b], Julian Schwenzel[a], Róbert Kun[b]

[a]Fraunhofer IFAM, Wiener Str. 12, 28359 Bremen, Germany
[b]University of Bremen, Faculty of Production Engeneering, Innovative Sensor and Functional Materials Research Group, Bagdasteiner Str 1, 28359 Bremen, Germany

Abstract

Autonomous self-powered devices may use energy harvested from the environment. However, both the harvested power, and the demanded power are typically nonconstant and not matching. In order to enable a sustained energy efficient operation, an energy storage device as buffer is needed. In general, electric energy can be directly stored in capacitors or through an electrochemical conversion in batteries, which provide a significantly higher specific energy. Numerous different battery chemistries are commercially available and differ significantly in their characteristics. The performance of different commercially available batteries was investigated and is discussed with respect to the needs of self-powered small scale devices. In particular, specific energy and power are typical conflicting objectives for the design of a battery. Most batteries use a liquid electrolyte that is contained in a sealed housing. Typical shapes are coin cells, cylindrical, or prismatic cells. A new class of batteries uses a solid state electrolyte instead and has been commercialized as thin film battery. Through the use of a solid electrolyte, the degree of freedom for the design of the battery is dramatically increased. Moreover, safety, cycling stability, and working temperature range can be improved. Therefore, these types of batteries provide an interesting option for future self-powered devices. Materials and their impact on battery performance and manufacturing options for thin film solid state batteries are discussed.

Peer-review under responsibility of the Organizing Committee of SysInt 2014.

Keywords: Battery;, energy storage; self-powered device; thin film battery; solid state electrolyte

* Corresponding author. Tel.: +49-421-5665-402; fax: +49-421-5665-499.
E-mail address: felix.andre@ifam.fraunhofer.de

Peer-review under responsibility of the Organizing Committee of SysInt 2014.
doi:10.1016/j.protcy.2014.09.078

1. Introduction

Self-powering electronic devices are seen as key enabler for many wireless applications. Main advantage of such a system is that it can be designed as a maintenance-free system. Especially when such systems are used in a large quantity and/or these systems are difficult to access, maintenance-free operation may provide a big advantage by enabling a high degree of operational reliability and reducing maintenance costs.

In general, this can be achieved by two different strategies: Either the energy that can be supplied by the storage system exceeds the total energy needed throughout the life cycle of the device or the device itself is equipped with an energy harvesting device. In the latter case, the total supplied energy has to meet at least the demanded energy on a certain timescale. However, there is typically a mismatch between the supplied and demanded power, as both are in most cases non-constant. In such cases, a buffer is needed. For example, if a device that is powered by a solar cell, driven by natural solar radiation, should be continuously operated throughout the night, a storage device for operation during the night is needed.

When designing a self-powering device, the two components primary energy supply and energy buffer storage have to be scaled in a suitable way. Different objectives are possible for the scaling, such as minimizing space, mass, cost, safety versus power shortage, etc. The optimal system design will depend on the specific objective and can lead to very different designs.

Objective of this contribution is to describe the state-of-the-art of rechargeable lithium-ion batteries with focus on small-scale applications, where the size is strongly constrained. For given energy and power requirements, the storage device should be as small and light as possible. Adequate numbers to compare this are the power and energy with respect to mass and volume, as introduced in the following section 2.1. However, these numbers are affected by the scaling of the device. In general, miniaturization will lead to a decrease, as discussed in section 2.2 for rechargeable lithium-ion batteries. All-solid-state lithium-ion batteries in form of thin film batteries represent a new class of highly miniaturized batteries offering a number of unique features which are highlighted in section 2.3.

Perspectives for the further development of this type through the use of new materials and manufacturing approaches are discussed in section 3.

2. Electrochemical Energy Storage Devices

2.1. Distinction of Energy Storage Devices

Electric energy storage devices can be distinguished between devices that directly store electric energy and devices where the energy is stored in another form and converted into electric energy. The former is the case for dielectric capacitors, the latter is used for example in fuel cells and batteries, where the energy is stored in chemical form and converted into electric energy through an electrochemical conversion.

Pure dielectric capacitors deliver very low specific energy (20mWh/kg) whereas electrochemical capacitors achieve the highest energy density amongst capacitors, reaching about 5Wh/kg [1]. However, these values are still well below the specific energy of batteries (see Fig. 1). Fuel cells are generally not rechargeable and thus not further discussed here.

Key numbers to compare different devices are the amount of energy stored per mass and volume unit, denoted here as specific energy and energy density, respectively. When looking at the dynamics of the process, specific power and power density are of importance.

2.2. Rechargeable Lithium-Ion Batteries

A battery comprises at least two electrodes that are connected by an electrolyte. The working principle is based on the local separation of a redox reaction into reduction and oxidation reaction. Main functional part of the electrodes is the active material, which stores the chemical energy and is oxidized (anode or negative electrode) or reduced (cathode or positive electrode) during discharge. Prerequisite for a battery to be rechargeable is the