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A comparative study of the performance of ultra-porous membranes as separators in supercapacitor devices

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Future development and successful marketing of hybrid-electric and all-electrical vehicles are highly dependent on the performance and cost of the available energy storage technologies. Supercapacitors are one of the most promising energy storage devices due to their high power density, high efficiency, short recharging times, long shelf and cycle life. Combining supercapacitors and batteries can significantly reduce the power stress on the batteries in vehicle applications, in which they are subject to high current pulses in both charge and discharge [1]. The two key properties of supercapacitors for their use in electric vehicles are then power density and cyclability.

The power of a supercapacitor follows the following equation: $P = V^2/4R$, P being the power (in watts), V the voltage (in volts) and R the equivalent series resistance (or ESR, in ohms). In order to get the maximum power from a supercapacitor, one has to increase its voltage and/or decrease its ESR. The ESR is generated by a number of ohmic barriers that take place in the electrical and electrochemical system of the supercapacitor. One of the highest ohmic barrier is caused by the separator layer that prevents the short circuits between the two electrodes.

A number of separators developed for more mature types of batteries (e.g. NiCd, Ni-MH, alkaline, Li-ion) are already commercially available. They display quite different characteristics of morphology, porosity, pore size, mechanical and chemical resistance according to their chemical composition and fabrication process (cf. Fig. 1).

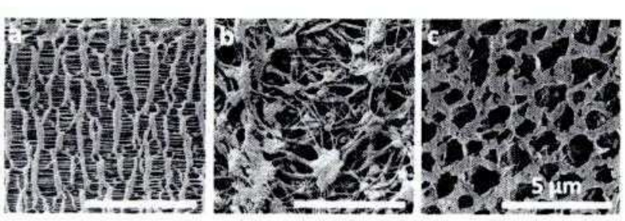

Figure 1. Scanning electron microscope (SEM) images of commercially available separators: a) Celgard 2500 PP separator; b) W.L. Gore PTFE separator; c) Porous Power Tech. Symmetrix PVDF separator. All images have the same magnification (x10000).

The porosity of these commercial membranes is typically between 40 and 70%. Increased porosity is highly desirable in order to maximize the power output in supercapacitor applications. In this work, we investigated the melt-blowing and electrospinning technologies to produce highly porous (over 80 %) nonwoven fiber structures. Fiber melt-blowing is a solvent-free, industrial scale process using a high velocity air flow to stretch the molten polymer into fibers with diameters down to a few microns. Webs of melt-blown fibers can be stacked and consolidated into mats of controlled thickness, porosity and pore size (cf. Fig 2a). Electrospinning uses a high voltage electric field to attract a polymer solution drop emerging from a spinneret towards a substrate. During the material's flight, the solvent is quickly evaporated and the polymer chains are considerably stretched before reaching the substrate, which results in the deposition of ultrafine fibers, usually in the sub-micron scale. By controlling the diameters of the fibers, the porosity and pore size of the mats can be easily tailored (cf. Fig. 2b,c).

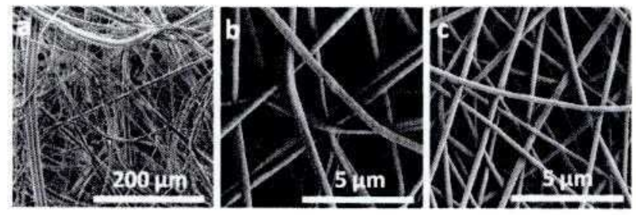

Figure 2. SEM images of melt-blown polyethylene terephtalate (a) and electrospun polyacrylonitrile (b,c) nonwoven mats obtained at NRC-IMI. Average fiber diameters are: 5 µm (a), 480 nm (b) and 340 nm (c). Magnification x250 (a) ; x10000 (b, c).

Although a number of studies have been undertaken to optimize the separators for different battery technologies [2-4], no such testing has been reported specifically for supercapacitors. Moreover, the evaluation of high porosity non-wovens as separators in supercapacitor devices is of major interest. A number of studies have demonstrated their superiority in lithium-ion batteries (Refs 5& 6 are examples among others), but only a few reports discuss their use in supercapacitors [7-8].

In order to evaluate and compare the performance of commercial porous membranes with the newly developed non-woven structures, a specific laboratory cell has been designed, in which the internal pressure of the cell can be controlled and monitored. The results of activated carbon-based cells in both aqueous and non-aqueous electrolytes will be presented, as well as correlations between the morphological characteristics of the porous membranes (thickness, porosity, permeability, pore size, fiber diameter) and their performance as separators in supercapacitor devices.

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