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"Separator-less" Rechargeable Lithium Ion Batteries Fabricated By Electrophoretic Assembly

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Electrophoresis, the motion of charged particles towards an electrode under an applied field, is widely used to characterize the behavior of solutions and suspensions, and has also been used to deposit materials in the form of thin films, coatings, and even bulk products. Our goal in this work is to employ electrophoretic forces to assemble *in-situ* two- and three-dimensional batteries without the use of physical separators. By carrying out electrophoresis of charged-particle systems within a confined volume, it is possible to separate and organize cathode-active and anode-active materials into a variety of device constructions.

The direction of electrophoretic migration was controlled for several particle-solvent systems useful in batteries by adjusting suspension chemistry. The electrophoretic mobility was directly observed using a two-dimensional gold electrode configuration (Figure 1). By applying the suspension to the microelectrodes and imaging particle migration under an applied potential difference, systems having selective deposition of cathodes and anodes were developed. The active materials studied to date include $LiCoO_2$, $LiFePO_4$ and various carbon anodes. The two-dimensional electrophoretic separation of materials shown in Figure 1 also results in separator-less 2D batteries, the characteristics of which will be discussed in the presentation.

We subsequently investigated the fabrication of three-dimensional battery architectures using electrophoretic assembly. Due to improved volumetric utilization of active material and reduced ion transport distances, three-dimensional battery designs may provide improved energy and power density compared to conventional laminated designs[1]. A fundamental advantage of the electrophoretic approach is that physical separation can be produced between the two active electrode materials without requiring the insertion or deposition of a discrete separator film or electrolyte layer.

One model system for electrophoretically assembled 3D batteries uses reticulated vitreous carbon foams as the anode. Figure 2 shows the carbon foam open pore structure and a cyclic voltammogram after heat treating which improves its electrochemical storage capability. To create the 3D battery, the pore space within the carbon foam was infiltrated with a cathode active mixture of $LiCoO_2$ and Super P suspended in a solvent-solid polymer electrolyte solution. An electric potential was applied to electrophoretically separate the cathode from the carbon structure and densify the cathode network.

The lithium salt to polymer ratio is precisely controlled to obtain higher electrophoretic mobility. Details of the process and resulting electrochemical properties will be presented in the talk.

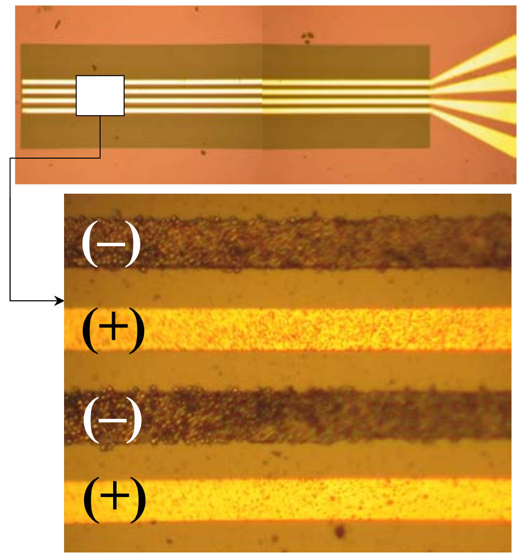

Figure 1 – Schematic representation of the 20 μm width Au microelectrode array on glass and typical micrograph showing electrophoretic deposition of materials at the negative electrodes.

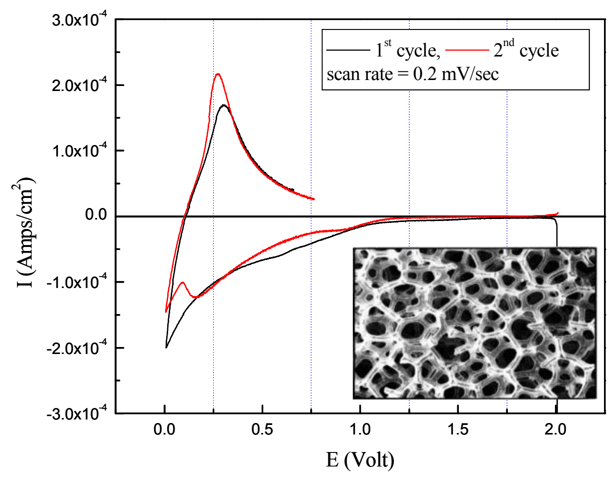

Figure 2 – Cyclic voltammogram of a heat treated carbon foam.

[1] Chiang *et al.*, Int. Patent App. WO 03/012908