

## Emerging Materials

### Room 104-106 - Session EM1-WeM

#### Battery and Energy Storage I

**Moderators:** Seungmin Hyun, Korea Institute of Machinery and Materials, Dongping Lu, Pacific Northwest National Laboratory

8:00am **EM1-WeM-1 Enhanced Thermal Stability of LTO Electrode by Atomic-Layer-Deposited  $\text{Al}_2\text{O}_3$** , *J Yoon, Seunghoon Nam*, Korea Institute of Machinery and Materials, Republic of Korea; *K Park, T Yoon*, ISAC Research Inc.; *H Park*, ISAC Research Inc., Republic of Korea; *S Hyun*, Korea Institute of Machinery and Materials, Republic of Korea

Despite of several inherent advantages as high-rate capability and cycling stability of  $\text{Li}_4\text{TisO}_{12}$  (LTO), the gas generation, as a result of the undesired reactions with commercial electrolytes, has been a challenge for the electric-vehicle (EV) application of the material as a negative electrode for Li-ion batteries. Since the gas generation from LTO tends to be accelerated under high temperature ( $\sim 40 - 60^\circ\text{C}$ ), the thermal stability of LTO should be guaranteed during discharge of the batteries for EVs. In order to mitigate such technical issue, a thin layer of  $\text{Al}_2\text{O}_3$  ( $\sim 1$  nm) was deposited on the LTO electrode by an atomic layer deposition (ALD), and the resulting electrochemical stability was accessed by cycling cells under  $60^\circ\text{C}$ . The retention of capacity after 500 cycles clearly shows that  $\text{Al}_2\text{O}_3$ -coated LTO outperforms the bare one, with the discharge capacity retained 98% of the initial value. Analysis by TEM with XPS corroborates suppressed surface reaction of the coated LTO, while the uncoated one exhibits the phase transformation of (111) to (222) plane, as indicated by earlier literatures.

8:15am **EM1-WeM-2 Electrochemical Performance of Atomic Layer Deposited Zinc Oxysulfide Thin Film in Li-ion Battery**, *Soumyadeep Sinha, J Heo*, Chonnam National University, Republic of Korea

In the recent time, the sustainable and eco-friendly rechargeable energy sources are in high demand to obtain the global environmental pollution free energy storage. Therefore, the choice of Li-ion batteries is not only the power source of the portable electronic gadgets but also for the next-generation electric vehicles. This factor eventually leads to the investigation of new electrode materials to maximize the energy/power density per unit mass as well as per unit area or volume of the active materials. Therefore, the 3D-porous conducting scaffolds coated with active electrode materials or the free-standing electrode materials are the need for the hour. In this regard, zinc (Zn) based materials always have a great importance in any field of energy applications due to its earth abundance, low cost, eco-friendly nature with an easy synthesis process by a variety of deposition techniques. On the other hand, atomic layer deposition (ALD) technique is a great tool for the conformal deposition of a thin film with a precise thickness and desired stoichiometry on any randomly oriented 2D/3D substrates.

In this study, zinc oxysulfide ( $\text{ZnO}_{1-x}\text{S}_x$ ) thin films on stainless steel (SS) current collector were deposited by ALD which were directly used as an anode material in Li-ion battery without any carbon and binder. The electrochemical performance of the anode material was investigated by cyclic voltammetry (CV) measurements against Li in a half cell configuration which showed prominent redox-peaks during both cathodic and anodic process. A stable discharge capacity of above  $500 \text{ mAh g}^{-1}$  was obtained at 100<sup>th</sup> cycle during the charge-discharge cycling performance of this electrode at a high current density of  $1 \text{ A g}^{-1}$  which was significantly higher than the pristine ZnO and ZnS. Thus, this work can be presented as a typical approach to study the electrochemical responses of a double-anion compound active material which can be easily obtained with a desired stoichiometry with high precision by ALD.

8:30am **EM1-WeM-3 Interfacial and Surface Design of Electrode by ALD and MLD for Next-generation Batteries**, *Xueliang (Andy) Sun*, University of Western Ontario, Canada

INVITED

The interface of electrode-electrolyte in Li batteries is root for poor cell lifetimes mainly due to various side reactions. The use of surface coatings to control of the electrode-electrolyte interface is an important strategy to design new electrodes. Atomic layer deposition (ALD) and molecular layer deposition (MLD) are ideal coating techniques to control the interface and surface of the electrodes in various battery systems [1]. This talk will include three parts:

In the first part, I will report our work on the applications of atomic layer deposition (ALD) in Li ion batteries including synthesis of coating materials

such as  $\text{Al}_2\text{O}_3$ ,  $\text{ZrO}_2$ ,  $\text{TiO}_2$ ,  $\text{AlPO}_4$  and  $\text{LiTaO}_3$  and  $\text{LiNbO}_3$  as well as the ALD coating materials to modify cathode (NMC) [2].

In the second part, we will discuss MLD alucone coating on Li-S batteries operating at 55C [3].

In the third part, we will discuss our recent results on ALD  $\text{Al}_2\text{O}_3$  and MLD alucone coatings on Na metal for Na ion batteries and Na-Air batteries [4,5,6].

#### References:

- [1] X. Meng, X.-Q. Yang, X. Sun. *Adv. Mater.* 2012, 24, 3589-3615.
- [2] B. Xiao, X. Sun et al., *Adv. Mater.* (2017).1703764
- [3] X. Li, X. Sun et al., *Nano Lett.*, 16 (2016) 3545-3549.
- [4] Y. Zhao, X. Sun et al., *Adv. Mater.*, (2017) 1606663, 1-7.
- [5] Y. Zhao, X. Sun et al., *Nano Lett.*, (2017), 17, 9, 5653-5659.
- [6] H. Yadegari, X. Sun et al., *Energy Environ. Sci.*, (2017) 10, 286-295

9:00am **EM1-WeM-5 Biodegradable ALD Materials for the Packaging of Thin Film Batteries for Implantable Medical Devices**, *Messaoud Bedjaoui, S Poulet*, Univ. Grenoble Alpes, CEA, LETI., France

Nowadays, biodegradable electronics are highly expected to play an important role to achieve a variety of medical applications and more particularly for transient medical devices. In fact, the implantable biodegradable electronic devices provide shorter-term therapeutic function for predetermined periods without any recourse to secondary surgical removal. In the meantime, the power supply of biodegradable electronics must be adapted by providing compatible energy sources. Thin Film Batteries (TFB) offer a unique combination of energy densities and safety properties that are attractive as an energy-storage. In practice, the ideal solid TFB should be biocompatible, and comprise biodegradable materials that would satisfy device power requirements and benignly degrade thereafter.

The purpose of this work is to evaluate the potential biodegradable materials obtained by ALD (Atomic Layer Deposition)/MLD (Molecular Layer Deposition) techniques for the packaging of TFB. The packaging materials can gradually degrade in an in vivo environment within an expected timeframe, during which the TFB is protected before fully dissolving. A judicious design of the packaging strategies can ensure an equilibrium between TFB lifetime and bioabsorption timelines that therefore conditioning the TFB effectiveness.

First, we explore the biodegradability properties of  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$  and alucone materials obtained as single layers as well as multilayers at low temperature range ( $80^\circ\text{C}$ - $150^\circ\text{C}$ ). In vitro degradation tests employ the exposition to Phosphate Buffer Saline (PBS) and Hank's Balanced Salt Solution (HBSS) for several weeks at different temperatures ( $37^\circ\text{C}$ - $67^\circ\text{C}$ ). In order to establish the biodegradation kinetics, the different structures have been characterized using infrared spectroscopy, scanning electron microscopy (SEM) and complementary analysis (spectroscopic ellipsometry, X-ray photoelectron spectroscopy) before and after exposition to PBS and HBSS saline solutions. The first results seem to prove the biodegradability characteristic of the selected materials. However, the degradation kinetic (from few hours to 4 weeks) may perform very differently depending on the exposition conditions (temperature, PBS, HBSS). It is quite clear for alumina layers in comparison to other materials (Figure 1 and Figure 2). On the other way, we demonstrate in this work that the introduction of multilayer structures ( $\text{Al}_2\text{O}_3$ -Alucone;  $\text{Al}_2\text{O}_3$ - $\text{TiO}_2$ ) permits the monitoring of this degradation. Finally, the developed structures transferred on TFB devices shown that the electrochemical performances is prolonged by using ALD/MLD materials but it instantaneously damaged without packaging.

9:15am **EM1-WeM-6 Enhanced Conductivity in Thin-Film Solid-Composite Electrolytes for Lithium-Ion Batteries by Combining Molecular and Atomic Layer Deposition**, *Simon Hollevoet, K Gandrud*, IMEC, Belgium; *A Patil, KU Leuven*, Belgium; *B Put, P Vereecken*, IMEC, Belgium

Improvements in energy storage are a critical aspect to enable future applications, such as the Internet of Things (IoT), which will lead to an exponential growth in wireless sensors and autonomous microsystems. Currently, planar solid-state thin-film lithium and Li-ion batteries are commercially available but have limited capacity ( $<0.3 \text{ mAh/cm}^2$ ). To meet the future demands in microelectronics in terms of safety, power and energy density the need for all-solid-state 3D thin-film Li-ion batteries arises [1], i.e. there is a need for batteries consisting of thin-films deposited conformally on high aspect ratio substrates.

# Wednesday Morning, August 1, 2018

Here, we present thin-film solid-state composite electrolytes (SCEs), manufactured by combining molecular layer deposition (MLD) with atomic layer deposition (ALD). The SCEs consist of a nanoporous oxide that provides both mechanical stability and a high internal surface area. This nanoporous oxide is coated with a nanometer thin Li-compound layer to exploit the enhanced ion transport at the interface between oxides and lithium salts, as first reported by Liang [2].

In this work, the SCE showed an enhancement in ionic conductivity of up to a few orders of magnitude compared to the pure Li-compound. Moreover, different enhancements were obtained based on different Li-compound/alumina matrix combinations. The nanoporous alumina matrices were obtained through several post-treatments of alumina deposited by MLD. Subsequently the alumina matrix was coated with lithium-compounds (e.g.  $\text{Li}_2\text{CO}_3$ ) by ALD. Thus, this is a novel approach to open up new paths regarding design and development of thin-film solid-state electrolytes. Moreover, the SCEs can be deposited on high aspect ratio features, required for e.g. 3D thin-film batteries, and on conventional particle-based electrodes as protective coating.

[1] Armand, M., & Tarascon, J.-M. (2008). Building better batteries. *Nature*, 451(7179), 652–657. <https://doi.org/10.1038/451652a>

[2] C. C. Liang, "Conduction Characteristics of the Lithium Iodide-Aluminum Oxide Solid Electrolytes," *Journal of The Electrochemical Society*, vol. 120, no. 10, p. 1289, 1973.

9:30am **EM1-WeM-7 Resolving the Mutual Contradiction between Porosity and Toughness of Carbon Textile for Flexible Supercapacitors, Do Van Lam, J Kim, S Lee**, Korea Institute of Machinery and Materials

Activated carbons, which are highly porous materials prepared from carbonization of carbon-rich precursors with chemical reagents, have numerous advantages in the current energy storage technologies, but could realize further gains in flexible electronics if their mechanical properties were highly improved. However, so far, the mutual contradiction between porosity and toughness in activated carbons still remains unsolved. By coating a nanothin film via atomic layer deposition on cotton prior to the conventional chemical activation, we prepared a flexibly activated carbon textile with high specific surface area ( $1065 \text{ m}^2/\text{g}$ ) and greatly enhanced toughness of over 40 folds, thus can be directly used for fabricating high-performance flexible supercapacitors. Our results open a general strategy for resolving the contradiction between porosity and toughness in carbon materials and thus hold great promise towards flexible/wearable electronics.

## Author Index

**Bold page numbers indicate presenter**

— B —

Bedjaoui, M: EM1-WeM-5, **1**

— G —

Gandrud, K: EM1-WeM-6, **1**

— H —

Heo, J: EM1-WeM-2, **1**

Hollevoet, S: EM1-WeM-6, **1**

Hyun, S: EM1-WeM-1, **1**

— K —

Kim, J: EM1-WeM-7, **2**

— L —

Lam, D: EM1-WeM-7, **2**

Lee, S: EM1-WeM-7, **2**

— N —

Nam, S: EM1-WeM-1, **1**

— P —

Park, H: EM1-WeM-1, **1**

Park, K: EM1-WeM-1, **1**

Patil, A: EM1-WeM-6, **1**

Poulet, S: EM1-WeM-5, **1**

Put, B: EM1-WeM-6, **1**

— S —

Sinha, S: EM1-WeM-2, **1**

Sun, X: EM1-WeM-3, **1**

— V —

Vereecken, P: EM1-WeM-6, **1**

— Y —

Yoon, J: EM1-WeM-1, **1**

Yoon, T: EM1-WeM-1, **1**