

Electrochemical Energy Storage and Conversion at EEST2016

The emission of CO₂ and other greenhouse gases (GHG) with large quantity resulting from the use of fossil fuels has significant impact on global climate change. In order to reduce the dependence on fossil fuels, one promising approach is the use of alternative energy sources, such as nuclear, solar, and wind power. However, these energy sources require the use of reliable energy storage devices to store and distribute energy effectively. Under this circumstance, the International Academy of Electrochemical Energy Science (IAOES) was established in 2013 for the purpose of creating a global community to encourage research and partnerships in the field of electrochemical energy science and technology. This organization aims to promote both the academic and technical exchange among members through journal publications, seminars, science and technology trainings, international conferences, student fellowship support, and so forth. In addition, the organization constantly seeks for and provides opportunities for professionals to share competitive knowledge and technology and encourage the implementation of new technologies for scientists and entrepreneurs around the world to join together with a common interest in meeting the rising global energy and environment challenges.

The International Conference on Electrochemical Energy Science and Technology 2016 (EEST2016) is the third conference co-organized by the International Academy of Electrochemical Energy Science (IAOES) and Kunming University of Science and Technology (KUST) in Kunming, China. The conference has attracted over 330 leading scientists from more than 20 different countries to hear presentations from world-renowned researchers in six major technology streams, including fuel cells, batteries and supercapacitors, electrolysis and hydrogen, electrochemistry energy fundamentals, advanced electrochemical materials (nanomaterials), and the electrochemical energy industry. Throughout the 3 day conference, the attendees were immersed in the latest electrochemical knowledge by 6 exceptional plenary talks, over 80 keynote speeches, 60 invited talks, and 107 posters (see Figure 1). The conference also featured a half-day workshop of "Conversation with Editors", focusing on "how to publish your research results in top journals". Six editors from *Nature Communications* (Dr. Luke Batchelor), *Nano Letters* (Dr. Yi Cui), *Advanced Energy Materials* (Dr. Guangcheng Xu), *Nano Energy* (Dr. Khalil Amine), *ACS Applied Materials and Interface* (Dr. Kirk Schanze), and *ACS Energy Letters* (Dr. Prashant V. Kamat) shared their experience on publishing research articles with conference participants.

The objective of this conference (EEST2016) is to stimulate fundamental and applied research toward electrochemical energy science and technology. Undoubtedly, "Secondary Batteries" was one of the most active symposiums. Their talks clearly indicate continuous interest in the research of electrochemical batteries. Although a number of achievements

have been obtained in this field, it is still challenging to resolve some bottlenecks, such as energy density, rate capability, stability and safety, and so on. This symposium reported some of the recent achievements in the context of addressing these challenges.

Prof. Quan-Hong Yang from Tianjin University presented their latest advance on lithium metal anodes. In their work, a three-dimensional (3D) porous Cu current collector is fabricated through a simple chemical dealloying technique from a commercial Cu-Zn alloy tape. The interlinked porous framework naturally formed in the collector can accommodate Li deposition, suppressing dendrite growth and alleviating the huge volume change during cycling. The Li metal anode combined with such a porous Cu collector demonstrates excellent performance while also presenting great commercial potential for use in secondary batteries due to facile integration into pre-existing infrastructure utilizing copper as a current collector. Besides widely used graphene, nanomembranes, such as 2D-like nanostructured materials, have also been fabricated for fast lithium storage. Dr. Chenglin Yan from Soochow University introduced a new self-roll-up technology, which can be widely employed to automatically rearrange 2D membrane materials due to residual stress. The recent important progress of the self-roll-up technology for microenergy storage devices was also given in the talk. Moreover, practical applications of self-roll-up technology for the preparation of single rolled-up lithium ion batteries (LIBs) and flexible batteries were highlighted. Dr. Yan pointed out that "the device could be applied to the many miniaturized devices such as self-powered microdevices, and the next step is to obtain really high energy density and power density devices with high flexibility". In addition, future challenges and development opportunities of rolled-up energy devices and flexible batteries were suggested in the final part of the talk. Besides these interesting reports on experimental results of LIBs, Dr. Siqi Shi from Shanghai University presented an introduction to the combined application of first-principles calculations, statistic mechanics, experiment, and machine learning, followed by an overview of computational work aimed at understanding fundamentals and carrying out the microscopic design of LIB materials. Specifically, Dr. Shi showed how each relevant property is related to the structural component in the material that is computable and how to benchmark the computational results with experimental observations.

With increasing demands for energy storage applications, high energy density and long cycle life are required for rechargeable batteries, which go beyond the limitations of current LIBs with energy density between 140–250 W h kg⁻¹.

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Figure 1. Participants of the International Conference on Electrochemical Energy Science and Technology 2016 (EEST2016) in Kunming University of Science and Technology (KUST), Kunming, China, August 18, 2016.

Li–S batteries have been predicted to afford higher energy densities of 500–600 W h kg⁻¹ and have a low price owing to the use of lower-cost active materials. However, the shuttle phenomenon, where highly soluble polysulfides with different chain lengths diffuse freely between the anode and the cathode, is one of the main reasons for corrosion of the lithium anode and thus contributes to self-discharge and low Coulombic efficiency. Dr. Qiang Zhang from Tsinghua University presented the introduction of nanocarbon materials into the field of Li–S batteries that shed light on the efficient utilization of sulfur by enhancing the conductivity of the electrodes and restraining the shuttle of polysulfides. The lithium anode can be well protected through the use and design of a robust solid electrolyte interface (SEI) that can appropriately control the transportation and deposition of a nanostructured lithium metal electrode. Zhang mentioned, “More attention should be paid to the working interfaces between the electrolyte and electrode to build a safe and robust Li–S battery with very high energy density”. A systematic consideration to rational integration of all working components in an energy storage cell is strongly recommended. It is generally accepted that the addition of LiNO₃ salt into the liquid electrolyte can form an efficient protective film on the surface of lithium metal and thus weaken the shuttle effect. However, the protective films cannot prevent polysulfides from dissolving into the electrolyte. Dr. Zhaoyin Wen from Shanghai Institute of Ceramics, Chinese Academy of Sciences presented a hybrid inorganic solid electrolyte Li_{1.5}Al_{0.5}Ge_{1.5}(PO₄)₃ (LAGP) functioning as both the lithium ion conductor and the separator to block soluble polysulfides. They found no side reaction between the lithium metal and the polysulfides in their system. Therefore, the shuttle effect was eliminated, and the cells demonstrated an excellent Coulombic efficiency of ~100%.

As one of the most promising next-generation battery technologies, Li–O₂ batteries can provide energy density that is comparable to gasoline. Compared with the research history of LIBs, the Li–O₂ battery is still in its early stage. Numerous challenges, particularly ambiguous reaction mechanisms, must be addressed before its practical applications. Although LiO₂ is proposed to be an intermediate discharge product, LiO₂ is thermodynamically unstable and thus difficult to synthesize in the form of a pure phase. Dr. Jun Lu from Argonne National

Laboratory demonstrated that crystalline LiO₂ can be formed without the presence of Li₂O₂ based on a novel templating growth mechanism involving the use of iridium nanoparticles on the cathode surface. Interestingly, the crystallized Li–O₂ is stable enough to be charged and discharged at a very low charge potential of 3.2 V. Dr. Lu expected that this pure phase, crystallized, and stable Li–O₂ could open a new window to obtain high-energy-density batteries based on Li–O₂.

Compared with Li, sodium (Na) is abundant in the earth and cost-effective. Na has similar chemical properties as Li, resulting from the same main group. Na-ion batteries (NIBs) are quickly being recognized as a promising alternative to LIBs for large-scale energy storage application. Unfortunately, the energy density of NIBs is slightly lower than that of the LIBs. Conventional anode materials like graphite for LIBs cannot be used in NIBs because of the larger Na⁺ radius, and thus, optimization of materials employed as a electrode material is urgently required. Poor electron and ionic conductivity are the main reasons for the lower power density and rate capability of SIBs. Surface carbonaceous coating has been shown to attack these problems effectively. Dr. Yu Yan from the University of Science and Technology of China designed a cathode consisting of carbon-coated nanosized Na₃V₂(PO₄)₃ embedded in a porous carbon matrix for NIBs. Double-layer carbon coating allows for quick ion access to the active nanoparticles through the electrolyte and also for quick electron access via a 3D percolation conductive network, leading to good electrochemical performance in terms of the rate capability and cycle life. Yu mentioned that constructing highly efficient and stable electrochemical circuits around the active nanoparticles is required for maximizing the advantages of intrinsic to nanostructured electrode materials. A comprehensive consideration from the structure of electrode materials to the electrolyte is necessary to obtain excellent NIBs. To increase electron conductivity, reduce ion diffusion paths, and promote the cycling stability of NIBs, Dr. Liang Li from Soochow University proposed two surface engineering methods based on surface doping and coating with atomic layer deposition technology (ALD). Taking Na₂Ti₃O₇ (NTO) as an example, it has a high theoretical capacity up to 310 mAh g⁻¹ and a low Na-storage potential (0.3 V vs Na). However, it suffers from poor conductivity and sluggish Na⁺ insertion/extraction

processes. To resolve this problem, Li designed self-supported one-dimensional (1D) NTO nanotube arrays directly on a Ti substrate, which were further engineered by ALD of a TiO_2 nanolayer and subsequent sulfidation. The 1D arrays guarantee fast electron transport pathways and ion diffusion. The voids between nanotubes and the enhanced conductive TiO_2 protective layer allow for the expansion of electrode materials. As a result, the surface-engineered NTO nanoarrays demonstrated excellent Na-storage stability with high rate capacities. Furthermore, a more general approach via hydrogenation to the surface of $\text{Na}_2\text{Ti}_3\text{O}_7$ nanoarrays was demonstrated. The as-hydrogenated NTO can afford a high reversible capacity of 227 mAh g^{-1} and retain a capacity of 65 mAh g^{-1} over 10 000 cycles at a high rate of 35 C. These material and structure designs result in remarkably enhanced electrochemical activity.

In summary, this symposium has demonstrated some important progress in the fields of electrochemical cells, such as Li-ion, $\text{Li}-\text{O}_2$, $\text{Li}-\text{S}$, Na-ion, and so forth. Critical challenges have been addressed in the reports, including improving energy density, developing flexible and on-chip microdevices, resolving the shuttle effect in $\text{Li}-\text{S}$ batteries, elucidating the reaction mechanism in the $\text{Li}-\text{O}_2$ system, and engineering a surface to improve stability. All of the efforts have been completed by researchers working on materials, chemistry, physics, and engineering. We believe that these results will push forward continuously the development of Li-based batteries in the future.

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Notes

Views expressed in this energy focus are those of the author and not necessarily the views of the ACS.

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