them.

HighMag

The Magnesium Charge

Enhancing the Safety and Stability of Mg Batteries: Tailored Protective Coatings

Battery safety issues and challenges: transfer from lithium to magnesium technology

One of the key challenges for expanding any battery technology and transferring it to the wider market is safety. For batteries used in large-scale applications, particularly electric vehicles, it is essential to ensure safe operation under normal conditions while minimizing the risk of severe failure in the event of an accident. Although Li-ion batteries are currently the dominant technology for electric vehicles, their safety remains a concern, as demonstrated by a number of accidents involving intense fires and explosions.

One of the factors contributing to this issue is the high chemical reactivity of lithium, which is one of the strongest reducing metals. To address this challenge, alternative battery chemistries based on less reactive metals can be considered. Magnesium is a particularly promising candidate, combining high volumetric capacity with greater chemical and electrochemical stability compared with lithium metal and other highly reactive metals.

"Ultrathin atomic layer deposition-based protective coatings can shield battery components and boost reliability of next-generation Mg-based energy storage."

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Safety can be further enhanced through the modification of electrode materials with protective coatings. Such coatings can suppress undesirable reactions between the electrode and electrolyte and protect the electrode material from the surrounding environment under abnormal conditions. At the same time, they can improve the stability of the electrode during normal operation, reducing material degradation and with the potential to enhance cycling stability and battery lifetime.

The key parameters of such coatings are their uniformity and thickness. The coating should uniformly cover the entire surface of the active material without leaving uncovered areas, ensuring consistent protection. At the same time, it should be sufficiently thin to allow the transfer of charged ions through the coating during the charge and discharge processes. Therefore, achieving an optimal balance between effective protection and efficient ion transport is essential for the successful application of protective coatings.

Atomic Layer Deposition: A Versatile Tool for Protective Coatings

One of the most powerful techniques for production of conformal, ultrathin thin-film layers is atomic layer deposition (ALD). In its simplest form, ALD is based on the alternating introduction of a volatile metal-containing precursor and an oxygen-containing reactant, such as water or ozone, into the ALD reactor. These precursors react with the substrate or particles surface in a controlled and self-limited process, enabling the growth of a metal-oxide thin films. The thin films thickness is precisely controlled by the ALD parameters, mainly the number of cycles.

Beyond this basic approach, ALD can be adapted to produce a wide range of materials and compositions. For example, molecular layer deposition (MLD) extends the concept of ALD to the deposition of organic materials through the sequential introduction of organic precursors. Combining the two approaches in ALD/MLD enables the deposition of hybrid organic-inorganic materials, providing conformal thin films with tunable chemical composition and improved mechanical flexibility.

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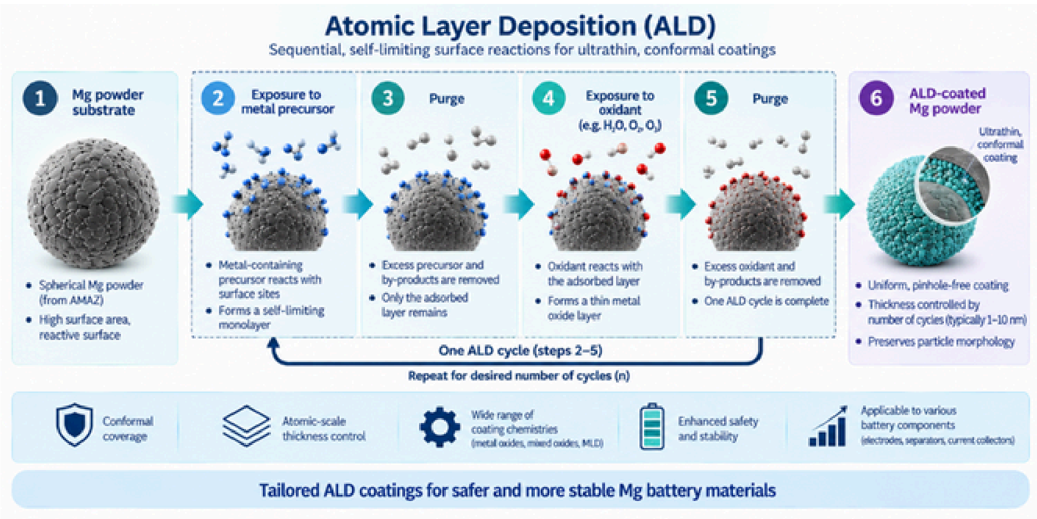
The versatility of these techniques also allows multiple metal precursors to be incorporated into a single coating process, enabling the formation of mixed-metal compounds. In addition, by introducing appropriate non-metal-containing precursors, coatings with different chemistries, such as phosphates, sulfates, and other functional materials, can be produced. This broad chemical versatility and controlled process capability make the ALD and MLD highly attractive for tailoring protective coatings to the specific requirements of battery electrodes.

ALD in the HighMag project: Expertise and Capabilities at Bar-Ilan University

As part of the European Union's Horizon Europe-funded HighMag consortium, Prof. Malachi Noked's group at Bar-Ilan University (BIU) is responsible for developing ALD-based techniques for applying protective coatings to a wide range of battery components using different ALD thin films chemistries. These include Mg powder anodes, various cathode materials for Mg-ion and Mg-sulphur batteries and separators materials.

Scheme 1 presents schematic illustration of the ALD process for Mg powder surface modification. One ALD cycle consists of sequential metal-precursor exposure, purge, oxidant exposure, and purge, and is repeated to achieve a thin, conformal protective coating with controlled thickness.



Scheme 1: ALD Process for Protective Coatings on Mg powder

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By tailoring the coating chemistry, from metal-oxide thin films to more advanced coating systems, together with coating thickness and ALD parameters, BIU researchers aim to develop thin, conformal coatings that enhance the safety and stability of battery components investigated within the HighMag project.

During the project, the most promising ALD thin film will be further developed and upscaled, with the aim of optimizing the ALD coating processes for future large-scale production.

In addition, BIU researchers are investigating how the application of these coatings affects the thermal stability of the coated materials. This allows the actual contribution of the coating to battery safety to be evaluated and helps elucidate the mechanisms underlying its protective effect.

Conclusions

Mg-based battery technologies offer a promising pathway toward safer and more sustainable energy storage, owing to the intrinsic properties of magnesium-based materials and the potential for alternative cell chemistries. Within the HighMag project, researchers at Bar-Ilan University are contributing to this goal by developing conformal protective thin film coatings for electrode and separator materials using versatile ALD-based techniques. The influence of these coatings on material stability and thermal behaviour is also being systematically evaluated by comparing coated and uncoated materials.

This work aims to identify effective strategies for improving the safety and durability of Mg-based battery components and to support their further developments toward practical energy-storage applications, thereby contributing to Europe's transition towards a more sustainable energy future.

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