

Borates in batteries

Global efforts to reduce emissions and the need for improved energy storage for mobile applications are promoting rigorous research efforts in new battery technologies. While lithium-ion batteries have emerged as the principal technology, improvements in performance and safety are necessary for broader market adoption. Commercial and experimental applications of boron-based materials to improve both anodes and electrolytes indicate substantial benefits to batteries.



Surface treatment

When used to modify the surface of graphite, treatment with borates at $<1000\text{ }^{\circ}\text{C}$ results in promising improvements in rate capability, life cycle, and capacity [1-4]. High rate capability is essential in high power applications ie, power tools and hybrid electric vehicles. Increased capacity improves the amount of charge a battery can hold and is important in improving driving range. When applied to the anode or used in electrolytes borates likely improve the surface interface, a critical layer that forms during cycling [5]. In several studies, borates have proven beneficial to the formation of the solid electrolyte interphase (SEI) [6-8].

Graphite anodes are susceptible to lithium deposition and dendrite formation at high charge rates which can short out the cell and cause safety issues [10]. Borate surface coating may protect it from lithium deposition leading to better safety characteristics.

Borate surface coating on graphite may improve the stability of the SEI by participating in formation chemistry or altering morphology [4].

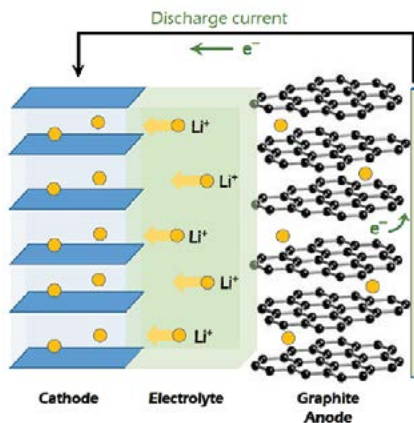


Figure 1: Schematic diagram of a lithium ion battery

The SEI forms a boundary between electrode and electrolyte. In this component of the cell, complex and potentially beneficial electrochemical reactions are expected, whereas reactions occurring outside of this interface are often self-destructive and lead to performance decay [9].

Mechanism

Upon further investigation with scanning electron microscopy, there is no evident change in morphology with borate treatment. Surface area and pore structure analysis indicate borate melts into pore structures and defect sites on the surface of graphite. Reactions during the formation of the SEI are likely influenced by the presence of borate, improving the capacity, rate capability, and life of the battery.

Borates lead to improvements in a variety of battery applications including: Surface treatment of graphite anodes, catalyzing the synthesis of graphite, and as electrolyte additives.

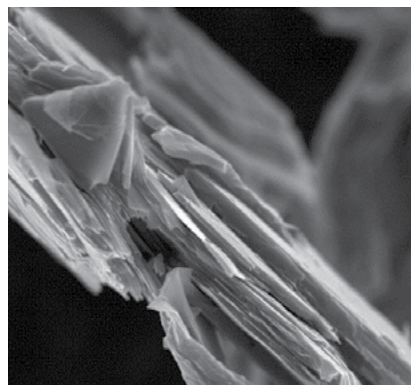


Figure 2: Scanning electron microscopy of borate treated graphite



Graphitization catalyst: Synthetic graphite is made from various materials including coal tar pitch, petroleum coke, and various other carbonaceous products. High temperature heat treatment of graphite contributes to a highly ordered crystalline graphite structure. High temperature graphitization is an expensive and energy intensive process requiring temperatures in the 3000°C range.

Borate addition prior to graphitization improves electrochemical properties and lowers temperatures required for graphitization [11]. In addition to increasing crystallinity, boron is thought to incorporate into the lattice structure of graphite at higher temperatures, initiating greater alignment and changing electronic structure. When residing in the graphite lattice, boron can act as an electron acceptor leading to a specific capacity of 437 mAh/g, higher than the theoretical maximum for pure graphite (372 mAh/g) [12].

Electrolytes: Borate compounds, including lithium bis(oxalato)borate (LiBOB) and related compounds, are widely used in commercial Li-Ion batteries. The decomposition reactions of the anode and cathode are substantially decreased by incorporation of borate compounds into the SEI, greatly improving battery life, performance, and safety [13] [6].

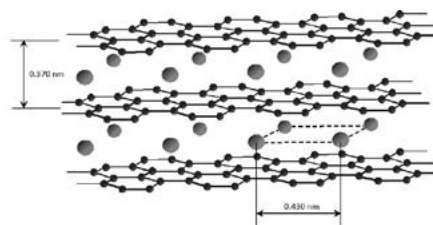


Figure 3: Lithium intercalation into graphite layers, adapted from an illustration in [3].

Works Cited

- [1] J.-S. Yeo, T.-H. Park, M.-H. Seo, J. Miyawaki, I. Mochida and S.-H. Yoon, "Enhancement of the Rate Capability of Graphite via the Introduction of Boron-oxygen Functional Groups," *International Journal of Electrochemical Science*, vol. 8, pp. 1308-1315, 2013.
- [2] M. S. Park, J. Lee, J.-W. Lee, K. J. Kim, Y.-N. Jo, S.-G. Woo and Y.-J. Kim, "Tuning the surface chemistry of natural graphite anode by H₃PO₄ and H₃BO₃ treatments for improving electrochemical and thermal properties," *Carbon*, vol. 62, pp. 278-287, 2013.
- [3] L. Fu, H. Liu, C. Li, Y. Wu, E. Rahm, R. Holze and H. Wu, "Surface modifications of electrode materials for lithium ion batteries," *Solid State Sciences*, vol. 8, no. 2, pp. 113-128, 2006.
- [4] S. S. Zhang, K. Xu and T. Jow, "Enhanced performance of natural graphite in Li-ion battery by oxalato borate coating," *Journal of Power Sources*, vol. 129, no. 2, pp. 275-279, 2004.
- [5] J. W. F. Victor A. Agubra, "The formation and stability of the solid electrolyte interface on the graphite anode," *Journal of Power Sources*, vol. 268, pp. 153-162, 2014.
- [6] M. Nie and B. e. a. Lucht, "Role of Lithium Salt on Solid Electrolyte Interface (SEI) Formation and Structure in Lithium Ion Batteries," *Journal of The Electrochemical Society*, vol. 161, pp. A1001-A1006, 2014.
- [7] J. Arai, A. Matsuo, T. Fujisaki and K. Ozawa, "A novel high temperature stable lithium salt Li₂B₁₂F₁₂ for lithium ion batteries," *Journal of Power Sources*, vol. 193, no. 2, pp. 851-854, 2009.
- [8] Z. Chen, Y. Ren, A. Jansen, C.-K. Lin, W. Weng and K. Amine, "New class of nonaqueous electrolytes for long-life and safe lithium-ion batteries," *Nature Communications*, vol. 4, p. 1513, 2013.
- [9] K. Xu and A. von Cresce, "Interfacing electrolytes with electrodes in Li ion batteries," *Journal of Materials Chemistry*, vol. 21, pp. 9849-9864, 2011.
- [10] M. S. Whittingham, "History, Evolution, and Future Status of Energy Storage," *Proceedings of the IEEE*, vol. 100, pp. 1518-1534, 13 May 2012.
- [11] H. Fujimoto, A. Mabuchi, C. Natarajan and T. Kasuh, "Properties of graphite prepared from boron-doped pitch as an anode for a rechargeable Li ion battery," *Carbon*, vol. 40, no. 4, pp. 567-574, 2002.
- [12] B. Way and J. Dahn, "The effect of boron substitution in carbon on the intercalation of lithium in Li_x(B₂C_{1-2x})₆," *Journal of the Electrochemical Society*, vol. 141, no. 4, pp. 907-912, 1994.
- [13] K. Amine, J. Liu, S. Kang, I. Belharouak and G. Henriksen, "Improved lithium manganese oxide spinel/graphite Li-ion cells for high-power applications," *Journal of Power Sources*, vol. 129, pp. 14-19, 2004.
- [14] H. Mao and J. Reimers, "Use of B₂O₃ additive in non-aqueous rechargeable lithium batteries". Canada Patent EP0805504, 1997.



About U.S. Borax

U.S. Borax, part of Rio Tinto, is a global leader in the supply and science of borates—naturally-occurring minerals containing boron and other elements. We are 1,000 people serving 500 customers with more than 1,700 delivery locations globally. We supply 30% of the world's need for refined borates from our world-class mine in Boron, California, about 100 miles northeast of Los Angeles. We pioneer the elements of modern living, including:

- **Minerals that make a difference:** Consistent product quality secured by ISO 9001:2015 registration of its integrated quality management systems
- **People who make a difference:** Experts in borate chemistry, technical support, and customer service
- **Solutions that make a difference:** Strategic inventory placement and long-term contracts with shippers to ensure supply reliability

About 20 Mule Team® products

20 Mule Team borates are produced from naturally occurring minerals and have an excellent reputation for safety when used as directed. Borates are essential nutrients for plants and key ingredients in fiberglass, glass, ceramics, detergents, fertilizers, wood preservatives, flame retardants, and personal care products.

