Natural polymers for energy storage devices – Professor Eddie Zhang

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The problem

Renewable electricity generation (such as solar and wind) has advanced in power and efficiency while reducing its cost, making it ever more accessible and useful and reducing reliance on coal. The development of smart power grids to support the technology has changed power use in industry and the home, broadening its application. However the keystone is energy storage and this has not developed at the same rate. Batteries have not made any great reduction in size, cost or increase in power, they are also highly toxic and relatively inefficient.

Lithium ion batteries (LIBs) are currently the most important energy storage source for portable electronics electric vehicles, and smart energy utility grids. Silicon (Si) anode and Sulfur (S) cathode are most promising electrode materials for next generation large capacity and high energy density batteries. These materials could reshape current LIBs industry due to its superior theoretical specific capacity, far greater than that of conventional graphite anodes and lithium metal oxide cathodes.

However, they are still far from commercialization due to challenges such as the substantial volume changes during recharging, which causes high stress and even electrode pulverization, resulting in rapid degradation of the electrode and a short cycle life. Dissolution of sulfur and polysulfides shuttling effect are the additional problems to the Lithium-sulfur (Li-S) batteries.

The group

A research group from the Centre for Clean Environment and Energy at Griffith University on the Gold Coast, led by Professor Eddie Zhang are trialing the effectiveness of natural, plant-derived polymers in energy conservation for LIB and Li-S batteries.

Inspired by 16th century Chinese medical doctor, Shizhen Li, the Griffith scientists are turning to nature for solution to improve the performance of the energy storage devices. . The team has identified three natural sources of highly efficient polymers, Gum Acacia (GA) [1, 2], Sodium Alginate (SA, sea algae) [3] and bamboo carbon [4,5}.

The solution

GA is a nontoxic natural polymer from Acacia Senegal (see Fig. 1), a deciduous legume from Northeast Africa that is widely used in food and medicine as a soluble dietary fibre. It has shown a remarkable tolerance to the volume changes and degradation experienced by batteries with Si anodes (see Fig. 2). It also has abundant functional groups for chemical bonding creating a “fibre in concrete” synergetic effect, which enhances mechanical strength and improves the output of LIBs and Li-S batteries.

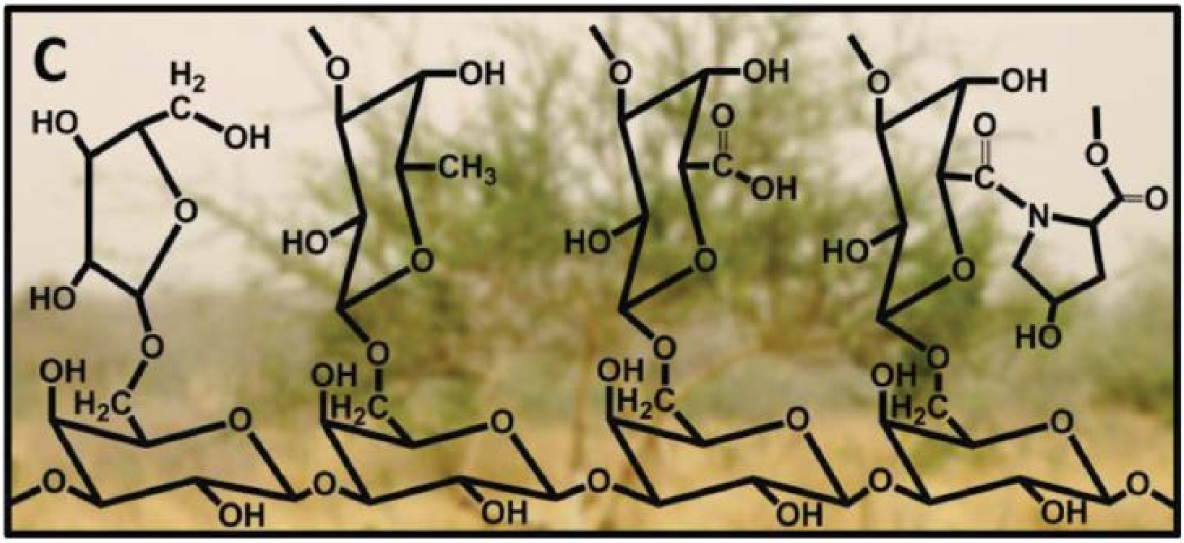

Figure 1 Proposed chemical structure of GA with the background of *Acacia senegal* .

Additionally, GA shifts the electrode fabrication process from the organic solvent process to an aqueous process, eliminating the use of toxic organic solvents and achieving uniformly distributed electrodes with lower impedance. A remarkable cycling performance, i.e., 841 mAh g^{-1} at low current rate of C/5, is achieved throughout 500 cycles for Si based LIBs due to the bifunctions of the GA binder[1],. Due to the unique C-S bonding between the sulfur, polysulfides and GA binder, the GA based Li-S delivered exception performance [2],

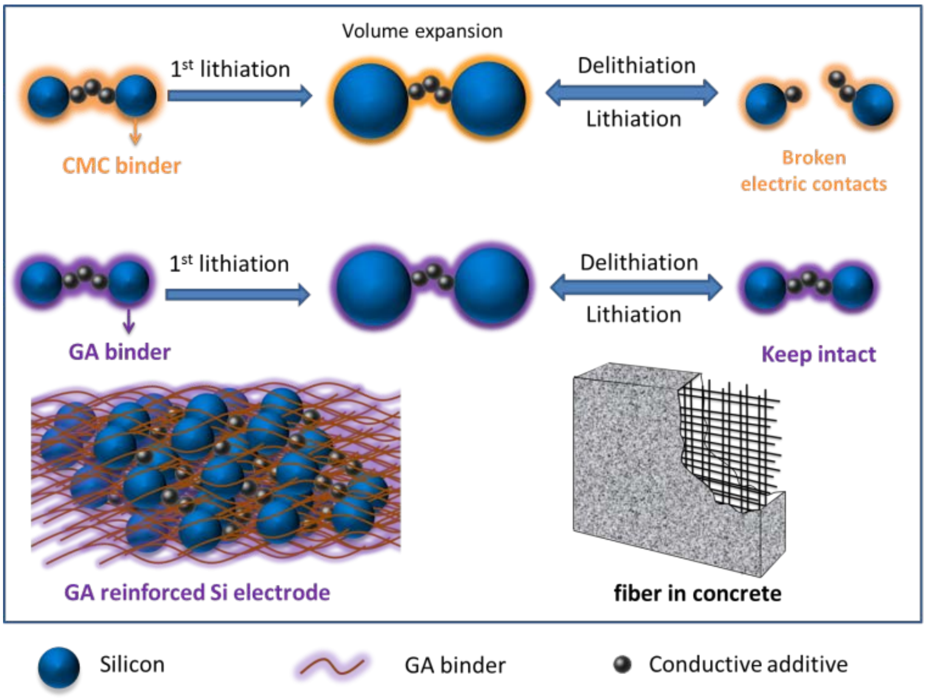

Figure 2. Schematics of the concept to address volume change issue in battery materials. GA with dual functionality could have both the strong chemical bonding and the ductile properties necessary to tolerate the expansion during lithiation/delithiation processes.

SA is a nonconductive binder with excellent mechanical properties, ionic conductivities, achieving superior battery performance. The substance is low-cost, environmentally sustainable and easy to work with. Through a functionalising process with 3,4-propylenedioxythiophene-2,5-dicarboxylic acid (ProDOT) an SA-PProDOT polymer is produced which improves energy density (see Fig. 3).

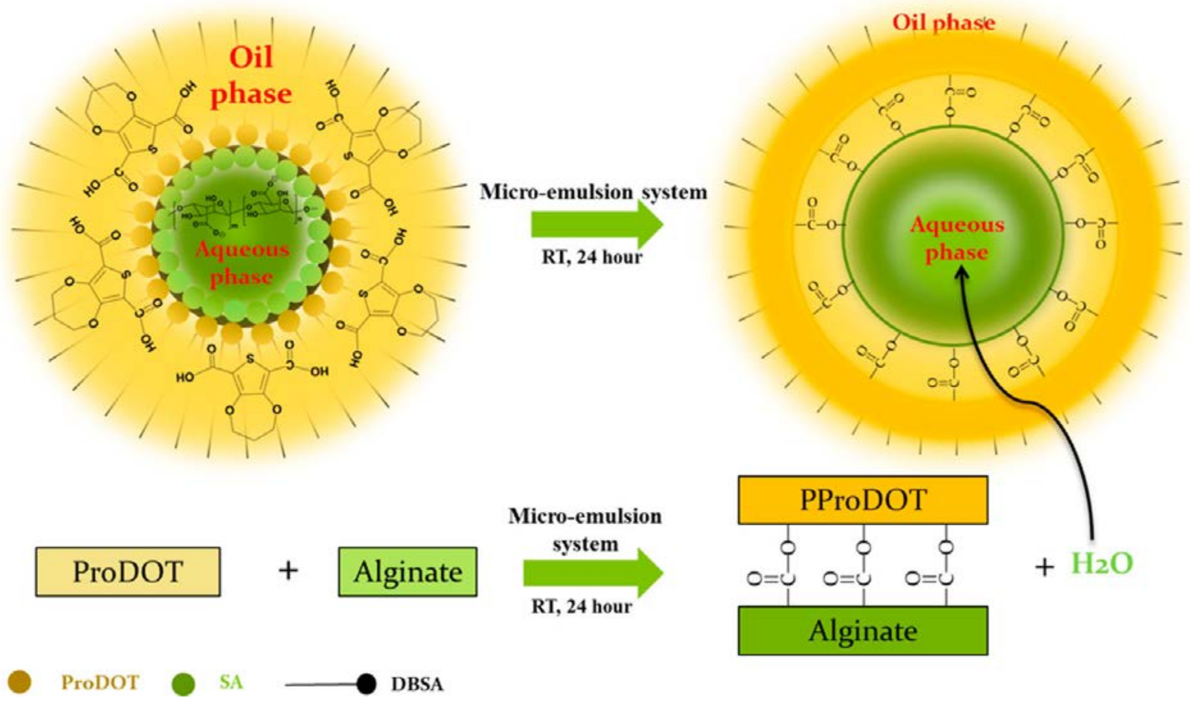

Figure 2. Schematic design of the microemulsion system for synthesis of SA-PProDOT polymer. SA and ProDOT molecules self-assemble along with hydrophilicity of the functional groups, forming an interface where the esterification reaction takes place. The produced water is removed from the interface to the hydrophilic phase, which advances the reaction equilibrium forward.

In Li-S batteries performance is lost through the shuttling effect of polysulfides. The use of a prepared, porous bamboo carbon fibre interlayer, between the Lithium anode and Sulphur cathode, has proven to address this shuttling process, improving the cycle life of the cells and therefore enhancing the electrochemical performance of the batteries [4,5]

Professor Zhang and his team have been collaborating with scientists at the Lawrence Berkeley National laboratory, USA, Australian Synchrotron, University of Queensland, and Queensland University of Technology and Peking University.

The possibilities

It is possible the use of sustainable, non-toxic, natural substances in Lithium and Sodium ion batteries could hold enormous potential for commercialization, as they not only reduce the pollution in the manufacturing of lithium ion batteries and Lithium-sulphur batteries, but improve overall performance and cyclability. Such solutions could power a new generation of batteries leading renewable power generation into a new future.

Key publications

1. Ling M., Xu Y., Gu X., Qiu J., Li S., Wu M., Song X., Yan C., Liu G**., Zhang S.,** Dual-functional gum arabic binder for silicon anodes in lithium ion batteries, ***Nano Energy,*** 2015**,** 12, 178–185 ***(IF: 10.325)***

2. Li G., Ling M., Ye Y., Guo J., Yao Y., Zhu J., Lin Z., **Zhang S.,** Acacia Senegal-Inspired Bi-functional Binder for Longevity of Lithium-Sulfur Batteries, ***Adv. Energy. Mater.*** 2015, 5, 1500878 ***(VIP paper, IF: 16.146)***

3. Ling M., Qiu J., Li S., Yan C., Kiefel M., Liu G., **Zhang S.,** Multifunctional SA-PProDOT Binder for Lithium Ion Batteries, ***Nano Lett.*** 2015, **2015**, *15* (7), 4440–4447 ***(IF: 13.592)***

4. Gu X., Wang Y., Lai C., Qiu J., Li S., Hou Y., Martens W., Mahmood W., **Zhang S.**, Microporous bamboo biochar for lithium–sulfur battery batteries**,** ***Nano Res.***, 2015, 8, 129-139. ***(IF: 7.010)***

5. Gu X., Lai C., Liu F., Yang W., Hou Y., **Zhang S.**, Conductive interwoven bamboo carbon fibres membrane for Li–S batteries**, *J. Mater. Chem. A***., 2014, 2 (26), 10211-10217 ***(IF 7.443)***