



**Success in Development of Technology for Practical Use of Advanced Lithium  
Secondary Battery (Silicon-Sulfur Battery)  
-Significant improvement in charge-discharge cycle performance-**

GS Yuasa Corporation (Tokyo Stock Exchange: 6674; "GS Yuasa") succeeded in significantly improving the charge-discharge cycle performance of lithium-sulfur battery, which has metal lithium as the negative electrode material and a sulfur-porous carbon composite as the positive electrode material<sup>Note 1</sup> as shown in Figure 1.

The improvement achieved in the cycle performance of lithium-sulfur battery means the substantial progress GS Yuasa has made towards practical use of silicon-sulfur battery<sup>\*1</sup>, which has 3 times higher energy density than that of conventional lithium ion battery. We will accelerate development of technology for practical use of silicon-sulfur battery with its cycle performance improved further by using silicon based material for the negative electrode from now on.

Sulfur used in this battery is much expected as the positive electrode material for the advanced lithium ion battery, because of low cost, abundance as a resource and low environmental hazard, in addition to its extremely high theoretical capacity ( $1675 \text{ mAh g}^{-1}$  <sup>Note 2</sup>) compared with conventional positive electrode materials for lithium ion battery.

It is yet to be commercialized, however, because polysulfide as an intermediate created by discharge reaction in the positive electrode, easily elutes out from the electrode due to its high solubility to electrolyte and the eluted polysulfide repeats the oxidation-reduction reaction between the positive and negative electrodes causing self-discharge and resulting in significant capacity decline along with charge-discharge cycle.<sup>\*2</sup>

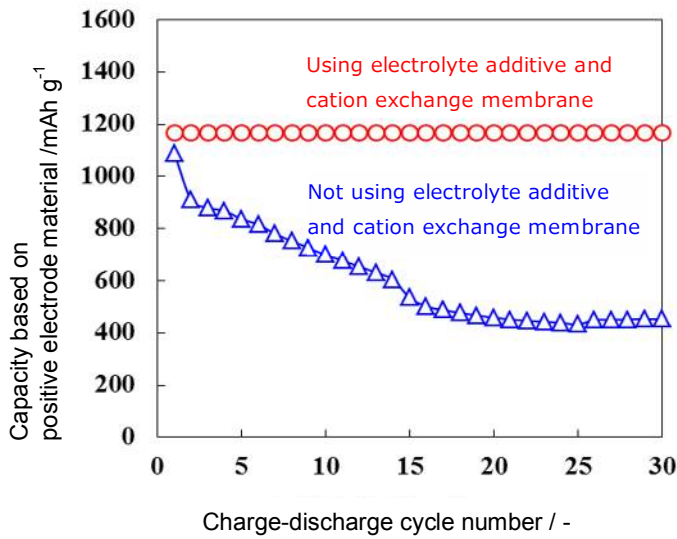
GS Yuasa prevented the elution of polysulfide by using electrolyte additive and the self-discharge with polysulfide's transfer between the positive and negative electrodes by using cation exchange membrane<sup>Note 3</sup> as a separator. As a result, we succeeded in suppressing capacity decline along with the charge-discharge cycle in lithium-sulfur battery using such materials, without losing the capacity of the sulfur-carbon composite as the positive electrode material. In other words, we succeeded in significantly improving its charge-discharge performance.

GS Yuasa will continue to contribute to the realization of a low carbon society through development of the new advanced lithium secondary batteries with even higher energy density.

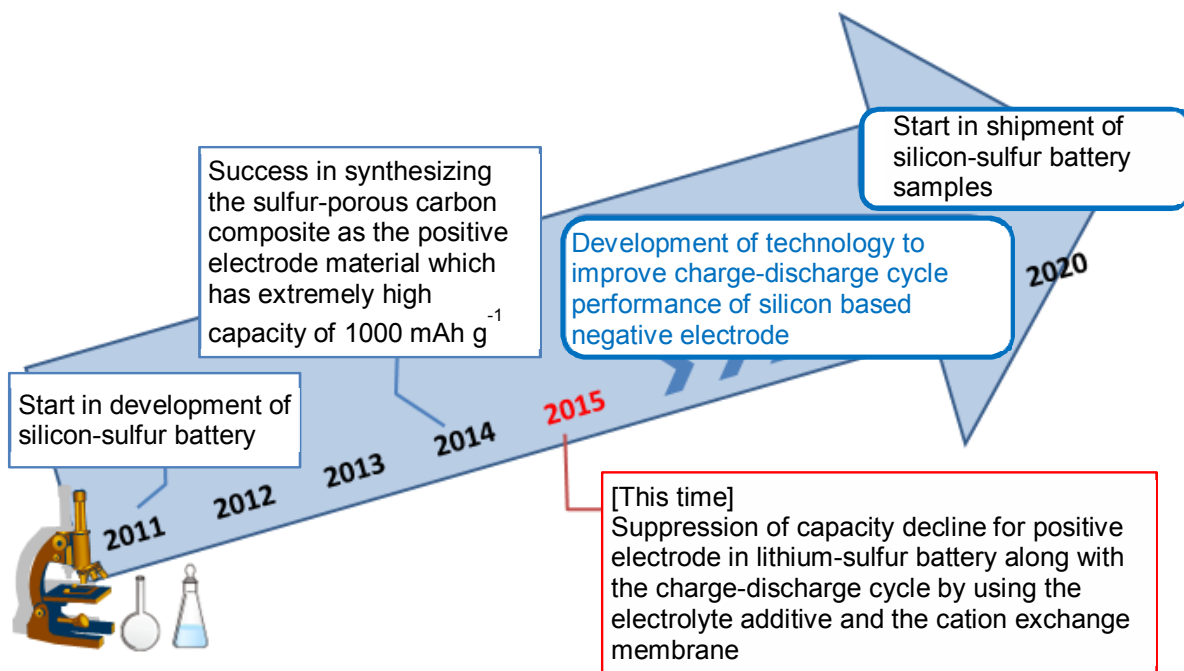
\*1 In November 2014, GS Yuasa announced the achievement of 3 times higher energy density of silicon-sulfur battery<sup>Note 4</sup> based on the positive and negative electrode materials than that of the conventional lithium ion battery (the lithium ion battery for electric vehicles sold by GS Yuasa) and the schedule to ship samples of such battery in 2020.

\*2 Till now, combining polymer and sulfur was proposed as a technology to control elution of polysulfide but that was not complete and not only cycle performance remained at low level but also the capacity based on composite as the positive electrode material remained below  $800 \text{ mAh g}^{-1}$  as the content rate of sulfur reduced due to combining the polymer.

[Figure 1] Charge-discharge cycle performance of lithium-sulfur battery



[Figure 2] Image of silicon-sulfur battery commercialization



[Reference]

1. Past news release related to this subject (November 17, 2014)  
[http://www.gs-yuasa.com/en/newsrelease/article.php?ucode=gs151009100709\\_160](http://www.gs-yuasa.com/en/newsrelease/article.php?ucode=gs151009100709_160)
2. Part of the achievement announced in this news release will be presented at the “56th Battery Symposium in Japan organized by “The Committee of Battery Technology / The Electrochemical Society of Japan; held from November 11 to 13

[Terminology]

Note 1: ‘Sulfur–porous carbon composite’ positive electrode material

Material that has 8 times higher capacity ( $1000 \text{ mAh g}^{-1}$ ) than that of the conventional positive electrode material for lithium ion battery

Capacity here refers to the amount of electricity that can be obtained from 1g of electrode material.

Note 2:  $\text{mAh g}^{-1}$  (milliampere hour per gram)

Unit for capacity. It is also expressed as  $\text{mAh/g}$ .

Note 3: Cation exchange membrane

Polymer membranes that selectively passes cation (atoms that are charged positively such as  $\text{Li}^+$  ion).

Note 4: Energy density based on positive and negative electrode material

Energy density calculated from the mass of electrode materials alone excluding battery parts such as the battery case, current corrector, separator and electrolyte.