Supplementary Information

## Understanding abnormal potential behaviors

at 1<sup>st</sup> charge in Li<sub>2</sub>S cathode material for rechargeable Li-S battery

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**Experimental Section** 

Sample preparation

Planetary ball milled sample was obtained by milling 1g bare sample with 1mm diameter zirconia balls at 500 rpm for 200 min under Ar.



Figure S1. Characteristic of planetary ball-milled sample (a) XRD pattern (b) SEM image (c) Voltage curve during 1<sup>st</sup> charge.

Planetary ball milled sample has only single phase Li<sub>2</sub>S without any impurities in Figure S1 (a). Lattice parameter of the planetary milled sample is 5.717Å and is similar with that of bare sample. Therefore, the bulk structure is not significantly changed.

Figure S1 (b) shows the particle size and morphology of particles in the planetary milled sample. Its particle size is below 2  $\mu$ m and much smaller than that of the bare sample (~ 10 $\mu$ m). Its morphology is spherical that is similar with that of bare sample. Therefore, the planetary ball milled sample changed only particle size.

Figure S1 (c) shows the voltage curve of the planetary milled sample. The potential barrier is  $\sim 3.3$ V and is reduced by 0.3V compared to that of the bare sample ( $\sim 3.6$ V). However, the effect of the particle size on the potential barrier is not significant compared to the effect of surface characteristics in the ACNT-washed sample on the potential barrier. Therefore, we can conclude that the particle size and aggregation characteristics seem not to be dominant factor of affecting the potential barrier.



Figure S2. Photo images of the bare  $Li_2S$  sample in the acetonitrile solvent. (a) transparent acetonitrile solvent (left) and bare white  $Li_2S$  powder (right) (b) Solution of the bare sample into the acetonitrile solvent (sky blue color) (c) the solution after stirring for overnight (white color)