Electronic Supplementary Material (ESI) for Nanoscale

Supporting information:

β-FeOOH nanorod bundles with highly enhanced round-trip efficiency and extremely low-overpotential for lithium-air batteries

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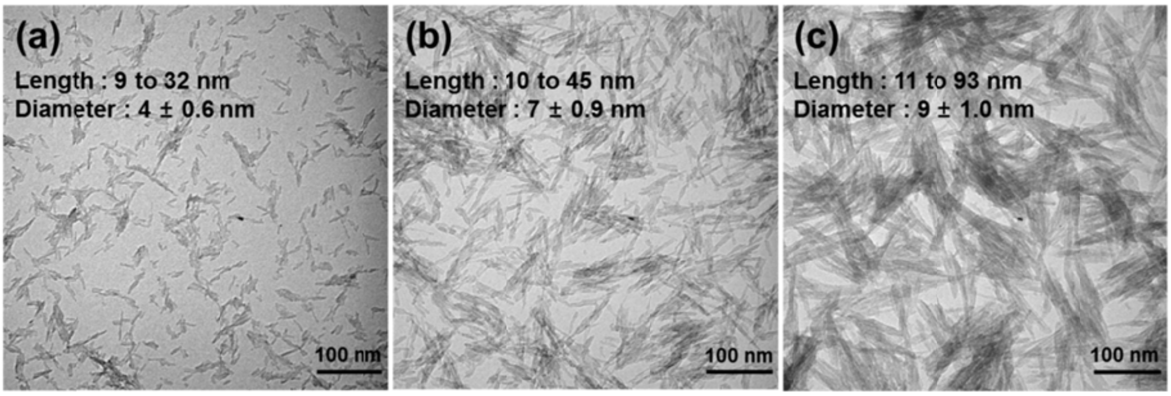

Figure *S*1. TEM images showing the morphology changes of β-FeOOH during ultrasonic irradiation; (a) after 10 min., (b) after 30 min., and (c) 60 min.

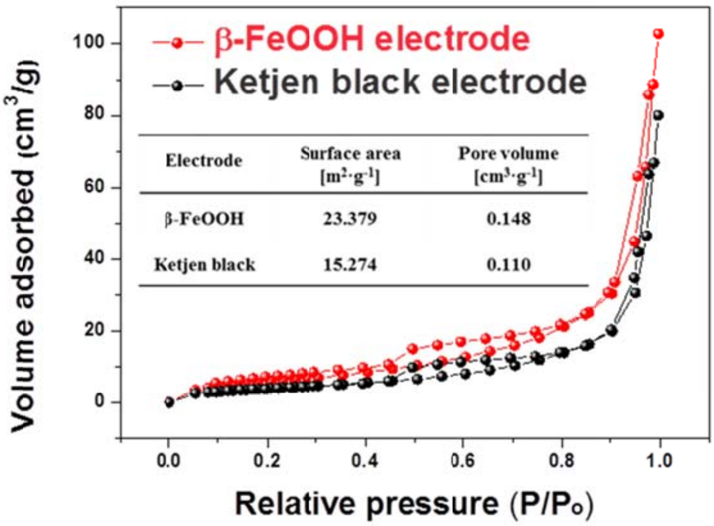

Figure *S*2. N_2 adsorption–desorption isotherms of air cathode having β-FeOOH NR bundles catalyst and catalyst-free air cathode. The insert BET surface area and pore volume for β-FeOOH NR bundles and catalyst-free electrode.

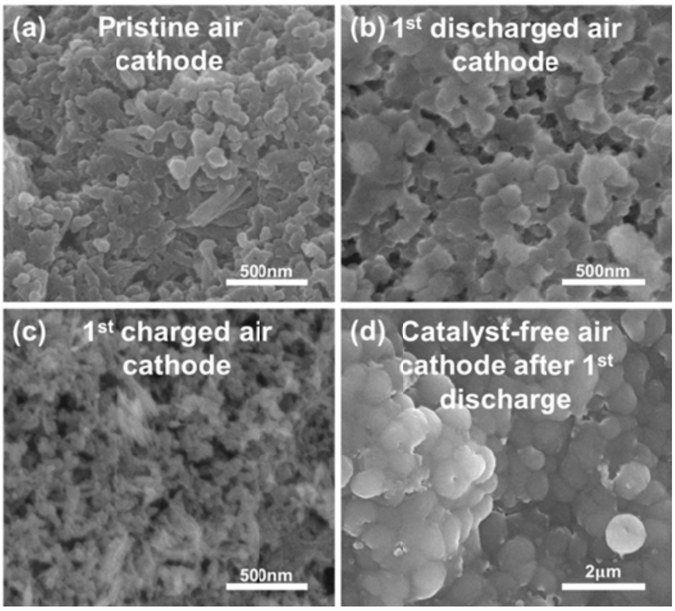

Figure *S*3. SEM images of (a) the pristine air cathode, (b) 1st discharged air cathode, and (c) 1st charged air cathode commonly adopting β-FeOOH NR bundles as the cathode catalyst. (d) SEM image of catalyst-free air cathode after 1st discharge.

Morphological observation indicates that β-FeOOH NR bundles are well mixed with conducting agent and binder in the air cathode having β-FeOOH. After discharge, discharge products (Li_2O_2) are uniformly distributed on the electrode surface without typical toroidal growth compared to the catalyst-free air cathode. Moreover, SEM image of the charged air cathode demonstrates that Li_2O_2 can be effectively dissociated leaving larger amount of pores, which enable Li ions and O_2 gas to easily diffuse inside the air cathode.

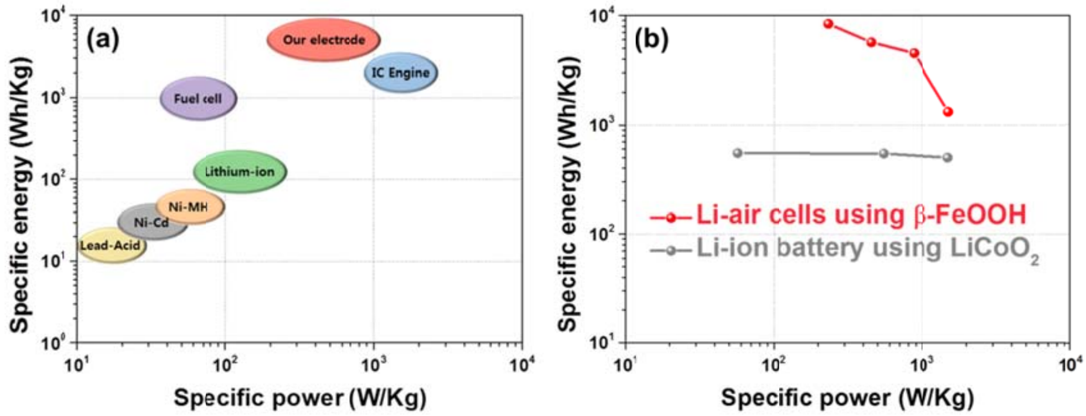

Figure *S4*. (a) Ragone plot comparing the conventional energy storage technologies with the Li-air cells using β-FeOOH NR bundle catalyst. (b) Ragone plot comparing the Li-air cells using β-FeOOH NR bundle catalyst with the conventional Li-ion secondary battery using $LiCoO_2$ cathode.

As shown in Fig. *S*4, Ragone plots demonstrate that the Li-air cells using β-FeOOH catalyst have much higher energy density and power density compared to not only the representative energy storage technologies but also the conventional Li-ion secondary batteries.[3-6] In details, the gravimetric energy density of the Li-air cells using β-FeOOH catalyst is approximately 8 times higher than that of the Li ion secondary battery using $LiCoO_2$ cathode. Even compared to IC engine, the energy density of the Li-air cell using β-FeOOH catalyst looks higher.

Normalization standard	Weight of carbon ($mAh/g_{(KB)}$)	Weight of carbon and Li_2O_2 ($mAh/g_{(KB+Li2O2)}$)	Area (mAh/cm^2)	Weight of electrode ($mAh/g_{(electrode)}$)	Weight of Li_2O_2 ($mAh/g_{(Li2O2)}$)
Li-air cells using β-FeOOH catalyst	7183.1	498.8	2.85	3232.4	6611.94
Li-air cells without catalyst	3622.9	471.7	2.72	3079.5	6226.40

Table *S*1. The capacity comparison between Li-air cells using β-FeOOH catalyst and those without catalyst using various normalization standard.

We have calculated the capacities of Li-air cells based only on the weight of conducting agent (ketjen black (KB)). Therein, the discharge capacity of Li-air cells using β-FeOOH NR bundles (7183 $mAhg_{(KB)}^{-1}$) is almost double that of a catalyst-free cathode (3622 $mAhg_{(KB)}^{-1}$). For more reliable comparison in capacity, we recalculated the capacities of Li-air cells using different normalization standard. These results clearly show that Li-air cells using β-FeOOH catalyst exhibit higher capacity than those without catalyst.

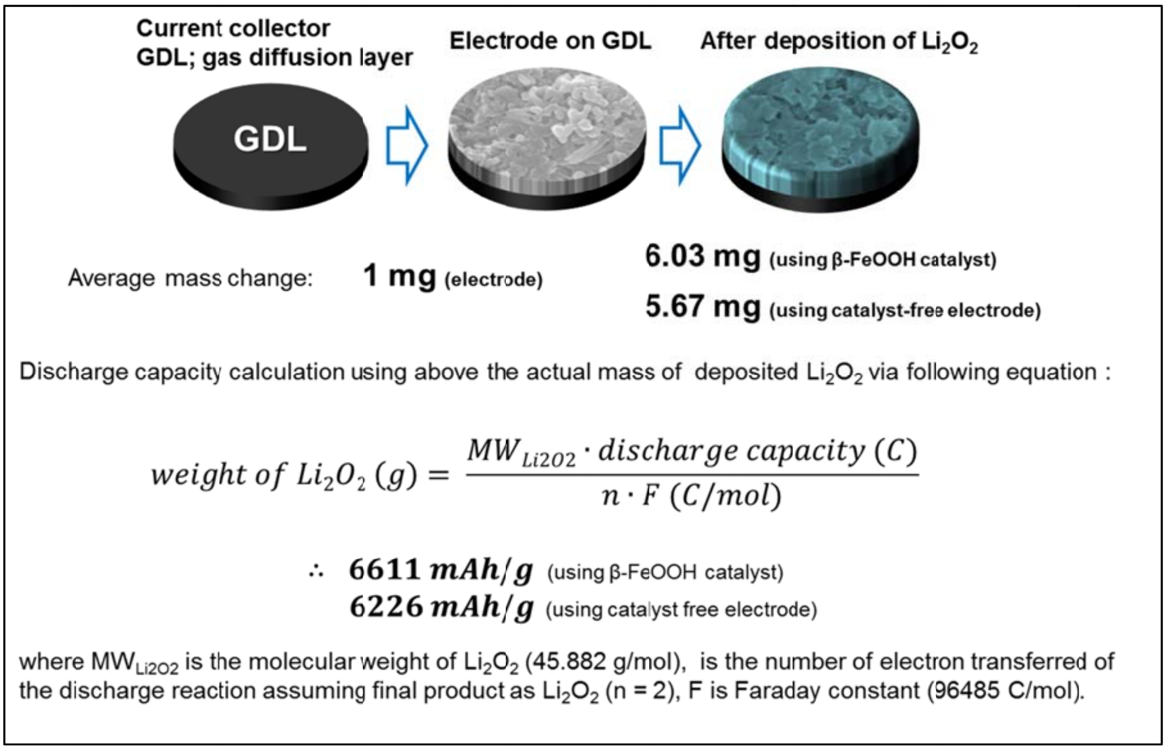

Figure *S*5. Our specific capacity normalization method using the weight of discharge product(Li_2O_2).[5]

References

1. R. Padbury, X. Zhang, *Journal of Power Sources*, 2011, **196**, 4436–4444

2. E.J. Cairns, P. Albertus, Annu. *Rev. Chem. Biomol. Eng*., 2010, **1**, 299–320.

3. H.D. Abruna, J.B. Goodenough, M. Buchanan, *Abstr. Pap. Am. Chem. Soc*., 2007, **234**, 28-ANYL.

4. F. Mizuno, Fundamental Study on Rechargeable Reaction of Lithium–Oxygen Battery. *Symposium on Energy Storage Beyond Lithium Ion: Materials Perspectives*, Oak Ridge National Laboratory, Oak Ridge, TN, 2010, October.

5. Y. C. Lu, D. G. Kwabi, K. P. C. Yao, J. R. Harding, J. Zhou, L. Zuin, Y. Shao-Horn, *Energy Environ. Sci*., 2011, **4**, 2999–3007.

6. H. Chen, M. Armand, G. Demailly, F. Dolhem, P. Poizot, J. M. Tarascon, *ChemSusChem*, 2008, **1**, 348–355.