ADVANCED FUNCTIONAL MATERIALS

Supporting Information

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On-Chip Ni–Zn Microbattery Based on Hierarchical Ordered Porous Ni@Ni(OH)$_2$ Microelectrode with Ultrafast Ion and Electron Transport Kinetics

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Calculations:

The capacity of the microelectrode or MB is calculated according to the following equation:

$$C = It/A \quad (1)$$

where *C* is the capacity, *I* is the discharge current, *t* is the discharge time, and *A* is area or volume of the microelectrodes. The area of each electrode is about 0.0533 cm^{-2}. The areal capacity is calculated based on

The energy density and power density of the MB were calculated using the equations:

$$E = \int_0^t IV(t)dt/A \quad (2)$$

$$P = E/t \quad (3)$$

where E is energy density, *t* is the discharge time, *I* is the discharge current, *V(t)* is the discharge voltage at *t*, dt is the time differential, *A* is the area or volume of the microelectrodes, P is power density.

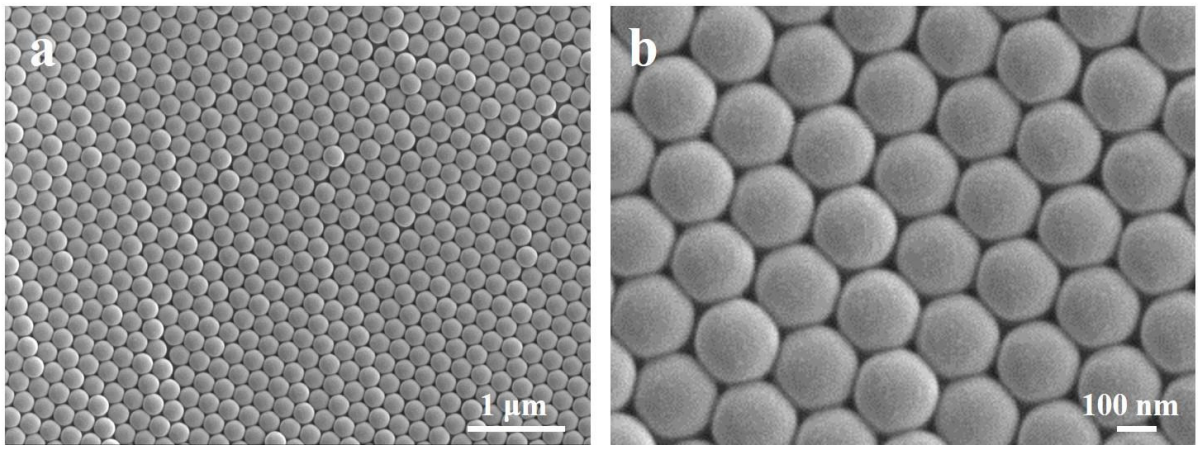

Figure S1. SEM images of as assembled polystyrene template.

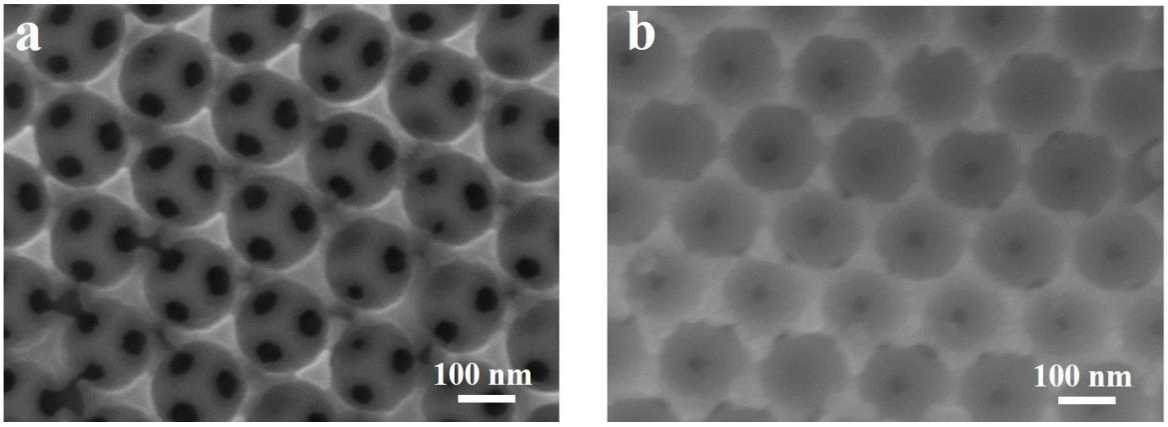

Figure S2. SEM images of a) HOP Ni skeleton, and b) the cross-section of HOP Ni skeleton.

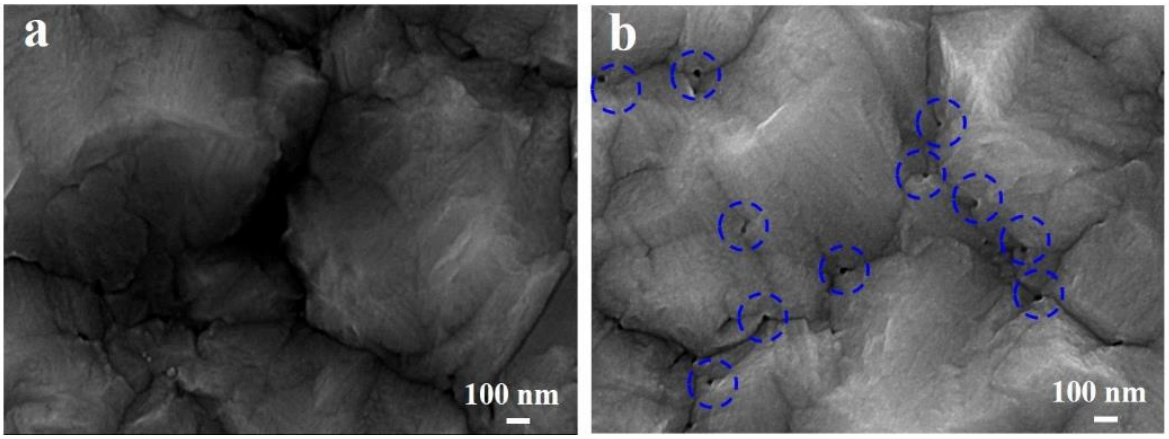

Figure S3. SEM images of a) solid Ni, and b) the cross-section of solid Ni.

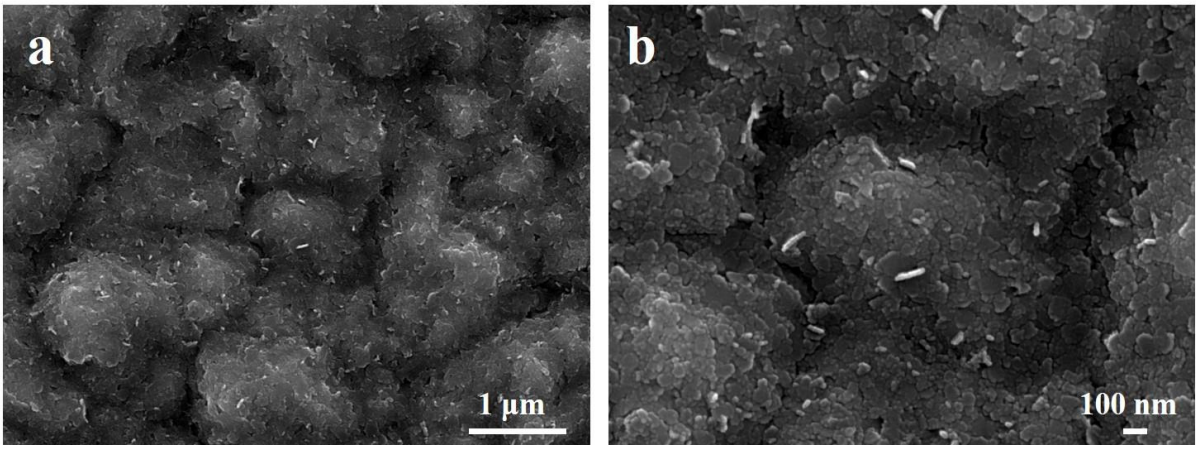

Figure S4. SEM images of S Ni@$Ni(OH)_2$ microelectrode.

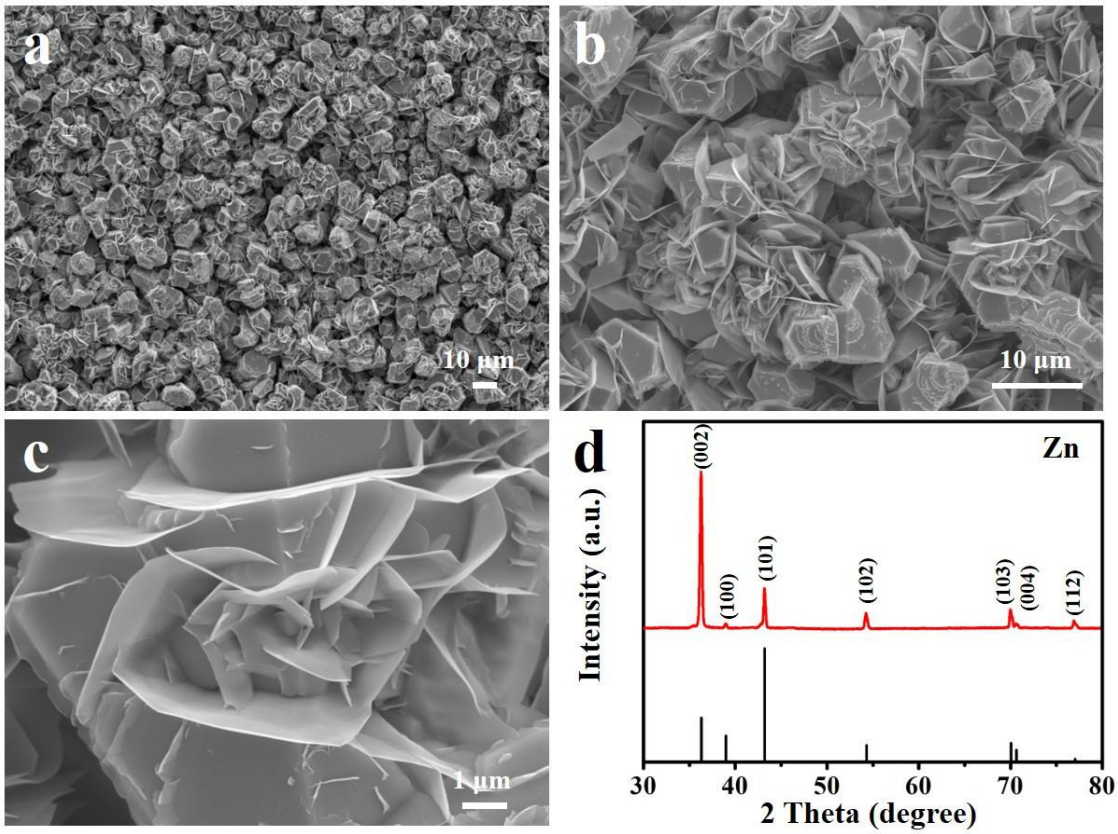

Figure S5. a-c) SEM images and d) XRD spectra of Zn microelectrode.

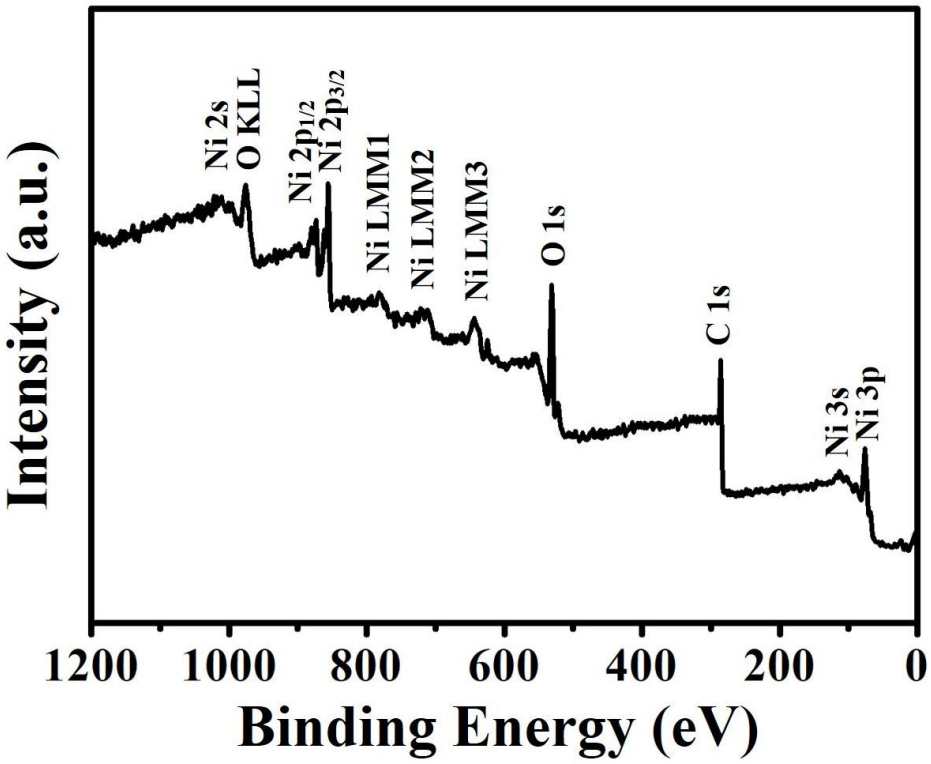

Figure S6. XPS survey spectra of HOP Ni@$Ni(OH)_2$-5.6 microelectrode.

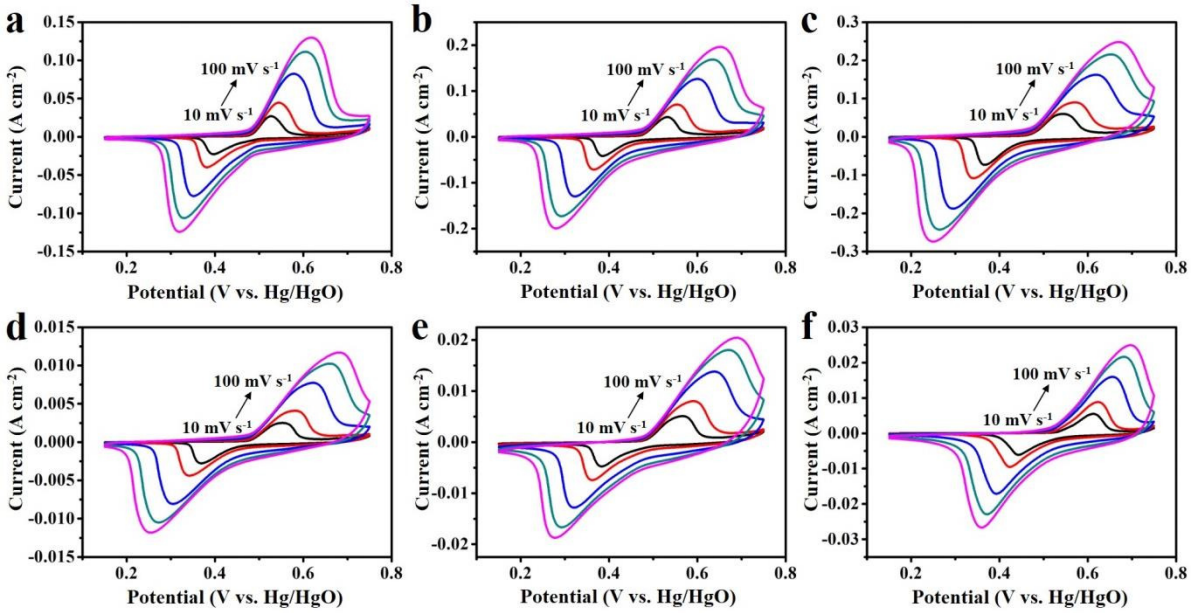

Figure S7. CV curves of a) HOP Ni@$Ni(OH)_2$-2.4, b) HOP Ni@$Ni(OH)_2$-4, c) HOP Ni@$Ni(OH)_2$-5.6, d) S Ni@$Ni(OH)_2$-2.4, e) S Ni@$Ni(OH)_2$-4, f) S Ni@$Ni(OH)_2$-5.6 microelectrodes.

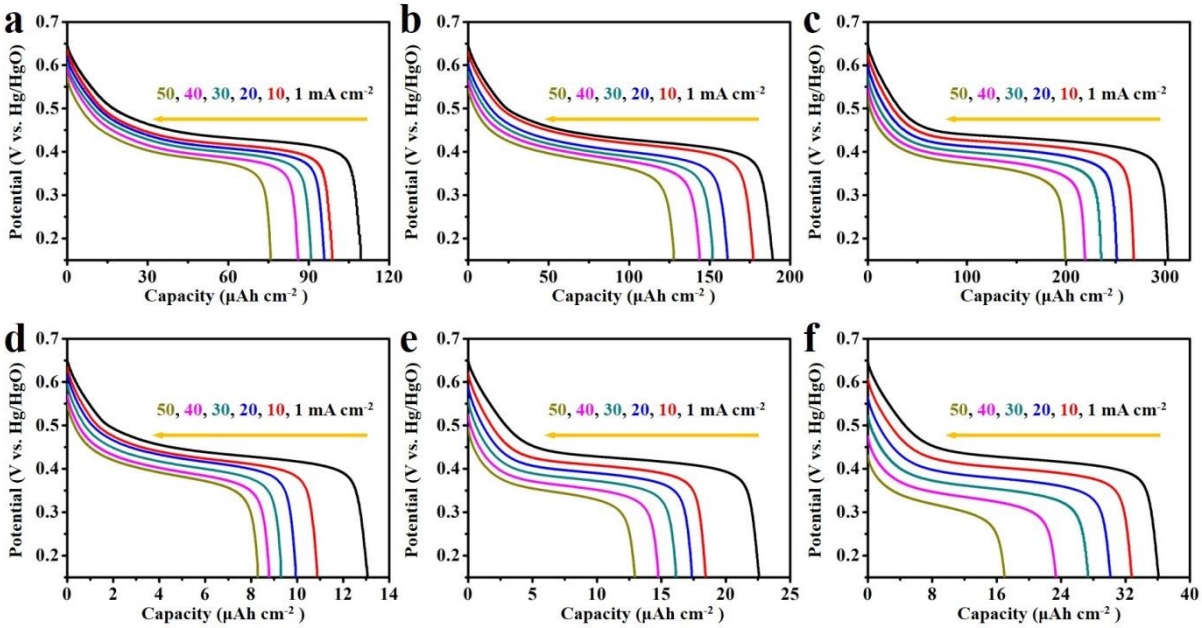

Figure S8. Discharge curves of a) HOP Ni@$Ni(OH)_2$-2.4, b) HOP Ni@$Ni(OH)_2$-4, c) HOP Ni@$Ni(OH)_2$-5.6, d) S Ni@$Ni(OH)_2$-2.4, e) S Ni@$Ni(OH)_2$-4, f) S Ni@$Ni(OH)_2$-5.6 microelectrodes.

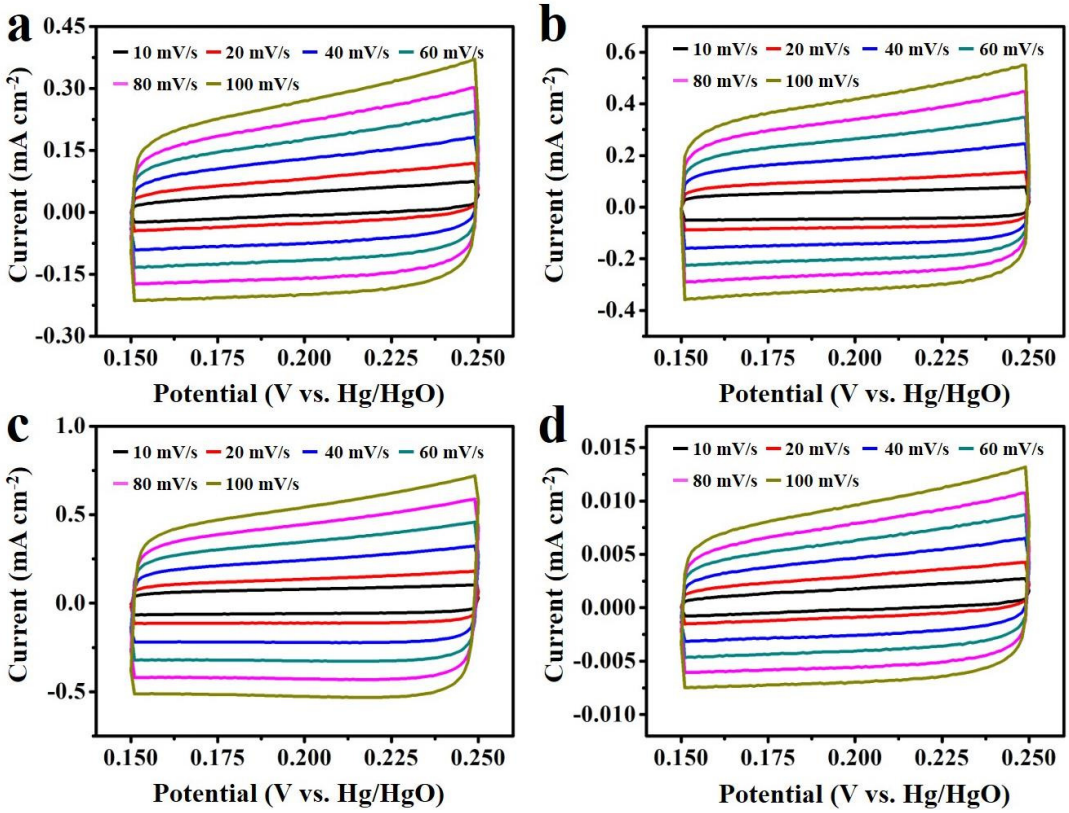

Figure S9. CV curves of a) HOP Ni@$Ni(OH)_2$-2.4, b) HOP Ni@$Ni(OH)_2$-4, c) HOP Ni@$Ni(OH)_2$-5.6, d) S Ni@$Ni(OH)_2$-5.6 microelectrodes with different scan rates (10-100 mV s^{-1}) in the region of 0.15-0.25 V.

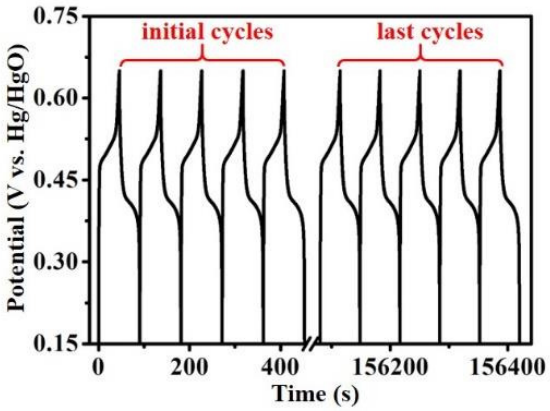

Figure S10. Charge-discharge curves of the initial and the last several cycles during the cycling test.

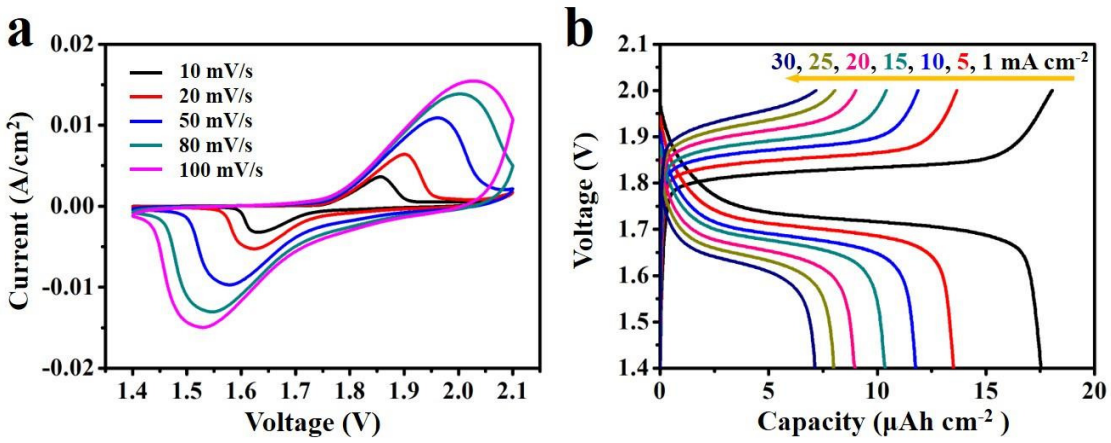

Figure S11. a) CV curves and b) GCD curves of aqueous S Ni-Zn MB.

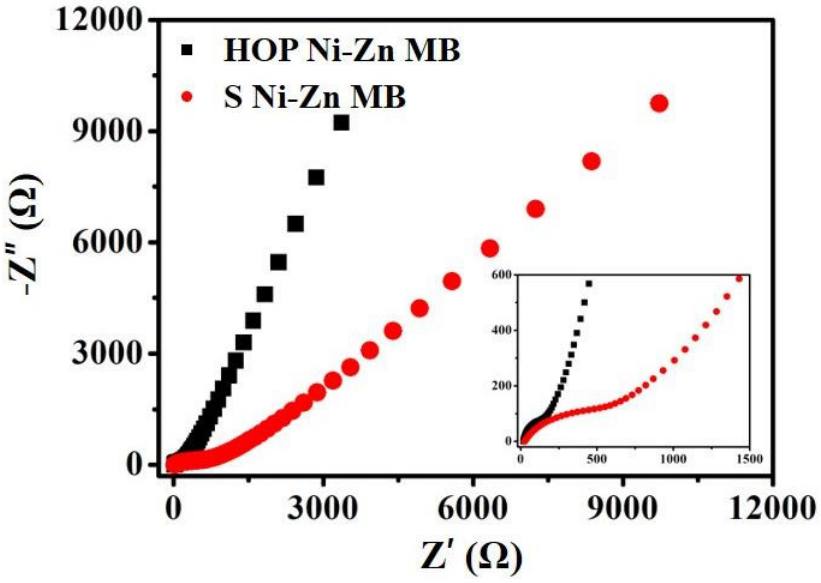

Figure S12. Nyquist plots of aqueous HOP Ni-Zn MB and aqueous S Ni-Zn MB with different electrolyte.

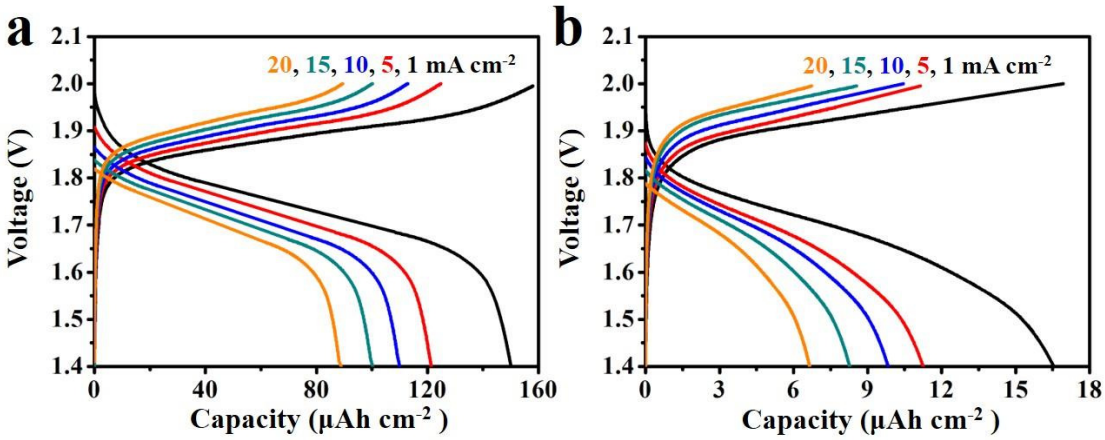

Figure S13. GCD curves of a) quasi-solid-state HOP Ni-Zn MB and b) quasi-solid-state S Ni-Zn MB.

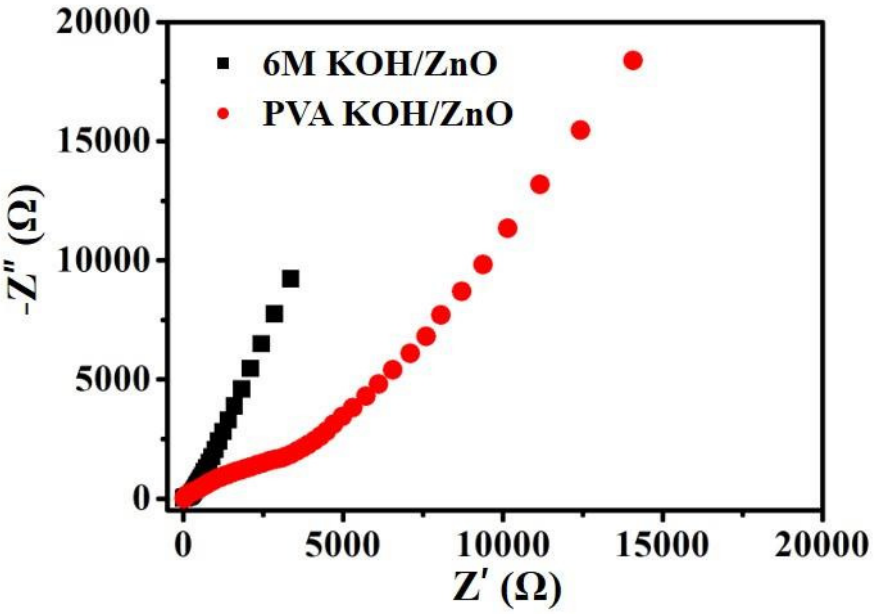

Figure S14. Nyquist plots of HOP Ni-Zn MB with different electrolyte.

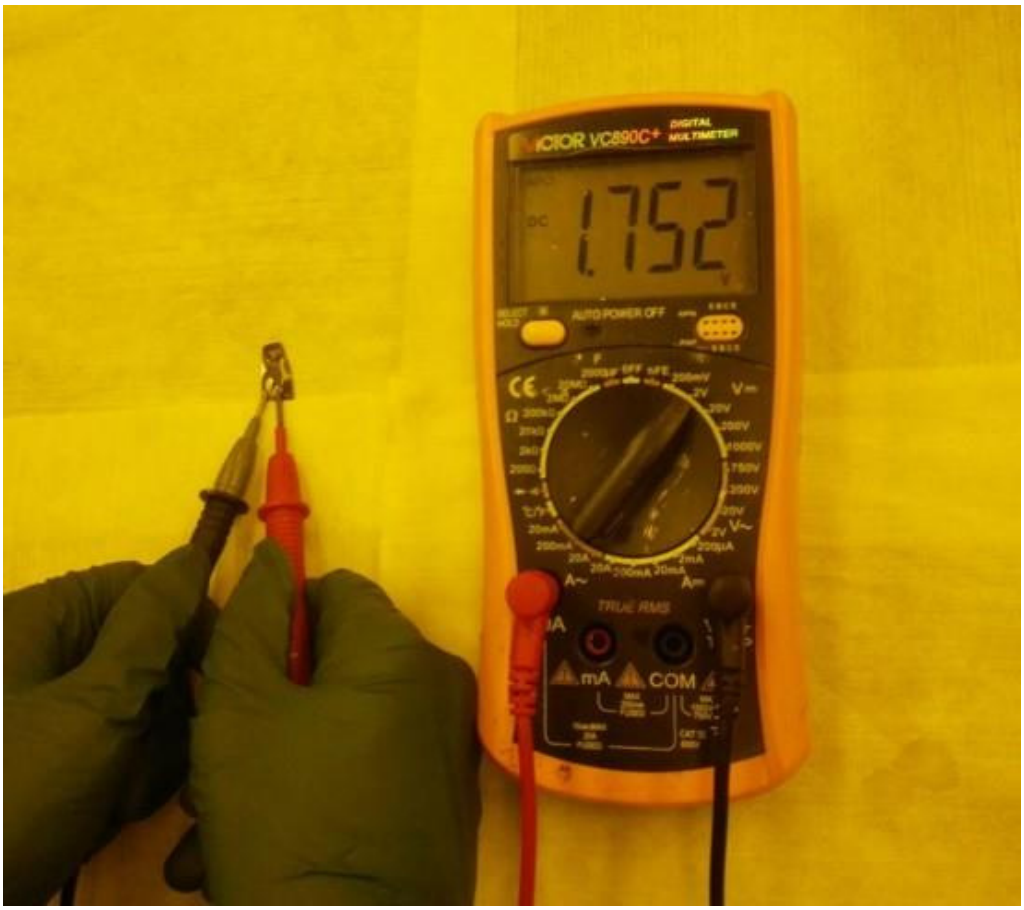

Figure S15. Digital image showing that a single HOP Ni@$Ni(OH)_2$-Zn MB has a typical voltage output of ~1.75 V.

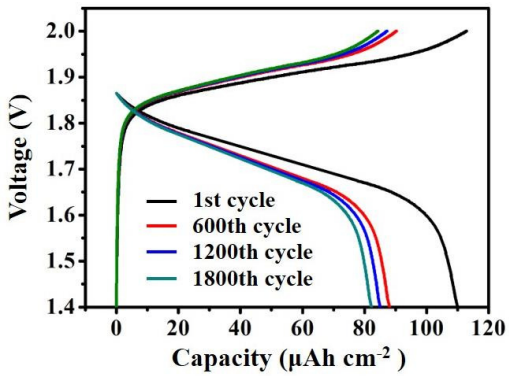

Figure S16. Charge-discharge curves of galvanostatic long-term cycling at current density 10 mA cm^{-2} at 1st, 600th, 1200th, and 1800th cycle.

Table S1. Comparison of volumetric energy/power densities between our quasi-solid-state on-chip Ni-Zn MB with other previously reported works.

Micro Devices	Power Density (W cm^{-3})	Energy Density (Wh cm^{-3})	Reference
HOP Ni@$Ni(OH)_2$//Zn	0.81	0.12	This work
HOP Ni@$Ni(OH)_2$//Zn	15.8	0.07	This work
CF@NiO//CF@ZnO	0.0274	0.0102	[S1]
Ni-NiO//Zn	0.22	0.00067	[S2]
CF@NiO//CF@Fe_3O_4	0.0674	0.00514	[S3]
CCH@CMO//ZnO@C-Zn	0.42	0.0046	[S4]
LTO//AG	1.397	0.0454	[S5]
4 V/500 μAh Li thin film battery	0.00131	0.0081	[S6]
4 V/500 μAh Li thin film battery	0.00484	0.00035	[S6]
Graphene//Co_3O_4	1.2	0.0001	[S7]
MnO_2//WON	0.6	0.0011	[S8]
VG//VG	15.75	0.0006	[S9]
$NiCoO_3H_x$//Zn	2.18	0.008	[S10]
LIG-FeOOH//LIG-MnO_2	2.891	0.0024	[S11]

Table S2. Comparison of areal energy/power densities between our quasi-solid-state on-chip Ni-Zn MB with other previously reported works.

Micro Devices	Power Density ($mW\ cm^{-2}$)	Energy Density ($mWh\ cm^{-2}$)	Reference
HOP Ni@$Ni(OH)_2$//Zn	1.73	0.260	This work
HOP Ni@$Ni(OH)_2$//Zn	33.8	0.150	This work
$NiCoO_3H_x$//Zn	32.77	0.12	[S10]
$NiCo_2O_4$//Zn	0.67	0.057	[S12]
SWNT/rGO	2.84	0.0161	[S13]
MnO_2//Zn	7	0.01	[S14]
ppy @MnO_2@rGO// ppy @MnO_2@rGO	1.33	0.023	[S15]
ppy//ppy	3.6	0.033	[S16]
Ni-NiO//Zn	6.0147	0.0039	[S2]
3D RuO_2//3D RuO_2	9.87	0.1	[S17]
CNTs//CNTs	32	0.0018	[S18]
CNTs//Fe_3O_4-C	1.33	0.009	[S19]

References

[S1] J. Liu, C. Guan, C. Zhou, Z. Fan, Q. Ke, G. Zhang, C. Liu, J. Wang, *Adv. Mater.* **2016**, *28*, 8732.

[S2] Y. Zeng, Y. Meng, Z. Lai, X. Zhang, M. Yu, P. Fang, M. Wu, Y. Tong, X. Lu, *Adv. Mater.* **2017**, *29*, 1702698.

[S3] C. Guan, W. Zhao, Y. Hu, Q. Ke, X. Li, H. Zhang, J. Wang, *Adv. Energy Mater.* **2016**, *6*, 1601034.

[S4] M. Li, J. Meng, Q. Li, M. Huang, X. Liu, K. A. Owusu, Z. Liu, L. Mai, *Adv. Funct. Mater.* **2018**, *28*, 1802016.

[S5] S. Zheng, J. Ma, Z. S. Wu, F. Zhou, Y. He, F. Kang, H. M. Cheng, X. Bao, *Energy Environ. Sci.* **2018**, *11*, 2001.

[S6] Z. S. Wu, K. Parvez, X. Feng, K. Müllen, *Nat. Commun.* **2013**, *4*, 2487.

[S7] X. Wang, B. Liu, R. Liu, Q. Wang, X. Hou, D. Chen, R. Wang, G. Shen, *Angew. Chem.* **2014**, *126*, 1880.

[S8] M. Yu, Y. Han, X. Cheng, L. Hu, Y. Zeng, M. Chen, F. Cheng, X. Lu, Y. Tong, *Adv. Mater.* **2015**, *27*, 3085.

[S9] S. Zheng, Z. Li, Z. S. Wu, Y. Dong, F. Zhou, S. Wang, Q. Fu, C. Sun, L. Guo, X. Bao, *ACS Nano* **2017**, *11*, 4009.

[S10] Y. Huang, W. S. Ip, Y. Y. Lau, J. Sun, Z. Jie, N. S. S. Yeung, W. S. Ng, H. Li, Z. Pei, Q. Xue, Y. Wang, J. Yu, H. Hu, C. Zhi, *ACS Nano* **2017**, *11*, 8953.

[S11] L. Li, J. Zhang, Z. Peng, Y. Li, C. Gao, Y. Ji, R. Ye, N. D. Kim, Q. Zhong, Y. Yang, H. Fei, G. Ruan, J. M. Tour, *Adv. Mater.* **2016**, *28*, 838.

[S12] C. Xu, J. Liao, C. Yang, R. Wang, D. Wu, P. Zou, Z. Lin, B. Li, F. Kang, C. P. Wong, *Nano Energy* **2016**, *30*, 900.

[S13] D. Yu, K. Goh, H. Wang, L. Wei, W. Jiang, Q. Zhang, L. Dai, Y. Chen, *Nat. Nanotechnol.* **2014**, *9*, 555.

[S14] Y. Zeng, X. Zhang, Y. Meng, M. Yu, J. Yi, Y. Wu, X. Lu, Y. Tong, *Adv. Mater.* **2017**, *29*, 1700274.

[S15] Y. Huang, H. Hu, Y. Huang, M. Zhu, W. Meng, C. Liu, Z. Pei, C. Hao, Z. Wang, C. Zhi, *ACS Nano* **2015**, *9*, 4766.

[S16] L. Yuan, B. Yao, B. Hu, K. Huo, W. Chen, J. Zhou, *Energy Environ. Sci.* **2013**, *6*, 470.

[S17] A. Ferris, S. Garbarino, D. Guay, D. Pech, *Adv. Mater.* **2016**, *27*, 6625.

[S18] J. Ren, W. Bai, G. Guan, Y. Zhang, H. Peng, *Adv. Mater.* **2013**, *25*, 5965.

[S19] R. Li, Y. Wang, C. Zhou, C. Wang, X. Ba, Y. Li, X. Huang, J. Liu, *Adv. Funct. Mater.* **2015**, *25*, 5384.