Supplementary Materials

Anion and Cation Co-Modified Vanadium Oxide for Cathode Material of Aqueous Zinc-Ion Battery

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Supplementary Results

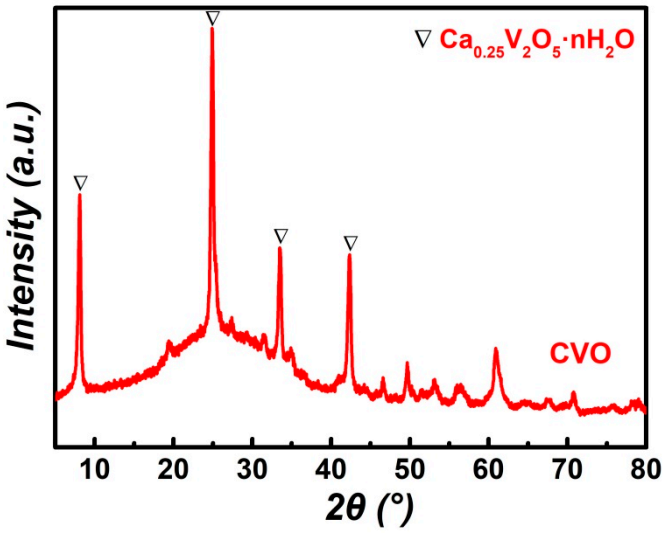

Figure S1. XRD spectrum of the synthesized CVO powder.

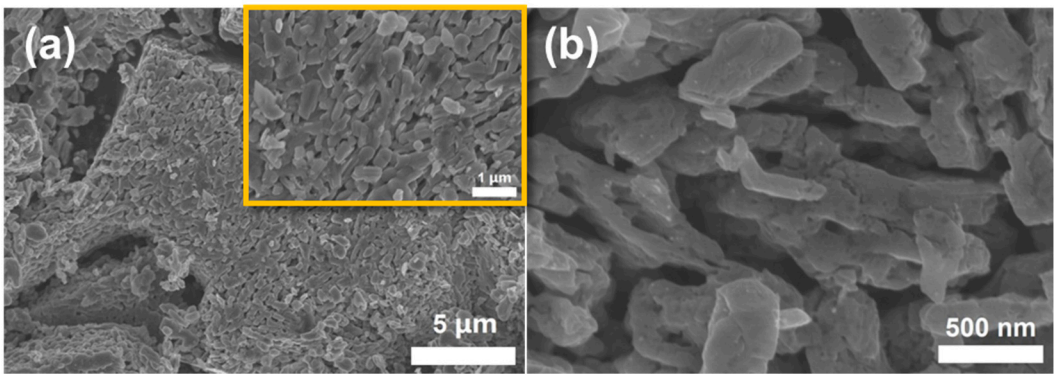

Figure S2. SEM images of (a) V_2O_5 powder and (b) VNO.

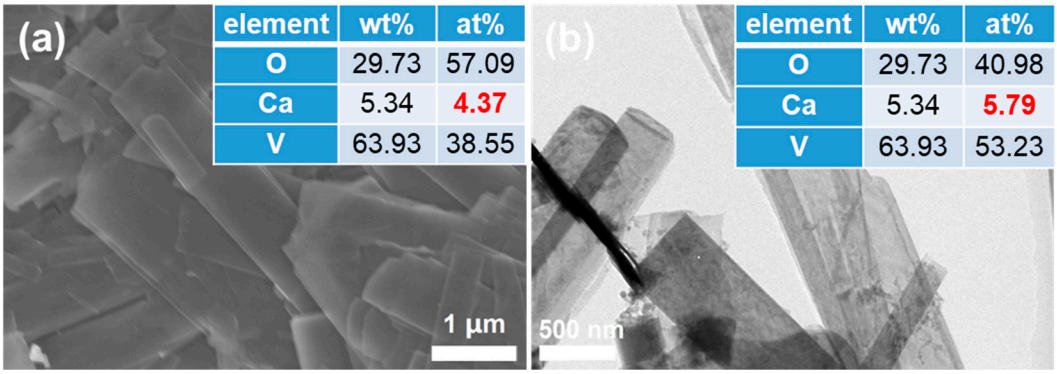

Figure S3. (a) SEM image and (b) TEM image with element content of CVO.

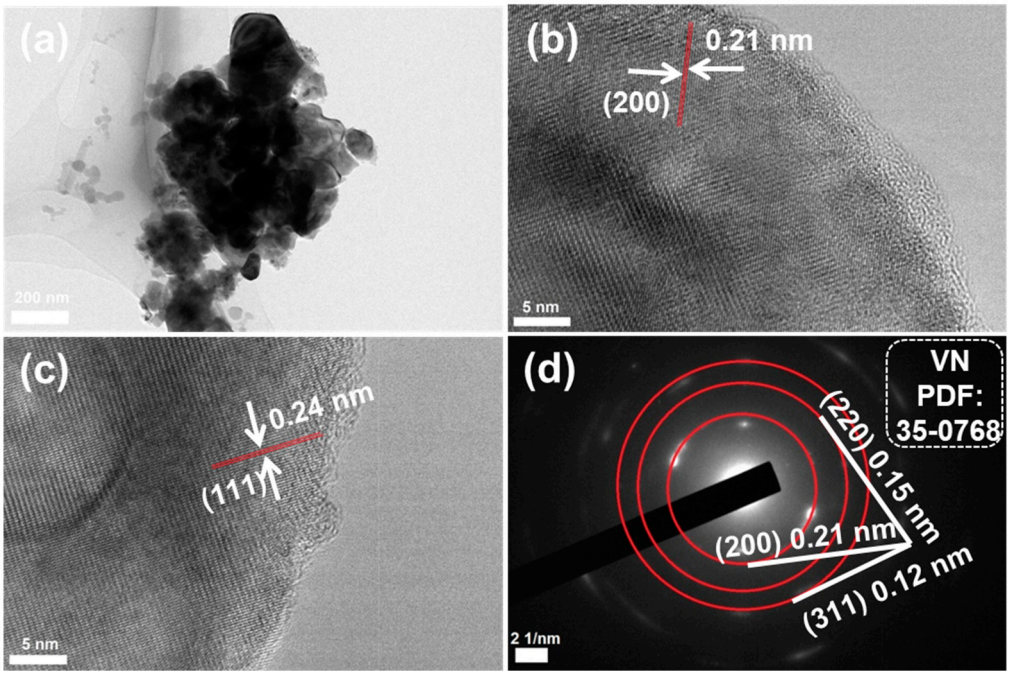

Figure S4. (a) TEM image, (b,c) HRTEM image, and (d) SAED image of the synthesized VNO powder.

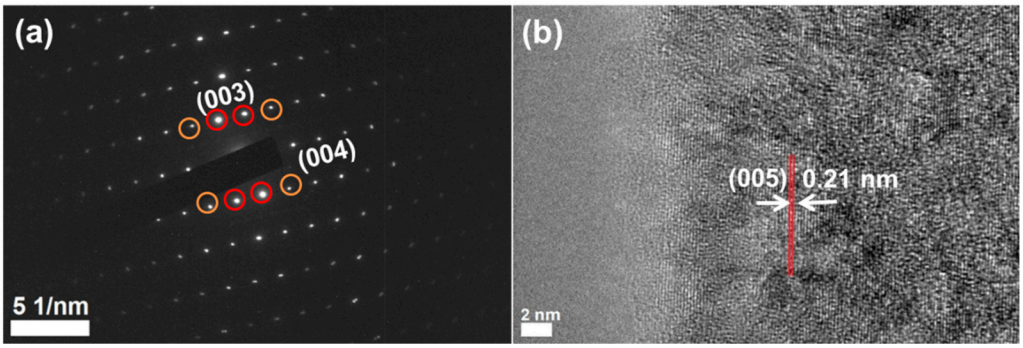

Figure S5. (a) SAED image and (b) HRTEM image of the synthesized CVO powder.

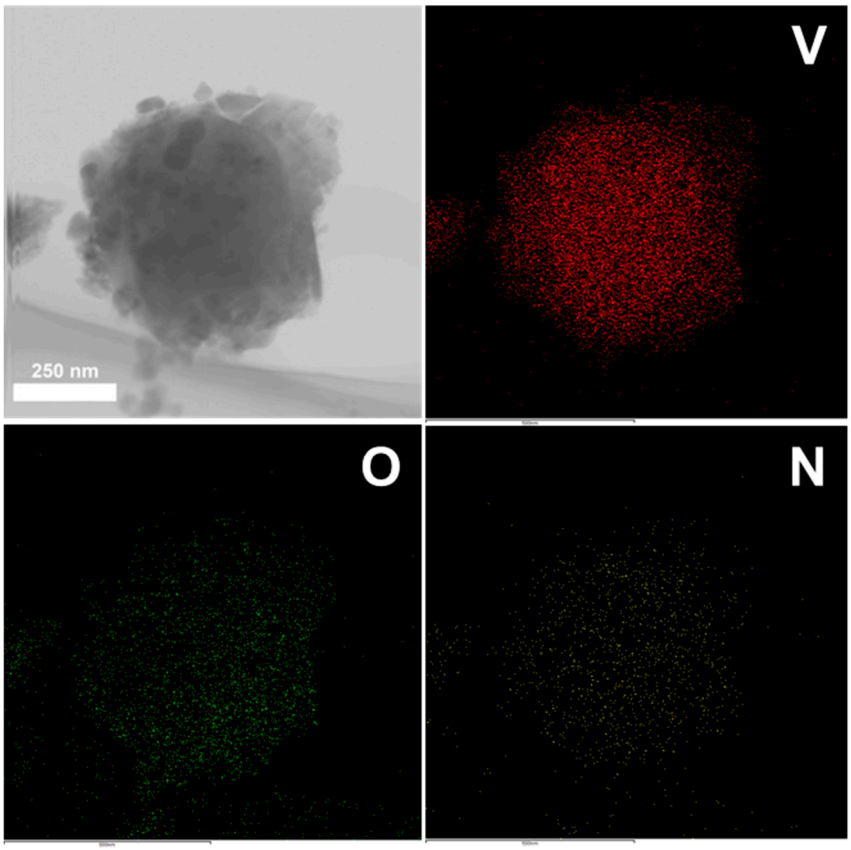

Figure S6. EDS elemental mappings of the synthesized VNO powder.

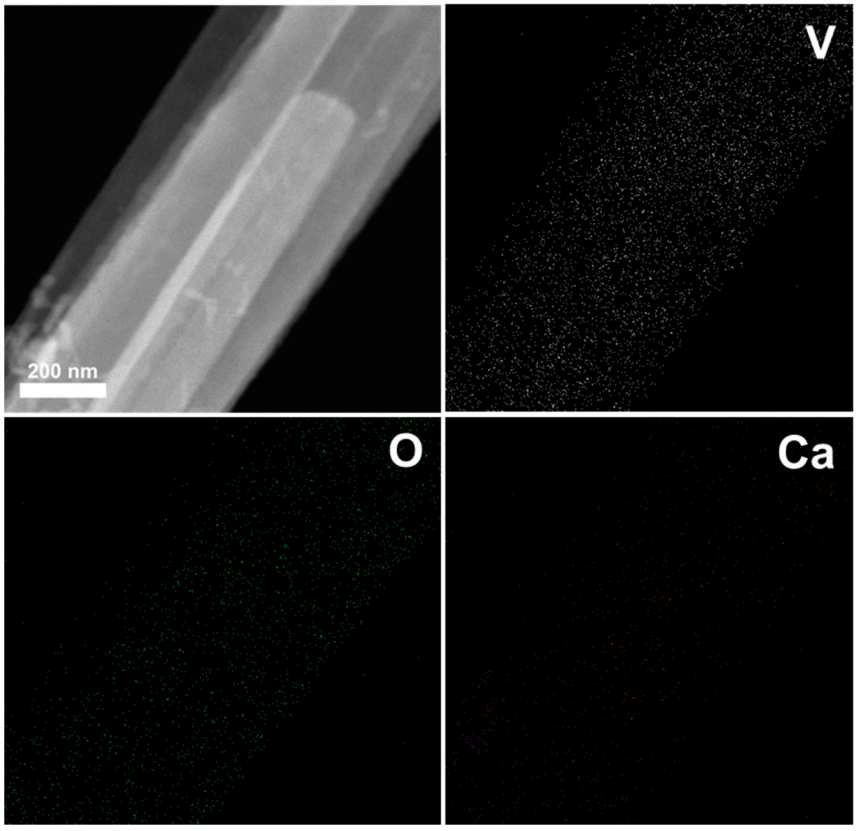

Figure S7. EDS elemental mappings of the synthesized CVO powder.

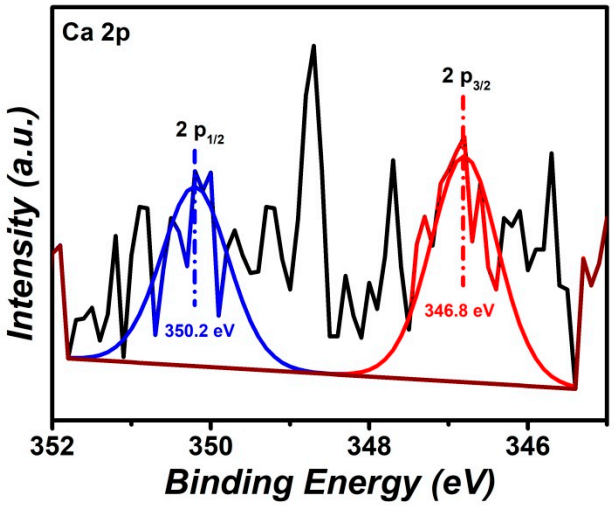

Figure S8. High-resolution XPS spectrum of Ca 2p of CVNO.

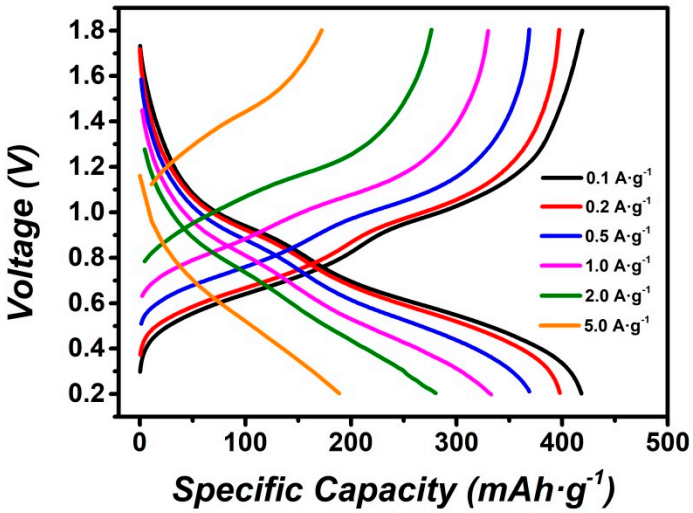

Figure S9. GCD curves of CVNO at different current densities.

Table S1. Electrochemical performance in related studies.

Materials	Specific capacity	Cycling stability	References
$Ca_{0.24}V_2O_5{\cdot}0.83H_2O$	340 $mAh{\cdot}g^{-1}$ at 0.2 C	96% retention after 3000 cycles at 80 C	[1]
$Mg_{0.34}V_2O_5{\cdot}0.84H_2O$	353 $mAh{\cdot}g^{-1}$ at 0.1 $A{\cdot}g^{-1}$	97% retention after 2000 cycles at 5 $A{\cdot}g^{-1}$	[2]
$(NH_4)_2V_{10}O_{25}{\bullet}8H_2O$	376 $mAh{\cdot}g^{-1}$ at 0.3 $A{\cdot}g^{-1}$	93% retention after	[3]

		1000 cycles at 10 $A \cdot g^{-1}$	
VO_2(D)	408 $mAh \cdot g^{-1}$ at 0.1 $A \cdot g^{-1}$	66.5% retention after 3000 cycles at 3 $A \cdot g^{-1}$	[4]
V_6O_{13}	360 $mAh \cdot g^{-1}$ at 0.2 $A \cdot g^{-1}$	92% retention after 2000 cycles at 24 $A \cdot g^{-1}$	[5]
VO_2(M)	248 $mAh \cdot g^{-1}$ at 2 $A \cdot g^{-1}$	84.5% retention after 5000 cycles at 20 $A \cdot g^{-1}$	[6]
$V_{10}O_{24} \cdot 12H_2O$	327 $mAh \cdot g^{-1}$ at 0.1 $A \cdot g^{-1}$	115 $mAh \cdot g^{-1}$ retention after 3000 cycles at 1 $A \cdot g^{-1}$	[7]
$(NH_4)_2V_{10}O_{25} \cdot 8H_2O$	417 $mAh \cdot g^{-1}$ at 0.1 $A \cdot g^{-1}$	252 $mAh \cdot g^{-1}$ retention after 100 cycles at 0.2 $A \cdot g^{-1}$	[8]
V_2O_5 yolk-shell	410 $mAh \cdot g^{-1}$ at 0.1 $A \cdot g^{-1}$	80% retention after 1000 cycles at 5 $A \cdot g^{-1}$	[9]
This work	418.5 $mAh \cdot g^{-1}$ at 0.1 A g^{-1}	81.2% retention after 500 cycles at 2 $A \cdot g^{-1}$	/

Table S2. Inductively coupled plasma optical emission spectroscopy (ICP-OES) characterization. The data were collected by analyzing the CVNO material.

Calcium Concentration ($mg \cdot L^{-1}$)/($mmol \cdot L^{-1}$)	**Vanadium Concentration ($mg \cdot L^{-1}$)/($mmol \cdot L^{-1}$)**	**Ca/V**	**Calcium Content (wt%)**	**Vanadium Content (wt%)**
2.705/0.0676	768.2/15.06	0.01/2	0.16%	46.73%
2.706/0.0677	768.8/15.07	0.01/2	0.16%	46.76%

Table S3. Specific surface areas.

materials	Specific Surface Areas ($m^2 \cdot g^{-1}$)
V_2O_5	17.700
CVO	72.672
VNO	196.499
CVNO	44.192

References

[1] C. Xia, J. Guo, P. Li, X.X. Zhang, H.N. Alshareef, Highly stable aqueous zinc-ion storage using a layered calcium vanadium oxide bronze cathode, Angew. Chem. Int. Edit. 57 (2018) 3943-3948.

[2] F. Ming, H. Liang, Y. Lei, S. Kandambeth, M. Eddaoudi, H.N. Alshareef, Layered $Mg_xV_2O_5 \cdot n H_2O$ as cathode material for high-performance aqueous zinc ion batteries, ACS Energy Lett. 3 (2018) 2602-2609.

[3] B.Y. Tang, J. Zhou, G.Z. Fang, S. Guo, X. Guo, L.T. Shan, Y. Tang, S.Q. Liang, Structural modification of V_2O_5 as high-performance aqueous zinc-ion battery cathode, J. Electrochem. Soc. 166 (2019) A480-A486.

[4] L.L. Chen, Z.H. Yang, Y.G. Huang, Monoclinic VO_2(D) hollow nanospheres with super-long cycle life for aqueous zinc ion batteries, Nanoscale 11 (2019) 13032-13039.

[5] J. Shin, D.S. Choi, H.J. Lee, Y. Jung, J.W. Choi, Hydrated intercalation for high-performance aqueous zinc ion batteries, Adv. Energy Mater. 9 (2019) 1900083.

[6] L. Zhang, L. Miao, B. Zhang, J. Wang, J. Liu, Q. Tan, H. Wan, J. Jiang, A durable VO_2(M)/Zn battery with ultrahigh rate capability enabled by pseudocapacitive proton insertion, J. Mater. Chem. A 8 (2020) 1731-1740.

[7] W. Liu, L. Dong, B. Jiang, Y. Huang, X. Wang, C. Xu, Z. Kang, J. Mou, F. Kang, Layered vanadium oxides with proton and zinc ion insertion for zinc ion batteries, Electrochim. Acta

320 (2019) 134565.

[8] H. Jiang, Y. Zhang, Z. Pan, L. Xu, J. Zheng, Z. Gao, T. Hu, C. Meng, Facile hydrothermal synthesis and electrochemical properties of $(NH_4)_2V_{10}O_{25}\cdot 8H_2O$ nanobelts for high-performance aqueous zinc ion batteries, Electrochim. Acta 332 (2020) 135506.

[9] R. Li, H. Zhang, Q. Zheng, X. Li, Porous V_2O_5 yolk–shell microspheres for zinc ion battery cathodes: activation responsible for enhanced capacity and rate performance, J. Mater. Chem. A 8 (2020) 5186-5193.