Electronic Supplementary Information (ESI)

for

A new spinel high-entropy oxide $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ with fast reaction kinetic and excellent stability as anode materials for lithium ion batteries

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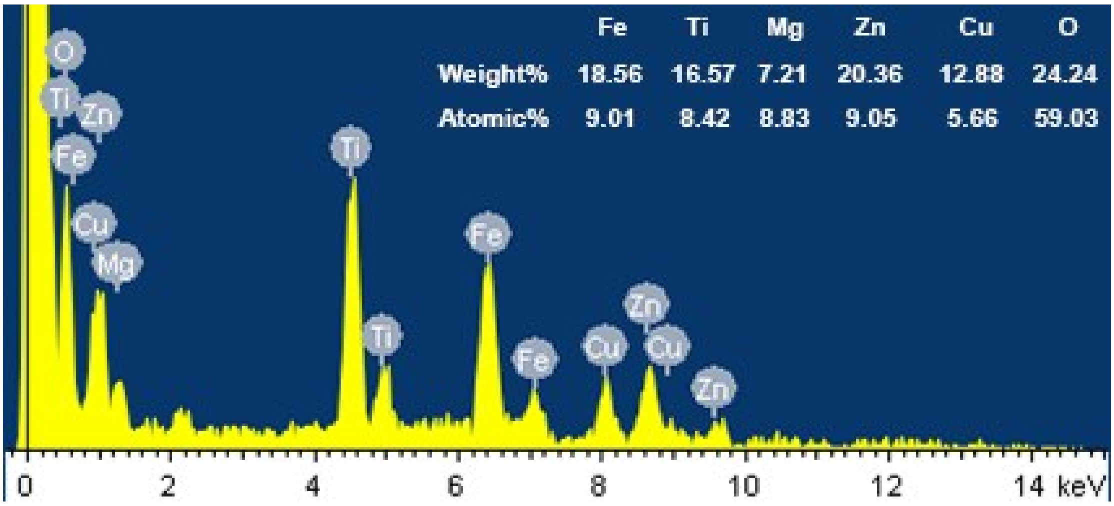


Fig. S1 EDS analysis result of the synthesized $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ particles. The corresponding element atomic ratio indicate the homogeneous spatial distributions of each element.

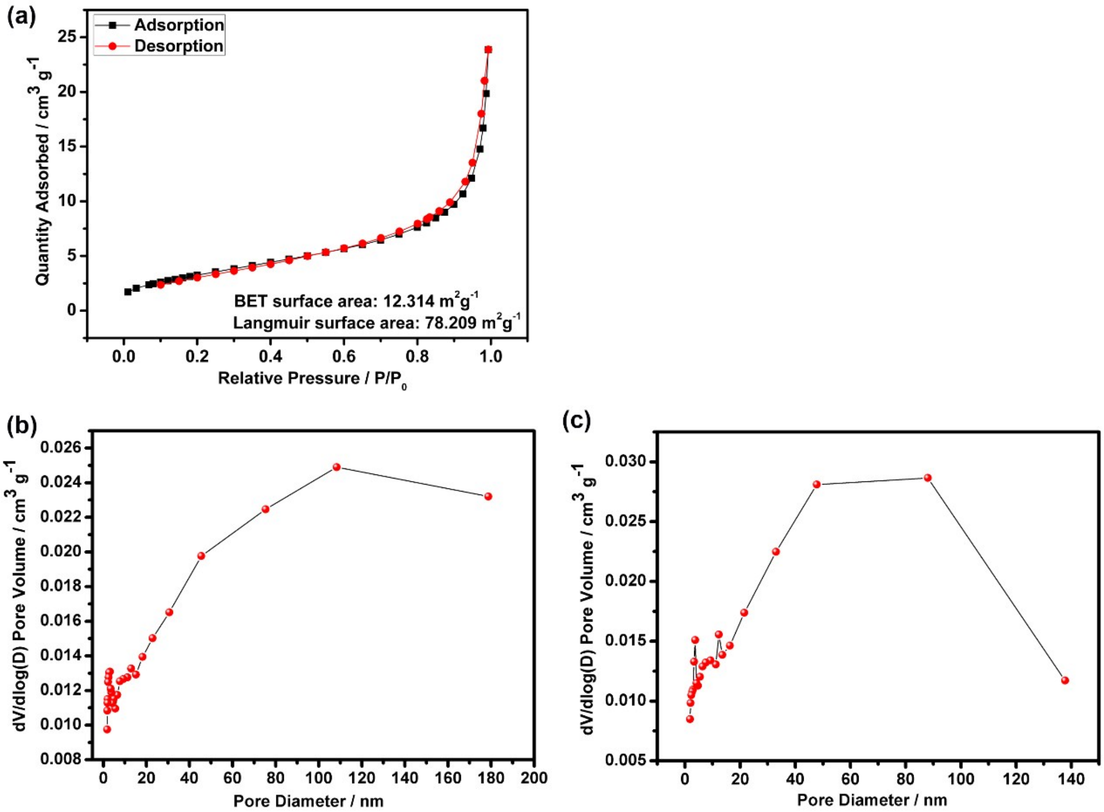


Fig. S2 (a) N_2 adsorption-desorption isotherms of the synthesized $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ particles. The BJH pore size distribution curves based on (b) Adsorption dV/dlog(D) Pore Volume, (c) Desorption dV/dlog(D) Pore Volume.

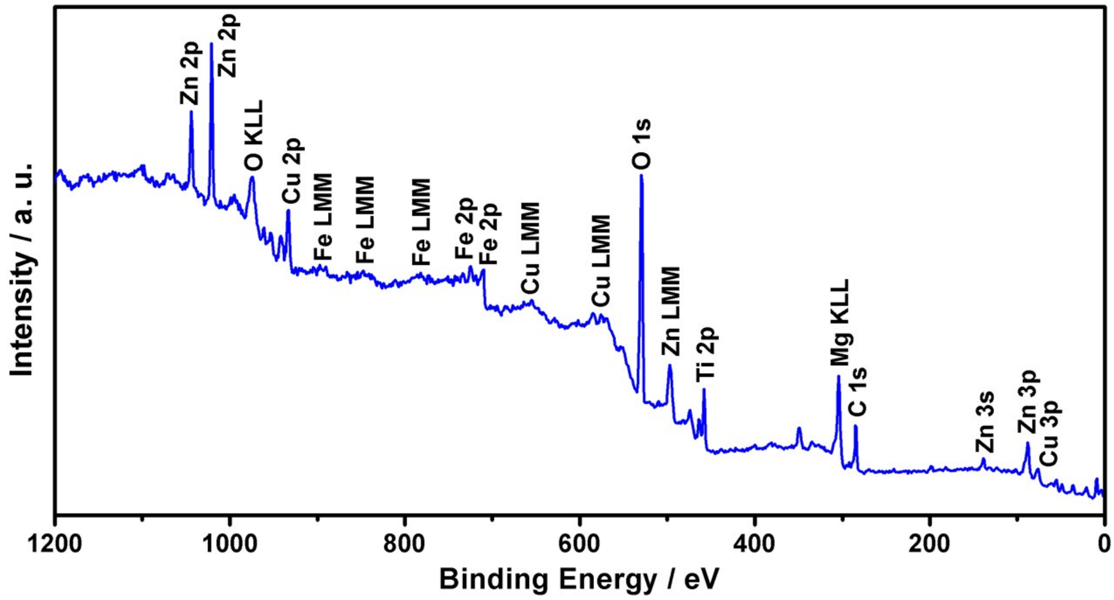


Fig. S3 XPS survey scan spectrum of the synthesized $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ particles.

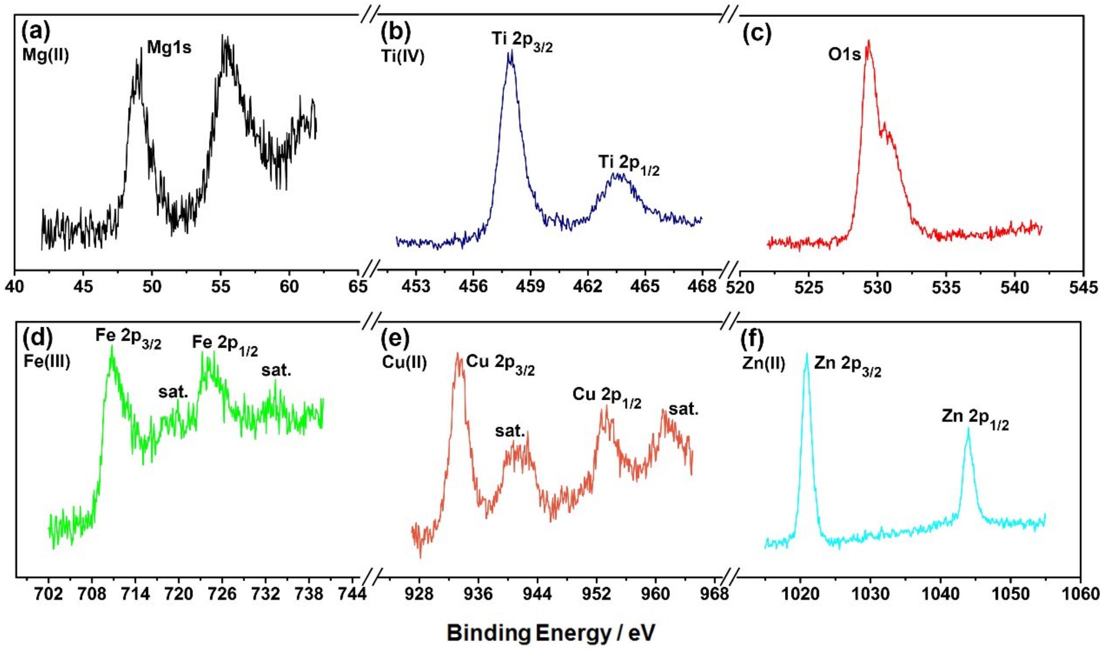


Fig. S4 High-resolution XPS spectra of the synthesized $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ particles: (a) Mg 1s; (b) Ti 2p; (c) O1s; (d) Fe 2p; (e) Cu 2p; (f) Zn 2p.

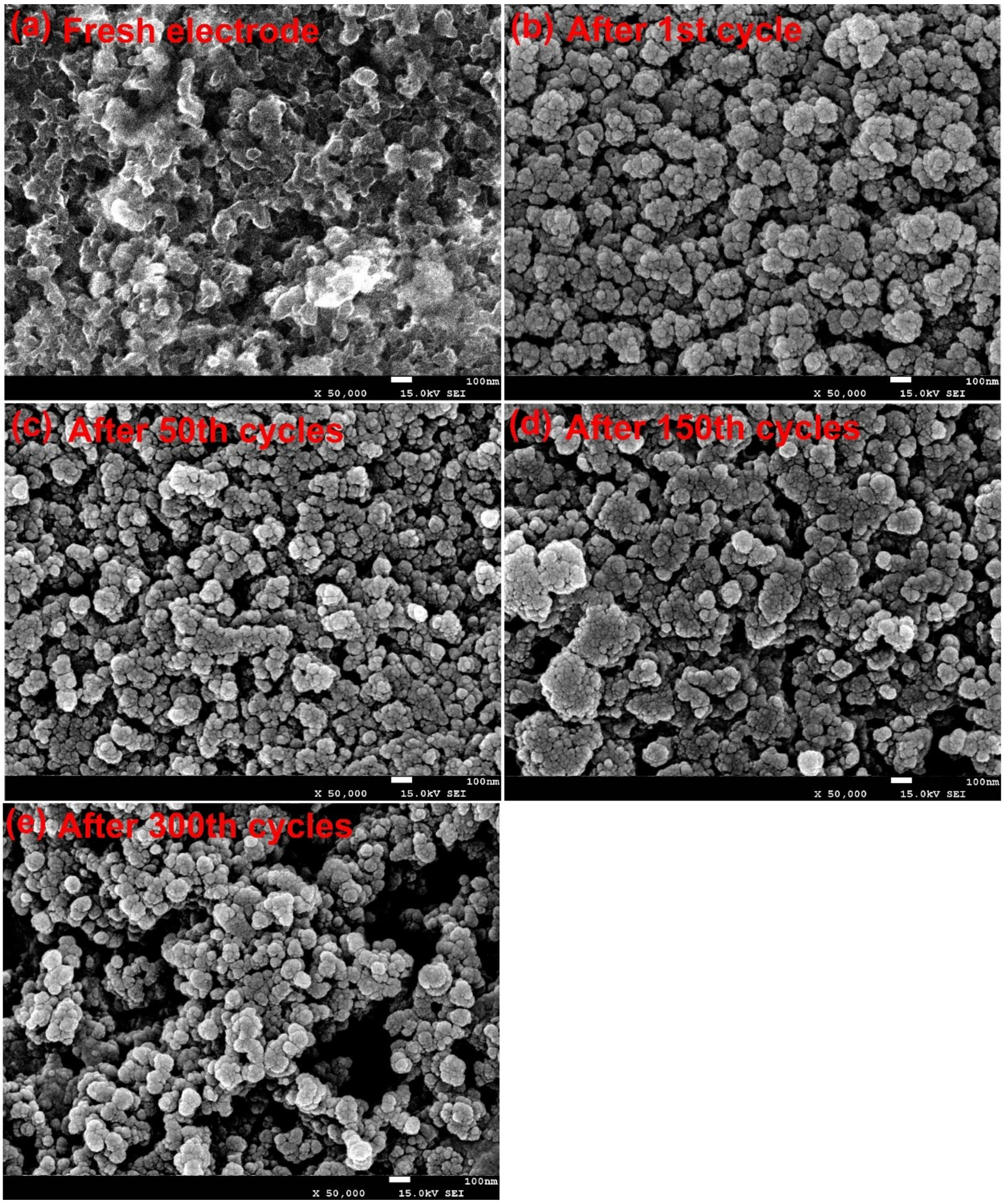
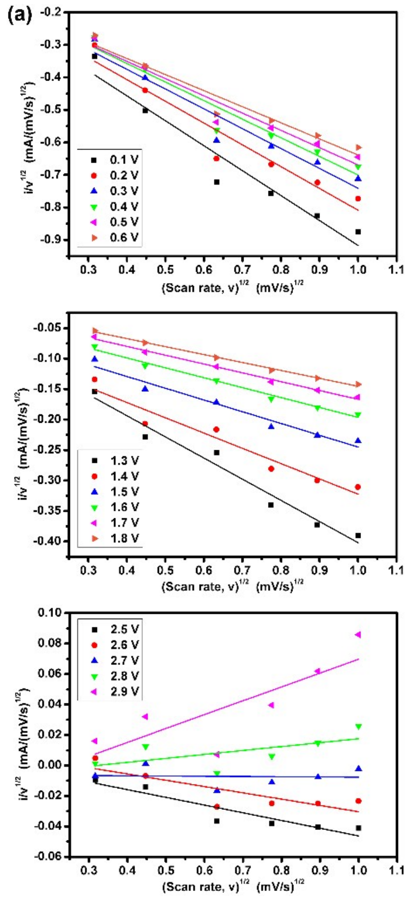


Fig. S5 SEM results of the evolution process of $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ electrodes at a current density of 100 mA g^{-1}. Surface morphology image of (a) fresh electrode, (b) the electrode at the potential of 3.0 V after 1st discharge/charge cycle, (c) the electrode at the potential of 3.0 V after 50th cycles, (d) the electrode at the potential of 3.0 V after 150th cycles, (e) the electrode at the potential of 3.0 V after 300th cycles.


(a)
0.1 V
0.2 V
0.3 V
0.4 V
0.5 V
0.6 V
0.7 V
0.8 V
0.9 V
1.0 V
1.1 V
1.2 V
1.3 V
1.4 V
1.5 V
1.6 V
1.7 V
1.8 V
1.9 V
2.0 V
2.1 V
2.2 V
2.3 V
2.4 V
2.5 V
2.6 V
2.7 V
2.8 V
2.9 V
i/v^1/2 (mA/(mV/s)^1/2)
(Scan rate, v)^1/2 (mV/s)^1/2

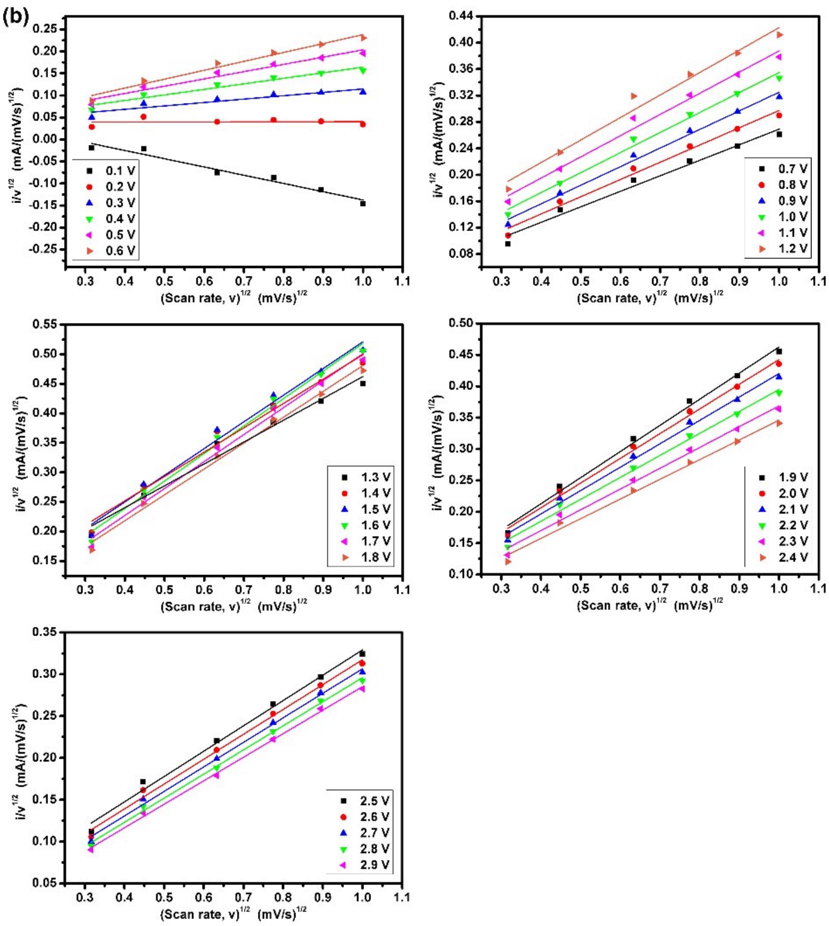

(b)
0.1 V
0.2 V
0.3 V
0.4 V
0.5 V
0.6 V
0.7 V
0.8 V
0.9 V
1.0 V
1.1 V
1.2 V
1.3 V
1.4 V
1.5 V
1.6 V
1.7 V
1.8 V
1.9 V
2.0 V
2.1 V
2.2 V
2.3 V
2.4 V
2.5 V
2.6 V
2.7 V
2.8 V
2.9 V
i/v^1/2 (mA/(mV/s)^1/2)
(Scan rate, v)^1/2 (mV/s)^1/2

Fig. S6 Correlation between the scan rates and corresponding currents of the $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ electrode at (a) cathodic and (b) anodic scan according to equation: $i(V)/ v^{1/2} = k_1v^{1/2} + k_2$.

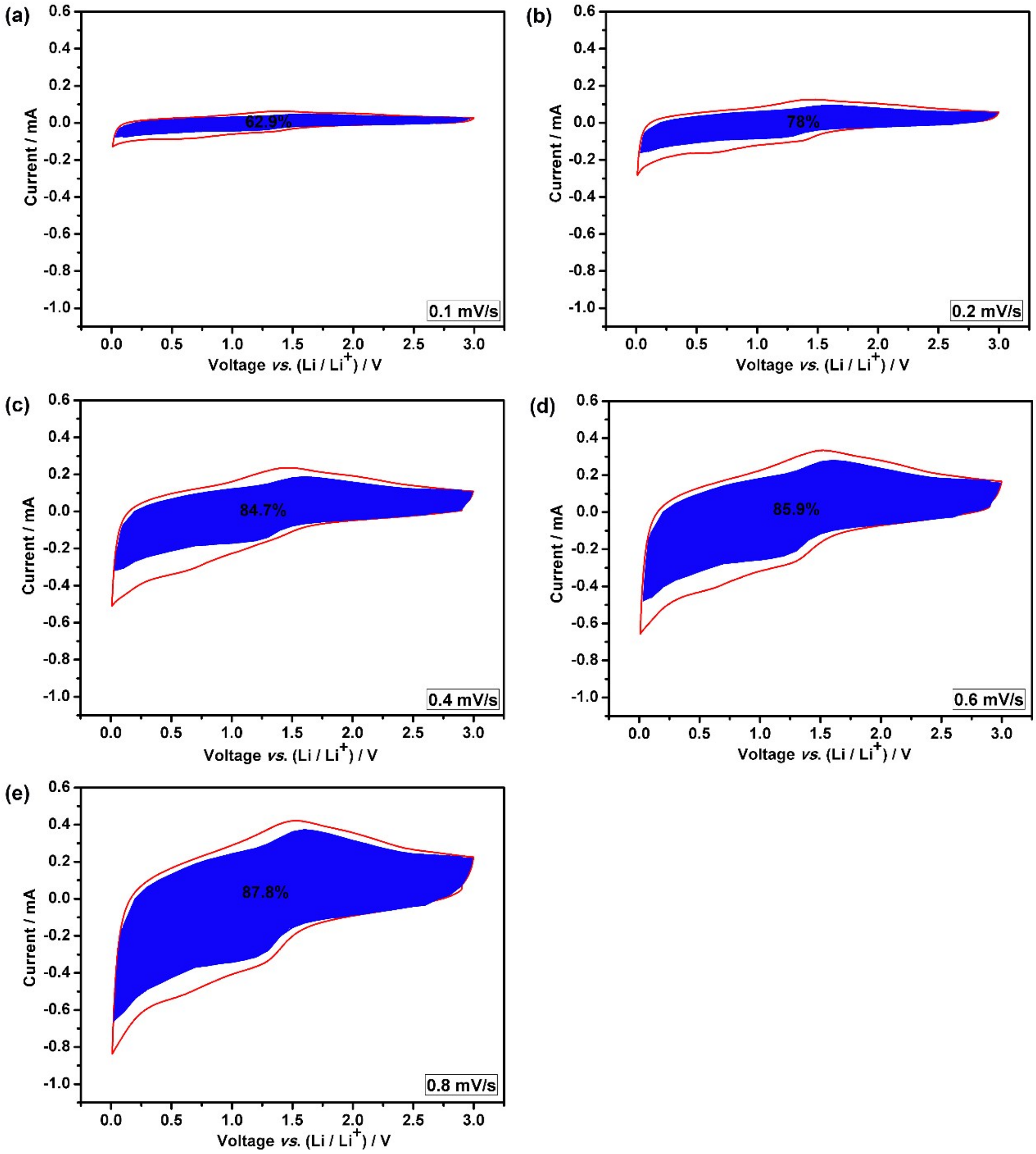


Fig. S7 The capacitive contribution (blue shaded region) to the total current contribution (red line) for the $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ electrode at (a) 0.1, (b) 0.2, (c) 0.4, (d) 0.6, (e) 0.8 mV s^{-1} *vs.* Li^+/Li.

Compounds	Lattice parameters (Å)	Synthesized temperature (ºC)	BET surface area	References

			(±0.1) $m^2\ g^{-1}$	
$NiFe_2O_4$	*a* = 8.3656(4)	900	6.88	*Journal of Physical Chemistry C*, **2015**, *119*, 4709-4718.
$(Zn_{0.25}Ni_{0.75})Fe_2O_4$	*a* = 8.3605(6)	900	4.93	*Journal of Physical Chemistry C*, **2015**, *119*, 4709-4718.
$(Zn_{0.5}Ni_{0.5})Fe_2O_4$	*a* = 8.3590(6)	900	2.25	*Journal of Physical Chemistry C*, **2015**, *119*, 4709-4718.
$(Zn_{0.75}Ni_{0.25})Fe_2O_4$	*a* = 8.3663(2)	900	4.26	*Journal of Physical Chemistry C*, **2015**, *119*, 4709-4718.
$ZnFe_2O_4$	*a* = 8.4375(0)	900	0.79	*Journal of Physical Chemistry C*, **2015**, *119*, 4709-4718.
5%ZnO.95%Fe3O4	For ZnO: *a* = 3.249 *c* = 5.2046 For Fe_3O_4: *a* = 8.4413	600	10.26	*Electrochimica Acta* **2014**, *118*, 75-80.
Fe_2O_3	*a* = 5.021 *c* = 13.734	280	18.95	*Electrochimica Acta* **2014**, *118*, 75-80.
Fe_2O_3	*a* = 5.041 *c* = 13.769	900	0.5	*Electrochimica Acta* **2014**, *118*, 75-80.
$(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$	*a* = 8.396	1000	12.31	This Work

Table S1. The comparison of lattice parameter, BET surface area values between $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ and some other solid solutions reported in literature.

Materials	The first	Capacity [mAh	Capacity	References

	discharge / charge capacities [mAh g^{-1}]	g^{-1}] / number of cycles	[mAh g^{-1}] / current density [mA g^{-1}]	
$Ni_xCo_{3-x}O_4$ nanosheets	2489/1340	1330/50th cycle	293/1600	*ACS Applied Materials & Interfaces* **2014,** *6*, 9256-9264.
Mesoporous $NiCo_2O_4$ microspheres	1712/1214	705/500th cycle	393/1600	*ACS Applied Materials & Interfaces* **2013,** *5*, 981-988.
Mesoporous $ZnCo_2O_4$ microspheres	1600/1205	1256/100th cycle	430/4000	*RSC Advances* **2015,** *5*, 19241-19247.
Mesoporous $ZnCo_2O_4$ microspheres	1332/979	721/80th cycle	382/5000	*Journal of Materials Chemistry A* **2013,** *1*, 5596-5602.
$ZnFe_2O_4$ nanoparticles	1322/933	829/100th cycle	600/1560	*RSC Advances* **2014,** *4*, 49212-49218.
Hollow $CoFe_2O_4$ nanospheres	2264/1230	1185/50thcycle	1030/900	*Nanotechnology* **2012,** *23*, 055402.
Porous $CoFe_2O_4$ nanosheets	1619/1139	806/200th cycle	303/10000	*RSC Advances* **2014,** *4*, 27488-27492.
$Mn_{0.5}Co_{0.5}Fe_2O_4$ hollow spheres	847/526	498/500th cycle	115/2000	*ACS Applied Materials & Interfaces* **2015,** *7*, 6300-6309.
$Ni_{0.33}Mn_{0.33}Co_{0.33}Fe_2O_4$ mesoporous nanospheres	955/686	490/60th cycle	---	*Journal of Materials Chemistry A* **2014,** *2*, 5041-5050.
$Ni_{0.33}Mn_{0.33}Co_{0.33}Fe_2O_4$ on oxidized carbon nanotubes	1092/692	674/100th cycle	300/1000	*RSC Advances* **2014,** *4*, 33769-33775.
$(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$	1261/634	504/300th cycle	268/2000	This work

Table S2. Summary of electrochemical performance of different transition metal oxides as anode materials for lithium ion batteries.

Samples	R_s [Ω]	R_{ct} [Ω]	σ [Ω Hz$^{1/2}$]	D_{Li+}[cm^2 s^{-1}]
The fresh half-cell	39.68	283.53	155.52	1.497×10^{-15}
The half-cell charged to 3.0 V after 300 cycles	0.07	43.35	87.61	4.716×10^{-15}

Table S3. The kinetic parameters of the fresh $(Mg_{0.2}Ti_{0.2}Zn_{0.2}Cu_{0.2}Fe_{0.2})_3O_4$ half-cell (at the open circuit voltage, 3.0 V) and the half-cell charged to 3.0 V after 300 discharge/charge cycles.