**Supporting Information**

**Magnesium Storage Performance and Mechanism of CuS Cathode**

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**Fig. S1.** The discharge curves for CuS cathode during conditioning at room temperature (25 °C) with different electrolyte: (a) Mg(ClO4)2/AN and (b) APC/THF.



**Fig. S2.** (a) CV curve of Mg|APC|Mo cell at 100 mV s−1 in −1.0-2.0 V; (b) the voltage-time curves of Mg|APC|Mg cell in galvanostatic charge/discharge test.



**Fig. S3.** The charge/discharge curves of CuS cathode in first three cycles at room temperature (25 °C).



**Fig. S4.** The charge/discharge curves of CuS cathode at 55 °C with cut-off potential of 1.8 V.



**Fig. S5.** The charge/discharge curves of CuS cathode at different current density at 50 °C.



**Fig. S6.** The charge/discharge curves of CuS cathode with MACC electrolyte at 50 °C.



**Fig. S7.** The SEM image of CuS after first discharged process.



**Fig. S8.** The GITT potential response plot with time in one pulse period.

*Calculation of Magnesium-ion diffusivities*

$$D^{GITT}=\frac{4}{πτ}\left(\frac{m\_{B}V\_{M}}{M\_{B}S}\right)^{2}\left(\frac{△E\_{s}}{△E\_{τ}}\right)^{2}$$

Where τ refers to constant current pulse time, *m*B, VM, MB, and S are the mass, molar volume, molar mass of the cathode material, and electrode-electrolyte interface area, respectively. △ES is voltage difference during a single-step experiment, and △Eτ is the total change of cell voltage during a constant current pulse (**Figure S4**).