Supplementary Information

Long-lasting, flexible, and fully bioresorbable AZ31-tungsten batteries for transient, biodegradable electronics

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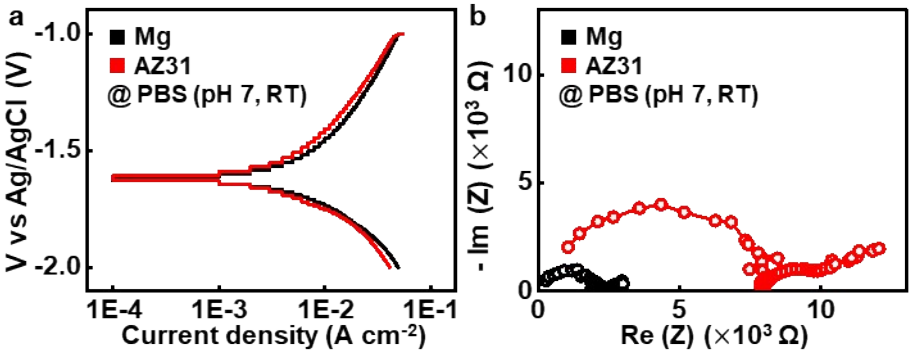

Figure S1. Comparison of electrochemical characteristics between Mg and AZ31. (a) Galvano-dynamic polarization of Mg and AZ31, showing voltage profiles corresponding to different current densities. (b) Nyquist plot of Mg and AZ31, where the diameter of the semicircle provides information about the charge transfer resistance.

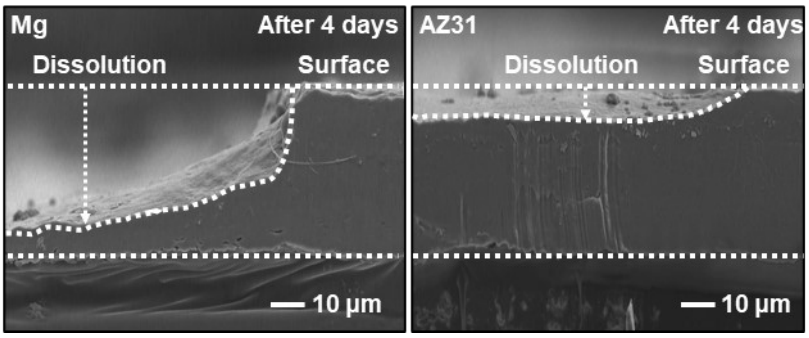

Figure S2. Cross-sectional scanning electron microscopic (SEM) images of Mg (left) and AZ31 (right) anodes, after immersion in phosphate-buffered saline (PBS, pH 7.4) solution at room temperatures for 4 days.

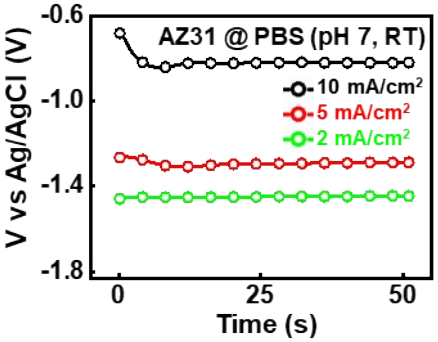

Figure S3. Measured electrodes potentials of AZ31 against the standard reference electrode (Ag/AgCl) at various discharge currents (2, 5, and 10 mA/cm^2).

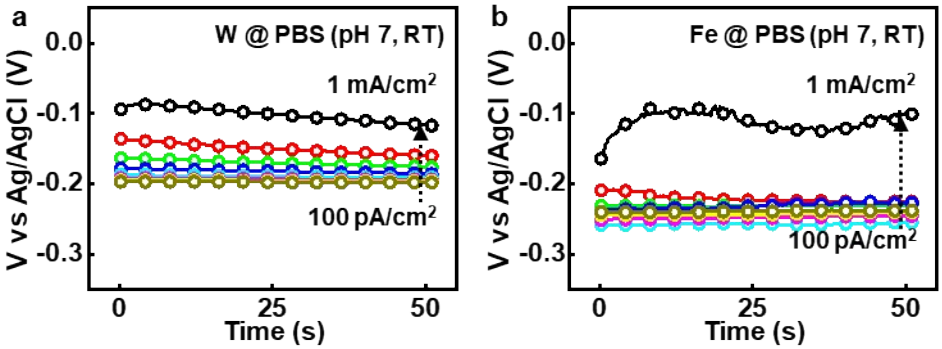

Figure S4. Temporal voltage profiles at various currents (from 100 pA/cm^2 to 1 mA/cm^2) of W (a), and iron (b), in biological electrolyte solutions (PBS pH 7, RT). Fe showed unstable voltage outcomes when current increased due to the oxidation.

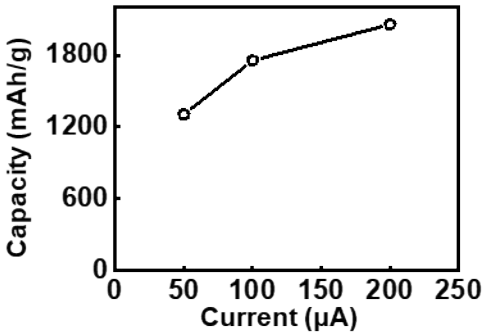

Figure S5. Capacity of an AZ31 (anode)-W (cathode) full cell in PBS solution (electrolyte) at different discharge currents.

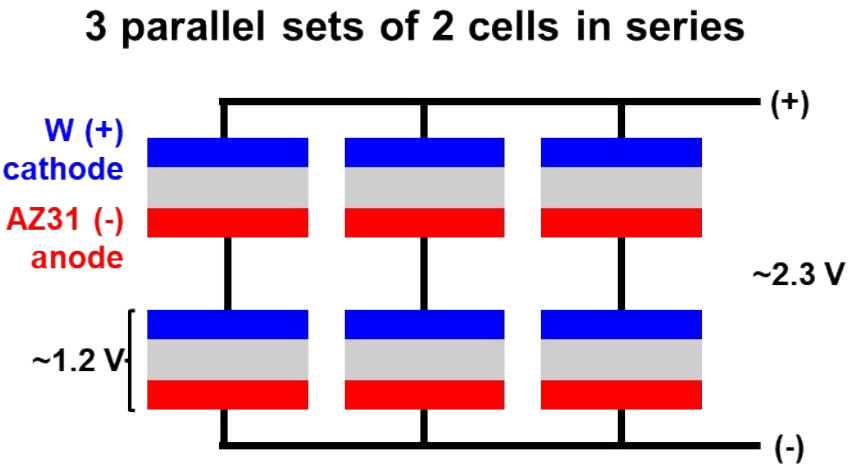

Figure S6. Circuit diagram illustrating the arrangement of W-AZ31 cells within the pouch battery.

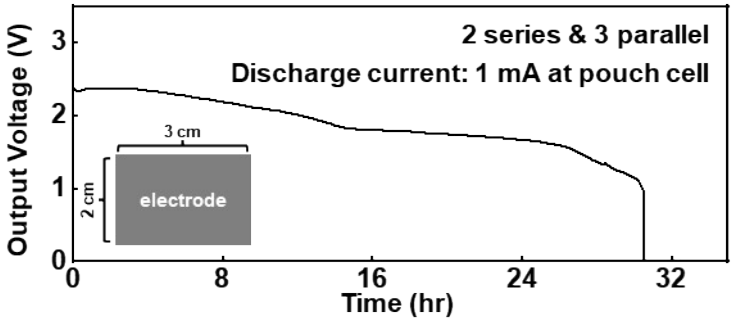

Figure S7. Discharge profiles of the pouch battery at a discharge current of 1 mA at pouch cell with the x-axis indicating discharge time.

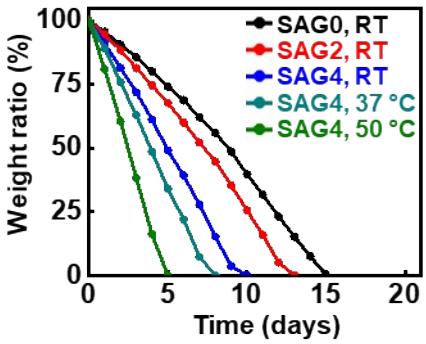

Figure S8. Time-dependent changes in weight ratios of SAG electrolyte films as a function of weight ratio of glycerol.

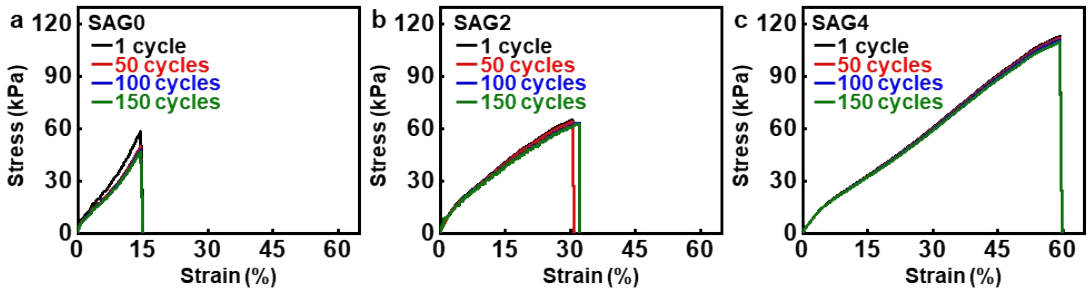

Figure S9. Mechanical cyclic stability of SAG0 (a), SAG2 (b), and SAG4 (c) electrolyte under a bend deformation at bending radius of 5 mm.

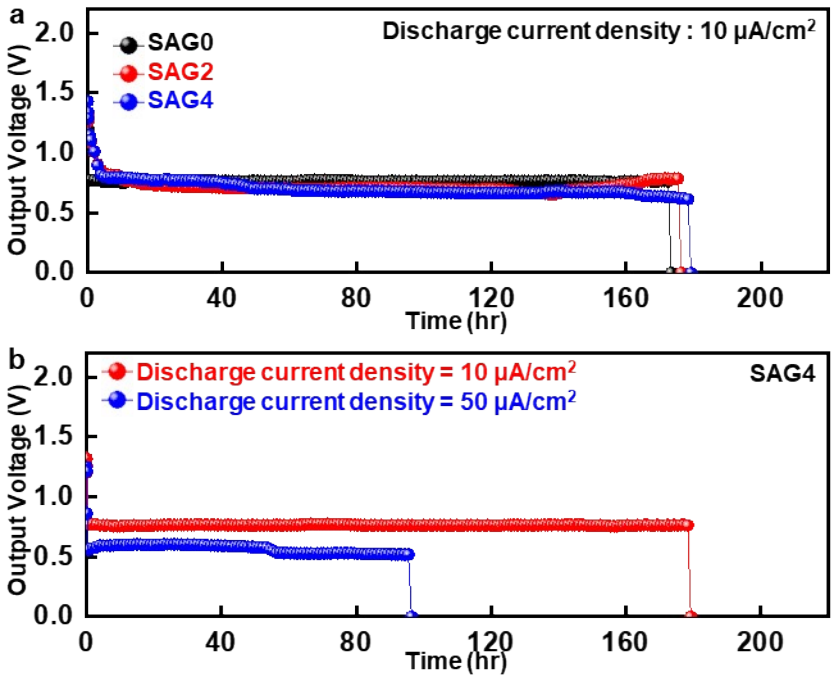

Figure S10. (a) Discharge curves of the degradable batteries based on discharge time with varying concentrations of glycerol within the solid-state electrolyte (discharge current density: 10 μA/cm^2). (b) Discharge curves of SAG4 based on discharge time with different discharge currents density.

Battery Type	Electrolyte	Working Voltage (V)	Discharge Current ($\mu A/cm^2$)	Lifetime (hr)	Ref
Mg-(Mo, W, or Fe)	PBS solution	Mo: 0.45 W: 0.65 Fe: 0.75	100	24	[1]
AZ31-PPy-pTS	Chitosan	1.33	10	160	[2]
Mg-Fe	PCL	0.7	45	99	[3]
Mg-MoO_3	Alginate	1.6 (50hr), 0.6 (250hr)	25	312	[4]
Mg-Fe	PCL	0.45	12.5	24	[5]
Mg-Mo	Alginate	1.5	45	100	[6]
Zn-Mo	Gelatin	0.6	10	288	[7]
Zn-Mo	PLLA-PTMC	0.5	25	50	[8]
AZ31-W	Alginate	0.9	10	180	Ours

*PBS: Phosphate buffered saline
*PPy-pTS: Polypyrrole–toluene-4-sulfonic
*PCL: Polycaprolactone
*PGS:Poly (glycerol sebacate)
*PLLA-PTMC: Poly (L-lactic acid) and Poly (trimethylene carbonate)

Table S1. Comparison of previous biodegradable batteries with our approach.

References

[1] Yin, L., Huang, X., Xu, H., Zhang, Y., Lam, J., Cheng, J., & Rogers, J. A. Adv. Mater. 2014, 26, 3879-3884.

[2] X. Jia, Y. Yang, C. Wang, C. Zhao, R. Vijayaraghavan, D. R. MacFarlane, M. Forsyth and G. G. Wallace, ACS Appl. Mater. Interfaces, 2014, 6, 21110–21117.

[3 Tsang, M., Armutlulu, A., Martinez, A. W., Allen, S. A. B., & Allen, M. G. Microsystems & Nanoengineering, 2015, 1, 1-10.

[4] X. Huang, D. Wang, Z. Yuan, W. Xie, Y. Wu, R. Li, Y. Zhao, D. Luo, L. Cen, B. Chen, H. Wu, H. Xu, X. Sheng, M. Zhang, L. Zhao and L. Yin, Small, 2018, 14, 1800994.

[5] D. She, M. Tsang and M. Allen, Biomed. Microdevices, 2019, 21, 17.

[6] M. Karami-Mosammam, D. Danninger, D. Schiller and M. Kaltenbrunner, Adv. Mater., 2022, 34, e2204457.

[7] X. Huang, H. Hou, B. Yu, J. Bai, Y. Guan, L. Wang, K. Chen, X. Wang, P. Sun, Y. Deng, S. Liu, X. Cai, Y. Wang, J. Peng, X. Sheng, W. Xiong and L. Yin, ACS Nano, 2023, 17, 5727–5739.

[8] B. Yu, J. Bai, Y. Guan, X. Huang, L. Liang, Z. Ren, X. Song, T. Zhang, C. Yang, F. Dai, X. Wang, X. Sheng, J. Peng, L. Wang, Y. Wang and L. Yin, Biosens. Bioelectron., 2024, 263, 116578.