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Supporting Information

Nacre-based carbon nanomeshes for soft ionic actuator with large and rapid deformation

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Supporting Table

Table S1

Electrode Materials	Voltage (V)	Strain (%)	Power consumption (mW cm^{-2})	Reference
Carbon nanomeshes/PVDF	3	1.11	205.7	This work
Platinum	3	0.32	3981.1	Ref. 54
SWNT	5	0.16	546.43	Ref. 47
PPy	5	0.15	1500.6	Ref. 52
SWNT	2.5	0.29	150.15	Ref. 46
BP-CNT	2.5	1.37	53.29	Ref. 49
BP-CNT	2.5	1.02	41.84	Ref. 49
RGO/MWCNT	2	0.27	53.16	Ref. 20
SWNT	2	0.10	7936.8	Ref. 48
SWNT	2	0.016	3645.5	Ref. 53
RGO/Ag	1	0.45	42.99	Ref. 19
SWCNT	1	1.26	159.79	Ref. 45
PANI@CNT	1	0.24	737.17	Ref. 50
GO/PANI	1	0.45	796.61	Ref. 51
Th-SNG/PEDOT:PSS	0.5	0.2	–	Ref. 10
HPNC/PEDOT:PSS	0.5	0.54	–	Ref. 55
Graphene/Nafion	0.5	0.03	–	Ref. 56

Supporting figures

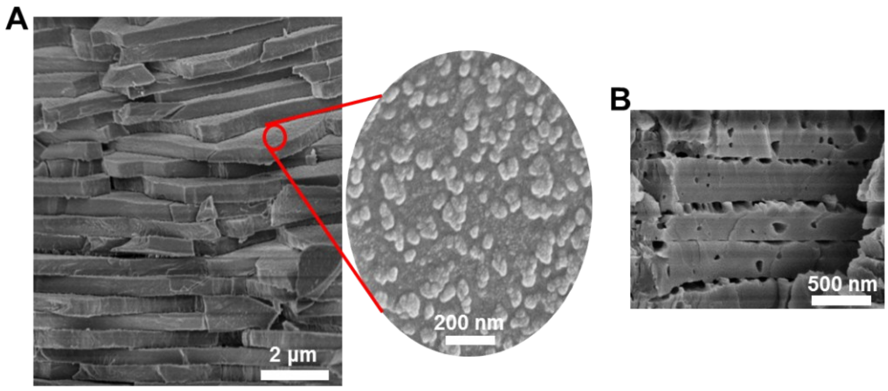


Fig. S1 Microstructures of nacre and mineral bridges.

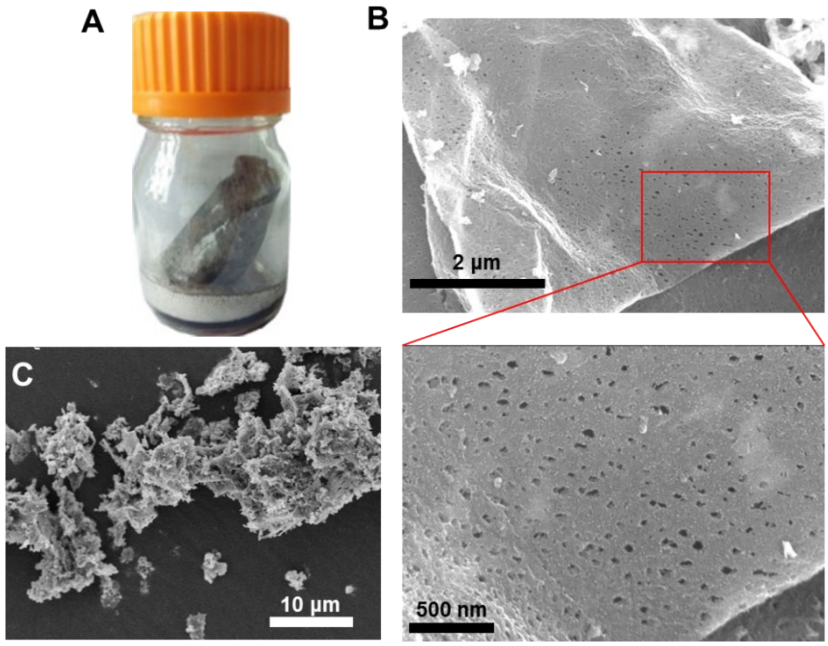


Fig. S2 Synthesis of carbon nanomeshes with Pathway I. (A) Optical image of calcinated nacre in acid solution. (B) SEM of carbon nanomeshes produced at 550 ^{o}C. (C) SEM of carbon residues after calcination at 700 ^{o}C.

$$CaCO_3 \overset{\Delta}{=\!=} CaO + CO_2 \uparrow \tag{1}$$

$$CO_2 + C \overset{\Delta}{=\!=} CO \tag{2}$$

Fig. S3 Thermal degeneration of $CaCO_3$ and CO_2 etching.

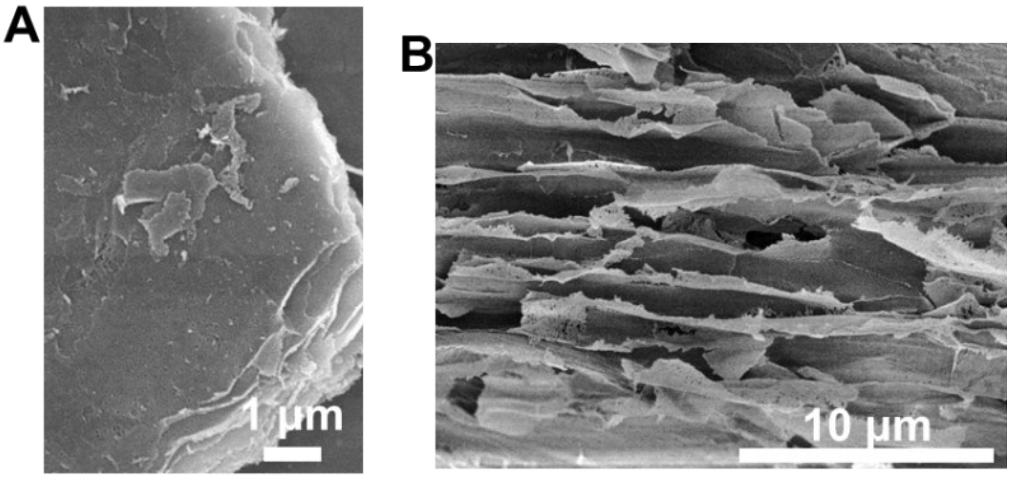


Fig. S4 SEM images of nacre after removing mineral with acids.

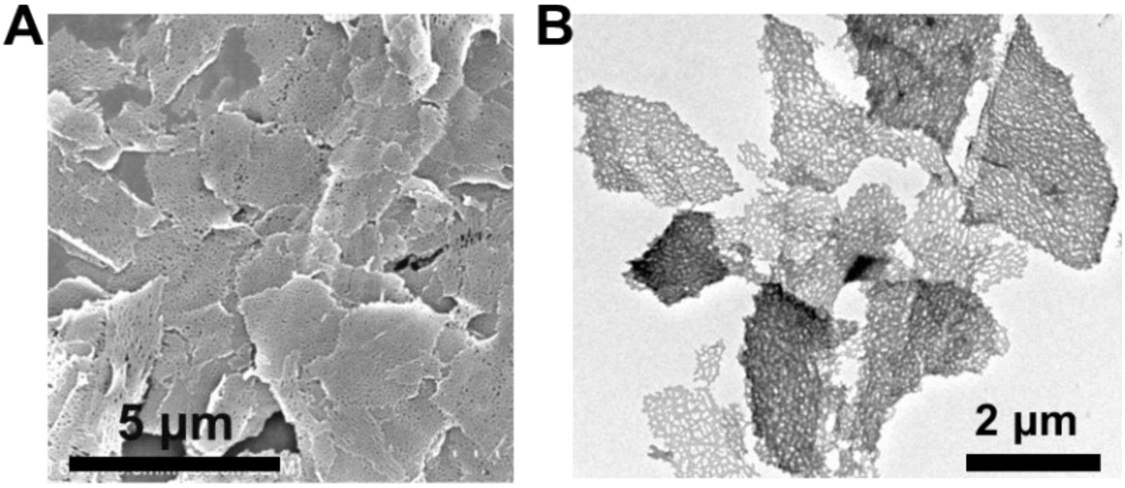


Fig. S5 SEM (A) and TEM (B) images of exfoliated organic nanomeshes.

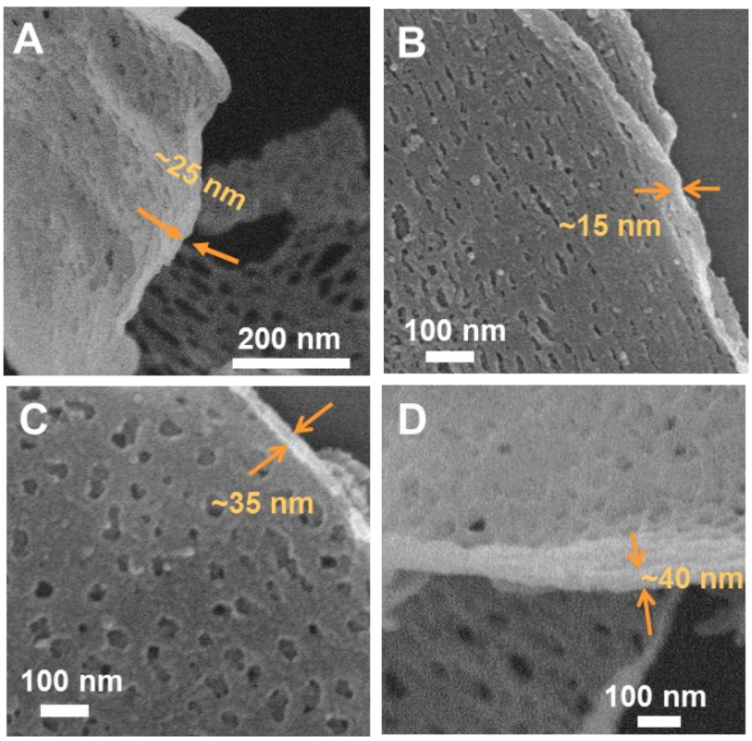


Fig. S6 Typical SEM images of organic nanomeshes, indicating a thickness of ~15–40 nm.

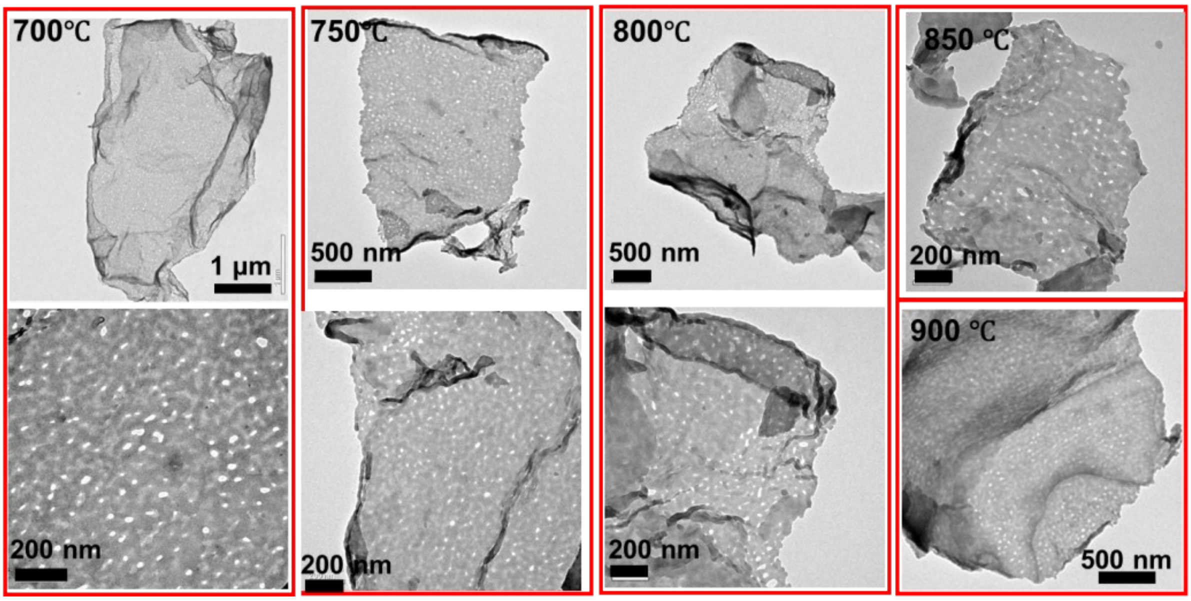


Fig. S7 Typical TEM images of carbon nanomeshes prepared at carbonization temperatures from 700 to 900 °C.

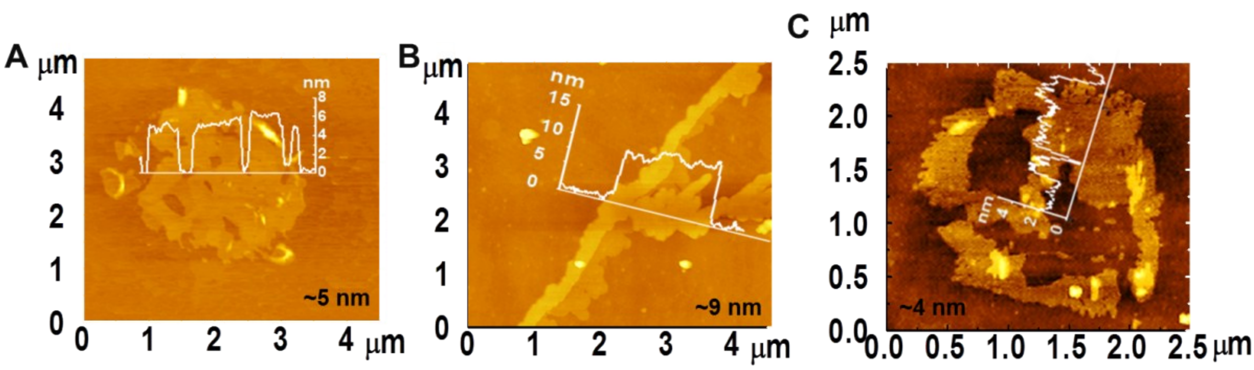


Fig. S8 Typical height AFM images of carbon nanomeshes prepared at 850 °C and profiles along the indicated line. A thickness of ~4–9 nm was observed.

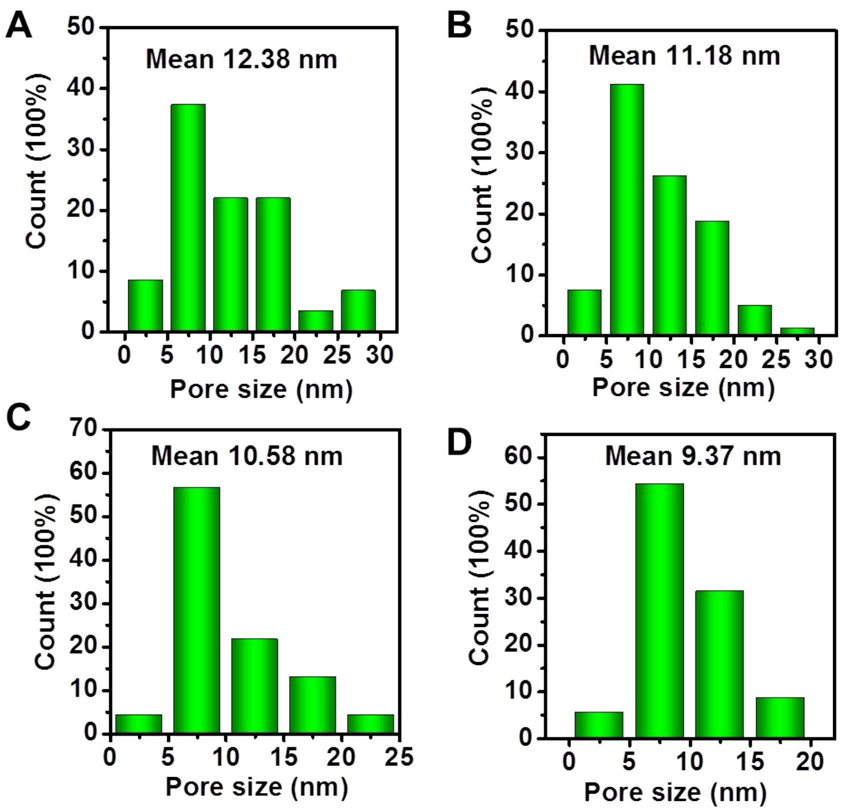


Fig. S9 Histogram of in-plane pore diameters of carbon nanomeshes prepared at temperatures of 700 (A), 800 (B), 850 (C) and 900 °C (D).

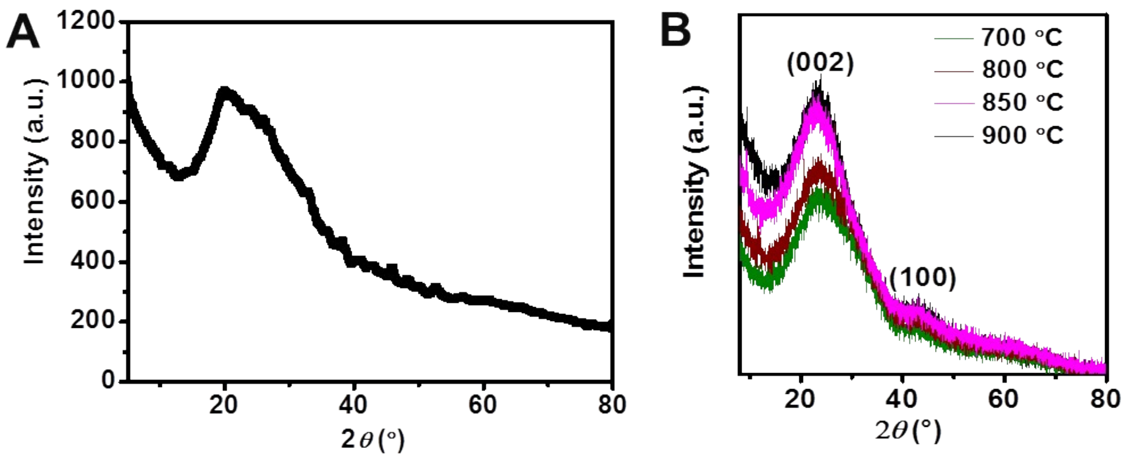


Fig. S10 XRD spectra of organic nanosheets (A) and carbon nanomeshes (B) produced at different temperatures.

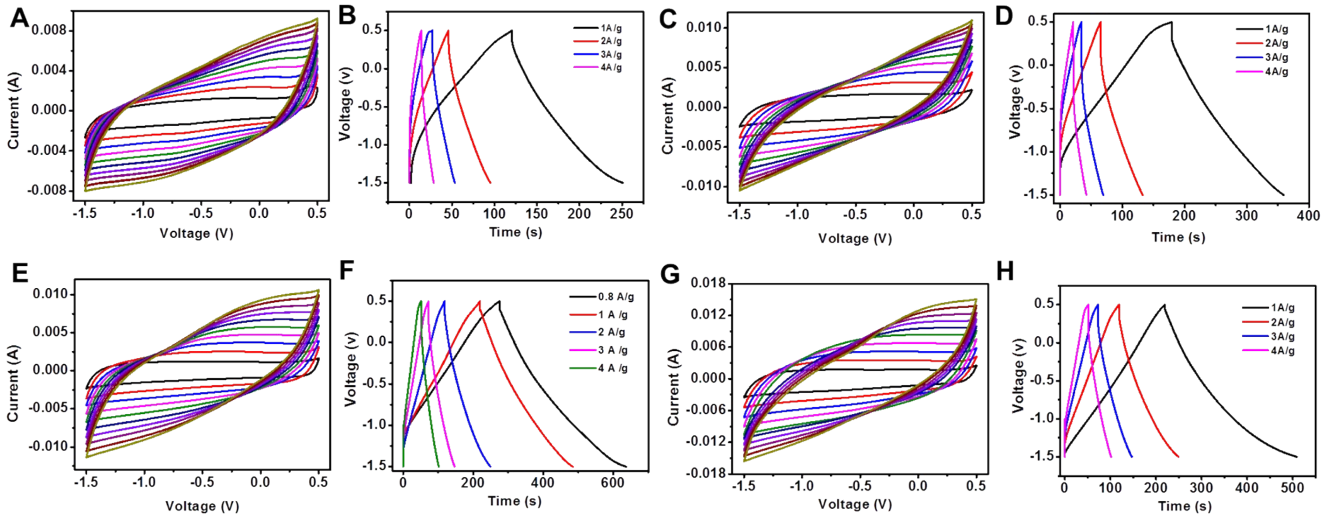
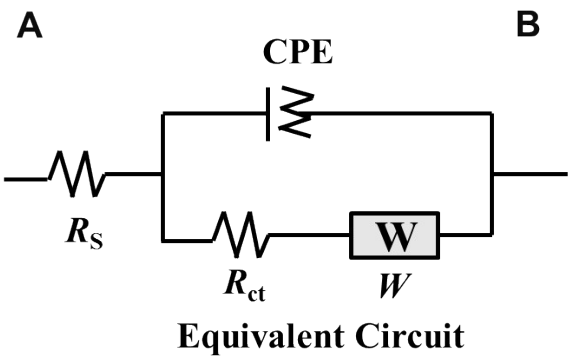


Fig. S11 (A, C, E & G) CV curves at different scan rates from 10 to 100 mV s^{-1} of carbon nanomeshes prepared at temperature of 700 (A), 800 (C), 850 (E) and 900 °C (G). (B, D, F & H) galvanostatic charge/discharge curves at different current densities from 0.8 to 4 A g^{-1} of carbon nanomeshes prepared at temperature of 700 (B), 800 (D), 850 (F) and 900 °C (H).



B

Samples	R_S	R_{ct}	Freq power
700	2.9	19.6	0.74
800	2.1	13.3	0.81
850	1.7	12.2	0.82
900	1.2	7.2	0.89

Fig. S12 Equivalent circuit of Nyquist plots (A) and fitting results (B) of carbon nanomeshes prepared with different calcination temperatures.

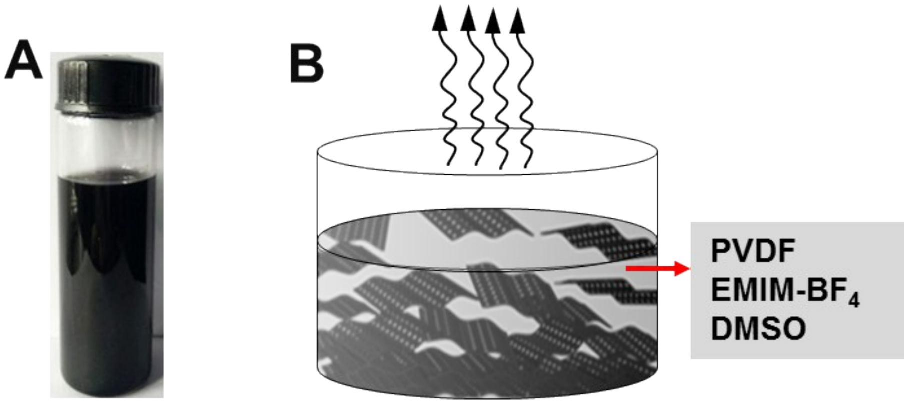


Fig. S13 (A) Optical image of carbon nanomesh dispersion in PVDF. (B) Schematic fabrication of gradient membrane electrode with casting method.

Fig. S14 Optical images of transparent pure ionic gel membrane and its sectional SEM image.

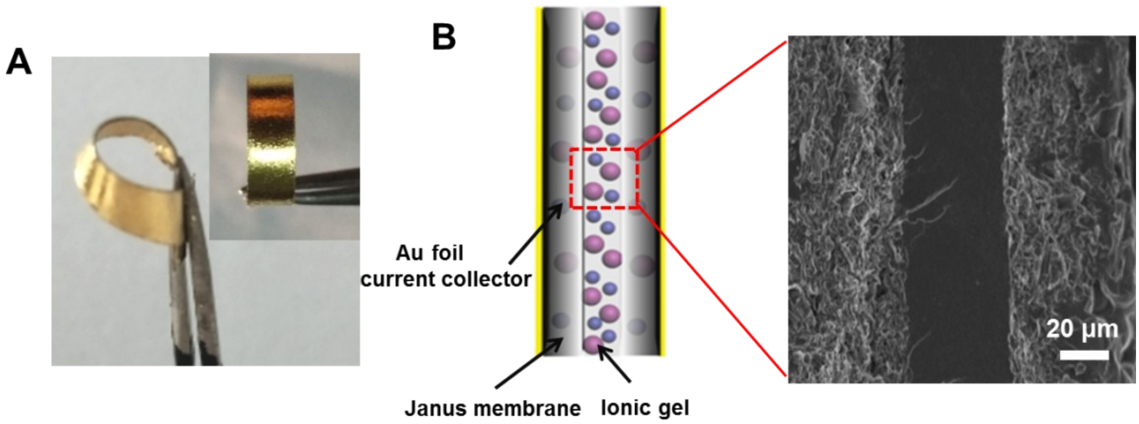


Fig. S15 (A) As-fabricated ionic muscle laminated by two 120 nm-thick Au foils as current collectors. (B) Schematic structure of the as-fabricated ionic muscle and its cross-sectional SEM image.

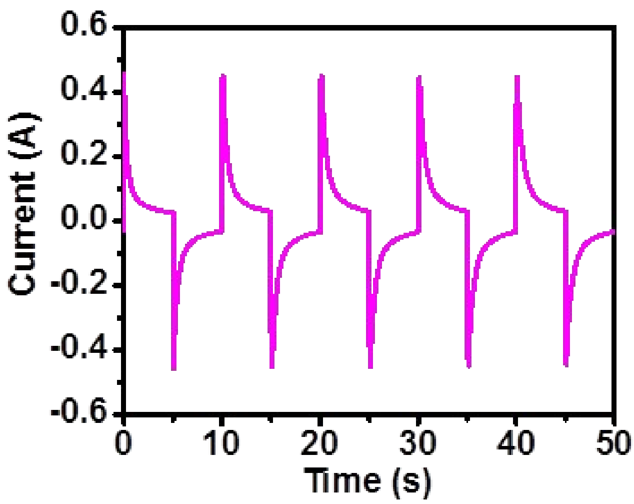


Fig. S16 Corresponding current with driving voltage of 3 V and frequency of 0.1 Hz. Power consumotion was calculated according to the equation: $P = \frac{\int_0^T vidt}{T}$, where p is power, v and i is the instantaneous voltage and current at time t, respectively, and T is the time period.

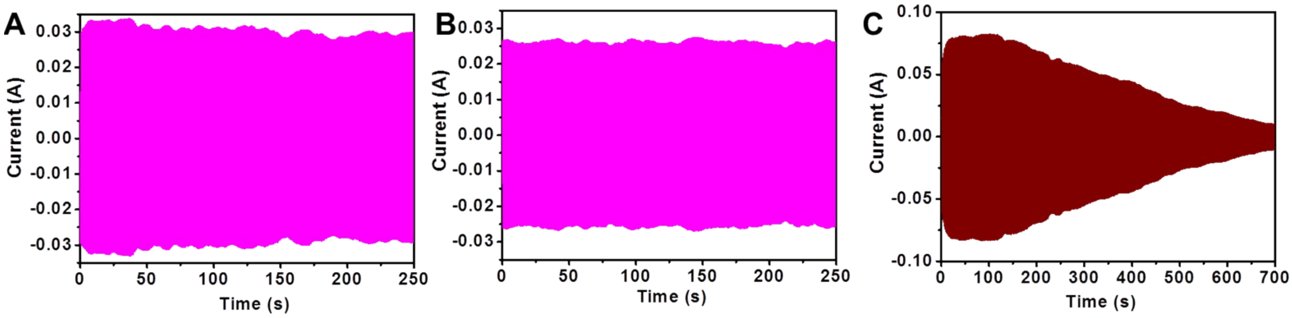


Fig. S17 Cyclic performance of the ionic muscles fabricated with gradient carbon nanomesh electrodes (A & B) and with pure ionic gel electrodes (C). A is for the first 250 cycles, B is for the last 250 cycles (9301st–10000th cycles), while C is for 700 cycles.

Supporting Videos

Video S1. Actuation performance of ionic muscle driven by 3 V at 0.1 Hz.

Video S2. Temporal actuating behavior of ionic muscle at diverse driving voltages.

Video S3. Temporal displacement (δ) at 3 V bias with varying frequencies.