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Supplementary information

Remote, fast actuation of programmable multiple shape memory composites by magnetic fields

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Experimental

Materials

Nafion® solution with polymer content 5.0 wt% was purchased from DuPont (Wilmington, USA). Fe_3O_4 nanopowder was purchased from Aladdin Chemistry Co.,Ltd. (Shanghai, China). Poly(ethyleneoxide) (PEO) (Mn=900 000) was obtained from Changchun Jinghua Co., Ltd.(Changchun, China). All these chemicals were used without any further treatment.

Characterization

The morphology of Nafion/Fe_3O_4 membranes was observed by FEI Nova Nano SEM FEG.

The mechanical performance was tested with a dynamic mechanical analyzer (DMA, TA) at a constant frequency of 1 Hz from 25 °C to 120 °C at heating rate of 10 °C/min.

The magnetic property measurements were carried out on a vibrating sample magnetometer (VSM).

The shape memory effect was measured by dynamic mechanical analyzer (DMA, TA) in force control model.

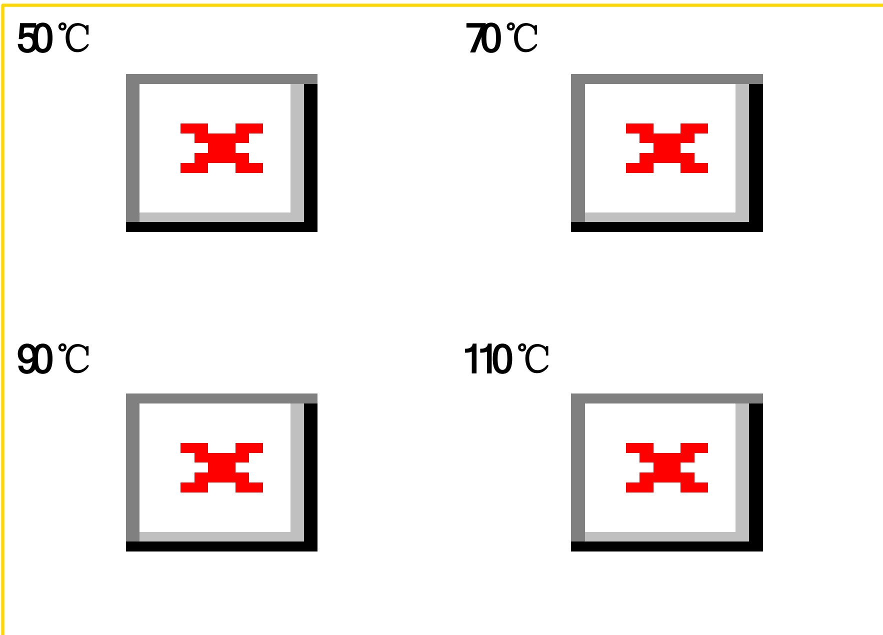

Fig. S1 SEM images of Nafion/Fe_3O_4 composite fibers treated under different temperatures.

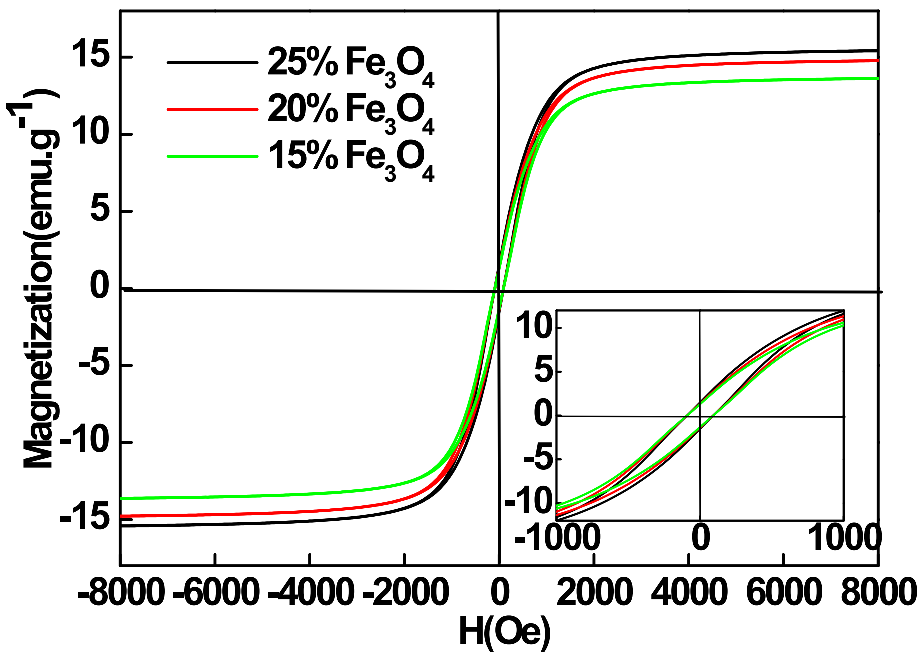

Fig.S2 VSM curves of Nafion/Fe_3O_4 composite fibers.

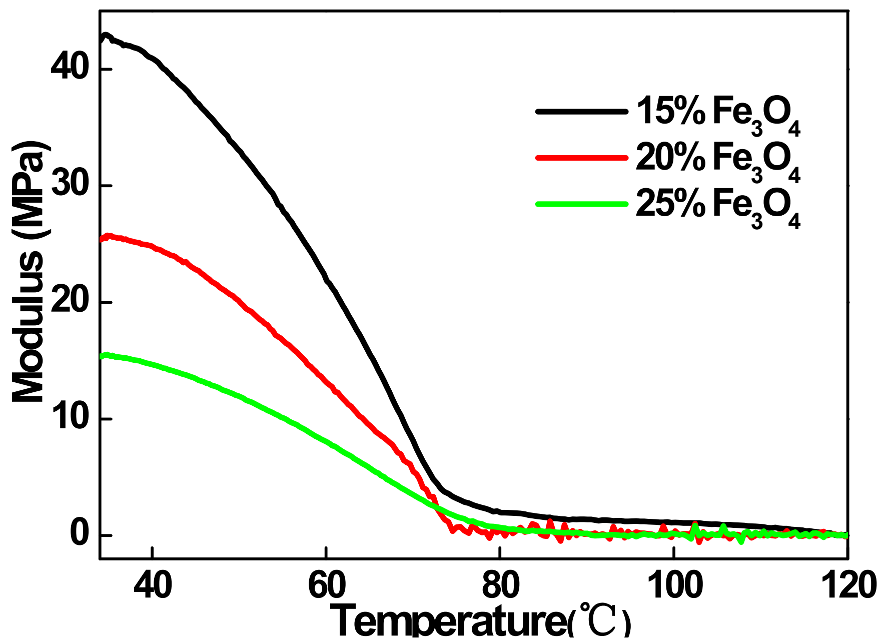

Fig. S3 DMA images of Nafion/Fe_3O_4 composites fibers.

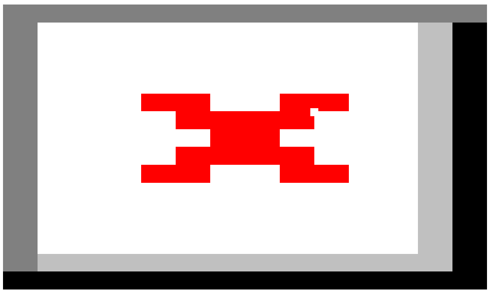

Fig. S4 Dual-shape memory effect: (a) shape recovery performance induced by magnetic field, (b) shape memory cycle, (c) three cycles.

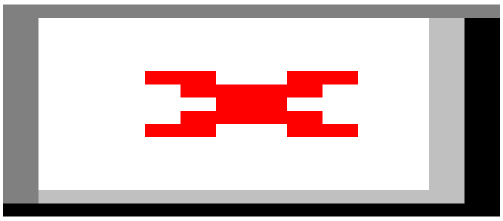

Fig. S5 Tangent delta curves (G”/G’) vs temperature: (A) Nafion N117, (B) Nafion/Fe_3O_4 composites fibers.

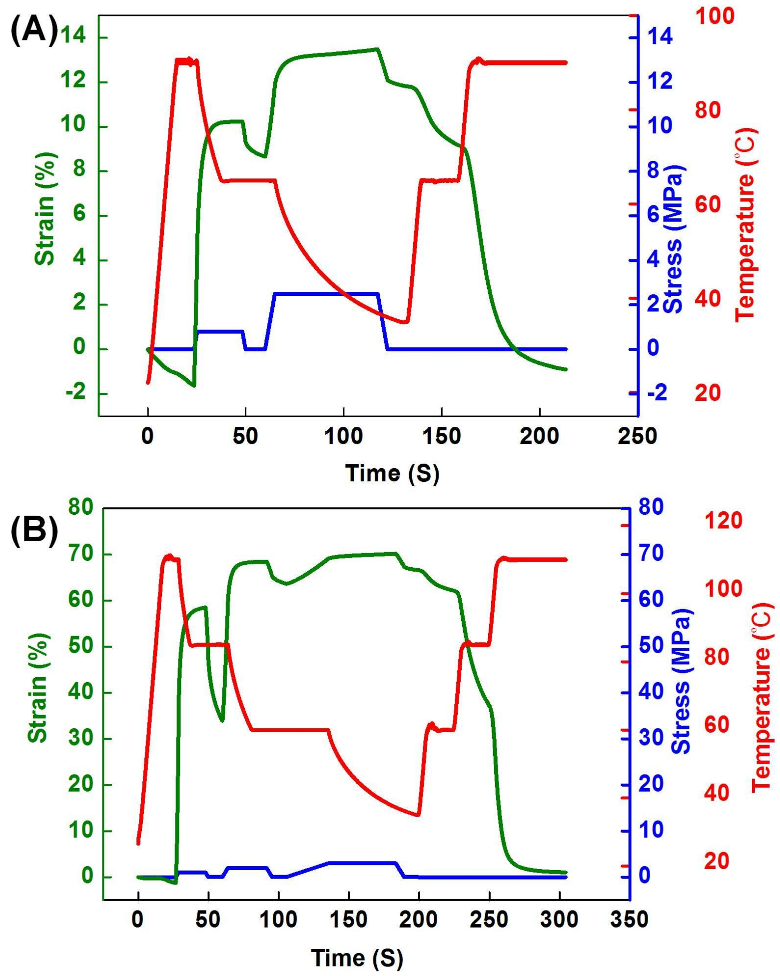

Fig. S6 (A) triple thermal mechanical cycle ($T_{d1} = T_{r2}$ = 90 °C, $T_{d2} = T_{r1}$ = 70 °C), (B) quadruple thermal mechanical cycle ($T_{d1} = T_{r3}$ = 110 °C, $T_{d2} = T_{r2}$ = 85 °C, $T_{d3} = T_{r1}$ = 60 °C).

Equations (1) and (2) were used to calculate R_f and R_r for the multi-shape memory effect [5].

$$R_f(X \rightarrow Y) = \frac{\varepsilon_y - \varepsilon_x}{\varepsilon_{y,load} - \varepsilon_x} \times 100\% \quad (1)$$

$$R_r(Y \rightarrow X) = \frac{\varepsilon_y - \varepsilon_{x,rec}}{\varepsilon_y - \varepsilon_x} \times 100\% \quad (2)$$

where X and Y denoted different shapes, $\varepsilon_{y,load}$ was the maximum strain under load, ε_y and ε_x were the fixed strains after cooling and load removal, and $\varepsilon_{x,rec}$ was the strain after recovery.

Tab. S1. Shape memory properties of Nafion/Fe_3O_4 nanofibers.

Multi-shape memory cycle	Shape fixity (%)	Shape recovery (%)
Triple-shape memory cycle	S0→S1=93.1 S1→S2=71.4	S1→S0=94.7 S2→S1=82.9
Quadruple-shape memory cycle	S0→S1=64.3 S1→S2=95.7 S2→S3=66.2	S1→S0=97.1 S2→S1=96.5 S3→S2=89.2

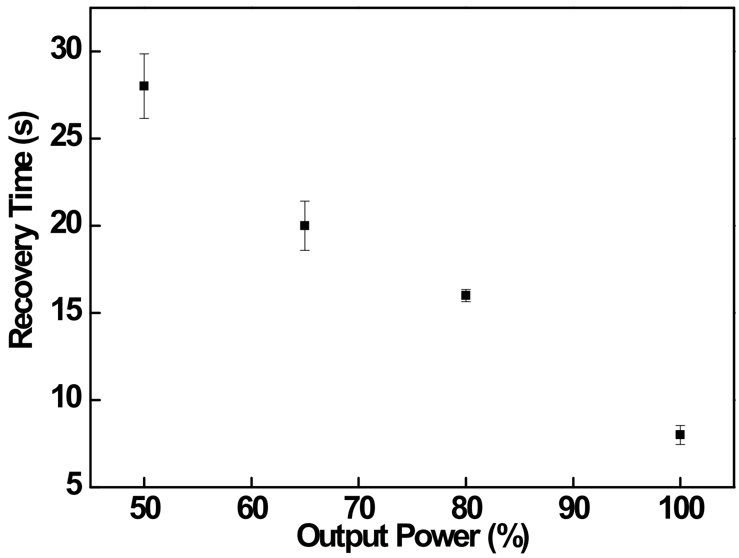

Fig. S7 Shape recovery time vs output power (Nafion composite fibers with 25% Fe_3O_4).