Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information for

Photo-driven nanoactuators based on carbon nanocoil and vanadium dioxide bimorph

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1. Resistivity-temperature curves of VO_2 films and CNT films

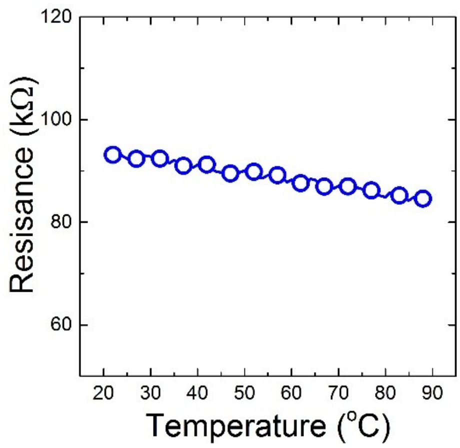

Figure S1. Resistance change of a pristine CNC as a function of temperature ranging from 20 to 90 ^{o}C. The resistance of the pristine CNC only decreases by ~4% when the temperature changes from 55 ^{o}C to 75 ^{o}C.

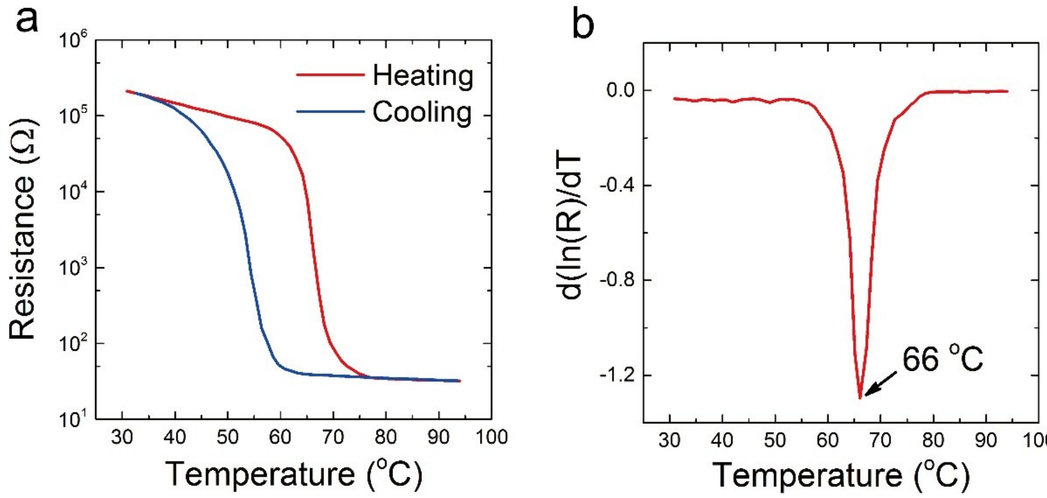

Figure S2. (a) Resistance of VO_2 film on quartz substrate as a function of temperature under heating and cooling processes. (b) The derivative logarithmic plot of the resistance of the VO_2 film on quartz substrate versus temperature. When heated from 55 to 75 °C, the VO_2 film decreases by ~2000 times in resistance and its MIT temperature during heating is determined to be ~66 °C.

2. Curvature change of the VO_2/CNC actuator with temperature

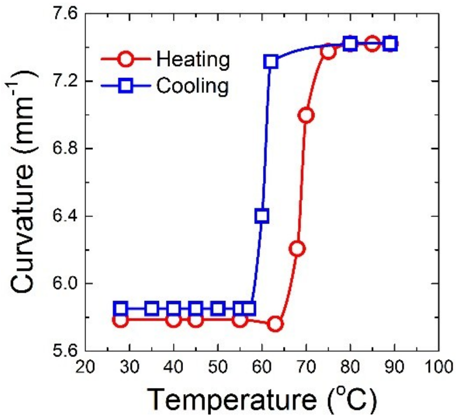

Figure S3. Curvature change of the VO_2/CNC actuator during heating and cooling processes. The drastic change of the curvature around the MIT temperature of VO_2 (~68 °C) and the existence of a hysteresis between heating and cooling processes suggest an MIT actuating mechanism for VO_2/CNC actuators.

3. Thermal transfer model for VO_2/CNC actuators

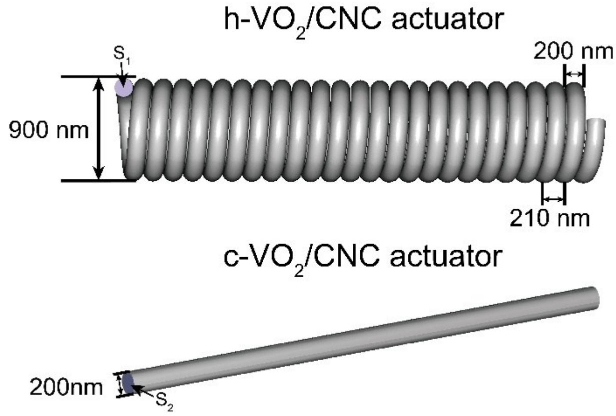

Figure S4. Geometrical models of h-VO_2/CNC and c-VO_2/CNC in the thermal transfer model.

In the 3D steady-state thermal transfer equation $\nabla \cdot (-k\nabla T) = Q$, k is the thermal conductivity of VO_2/CNC. The thermal conductivity of the CNCs at room temperature was reported to be in the range of 2-30 W/(m·K)[1, 2] and the thermal conductivity of the VO_2 film was reported to be 5 W/(m·K)[3]. In this model, we considered the thermal conductivity of the individual CNCs was 5 W/(m·k), which was same to the VO_2 film, thus the thermal conductivity of VO_2/CNC was also 5 W/(m·k). The thermal source (Q, W/m^3) was calculated by $(\frac{P \times S}{V}) \times A$, where P was the density of laser power, S was upper half surface area of the VO_2/CNC, V was the volume of the VO_2/CNC and A is the absorbance of the CNC. P and A were set to be 2000 mW/cm^2 and 0.85, respectively. Because surfaces S_1 and S_2 were connected to the substrate (tungsten probe), the boundary conditions for them (Fig. S4) are $-n \cdot \nabla(-k\nabla T) = h_{substrate}(T - T_{substrate})$, where $h_{substrate}$ was the heat transfer coefficient between the VO_2/CNC and the tungsten probe and $h_{substrate}$ is the temperature of tungsten probe. In our model, $h_{subsrate}$ was considered to be 1.33×10^5 W/(m^2·K), which originated from the interface thermal resistance in the Cu-polymer-CNT Si system[4] and $T_{substrate}$ was 298 K. The boundary conditions for all surfaces except of S_1 and S_2 were $-n \cdot \nabla(-k\nabla T) = h_{air}(T - T_{air})$, where h_{air} was the heat transfer coefficient of air (20 W/(m^2·K)) and T_0 was environmental temperature (298

K). The simulation was performed by the COMSOL Multiphysics software.

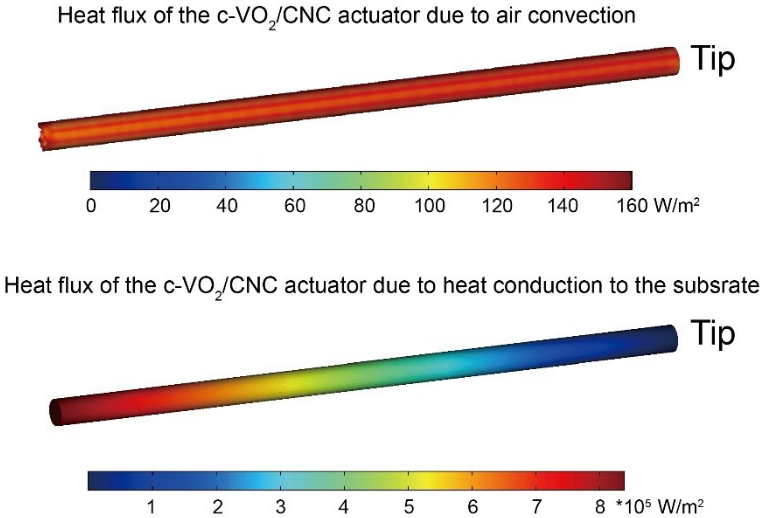

Figure S5. Comparison of simulated heat flux of the c-VO_2/CNC actuator due to air convection and heat conduction to the substrate, respectively. It shows that the heat flux through conduction is 3 orders of magnitude higher than that through convection, suggesting that most of heat in the c-VO_2/CNC actuator dissipates through the thermal conduction to the tungsten probe.

4. Response frequency of the VO_2/CNC actuators

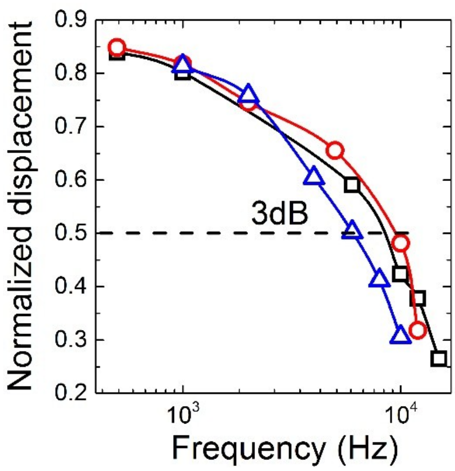

Figure S6. Enlarged image of Fig. 4e showing that the 3 dB attenuation frequency of sample 1, 2 and 3 are 8500 Hz, 9400 Hz and 6000 Hz, respectively.

5. Reliability test of the VO_2/CNC actuators

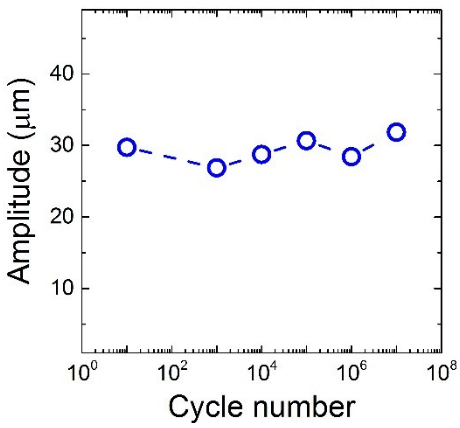

Figure S7. The reliability test of a typical VO_2/CNC actuator operating for up to 10^7 cycles in air.

Reference

1. C. Deng, Y. Sun, L. Pan, T. Wang, Y. Xie, J. Liu, B. Zhu and X. Wang, *ACS Nano*, 2016, **10**, 9710-9719.
2. H. Ma, L. Pan, Q. Zhao, Z. Zhao and J. Qiu, *Carbon*, 2012, **50**, 778-783.
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