Supporting information for

Joule heating driven infrared switching in flexible VO_2 nanoparticle film with reduced energy consumption for smart windows

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Contents:

1. Schematic diagram of two-terminal VO_2/ITO structure for applying voltage.

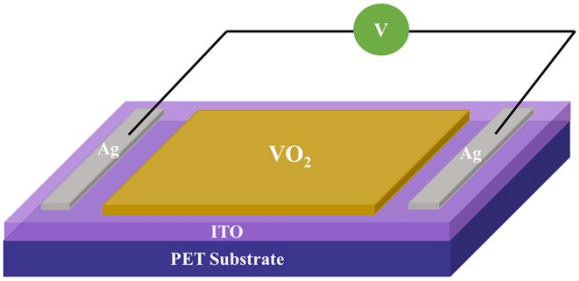


Figure S1 Schematic diagram of two terminal VO_2/ITO structure.

Figure S1 shows the schematic diagram of a two terminal VO_2-ITO structure, where copper wires were electrically connected to marginal ITO via silver paste, by which joule heating was effectively regulated by the applied voltage.

2. Film with 2.0 wt.% VO_2 nanoparticles at 25 ºC and 90 ºC, along with their transmittance spectra.

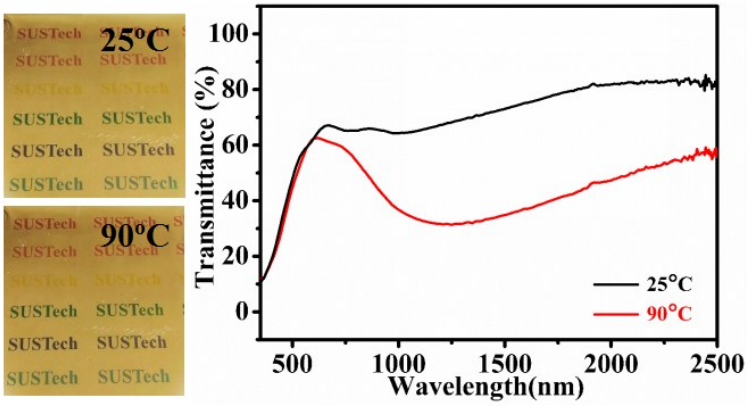


Figure S2 Film with 2.0 wt.% VO_2 nanoparticles at 25 ºC and 90 ºC, along with their transmittance spectra.

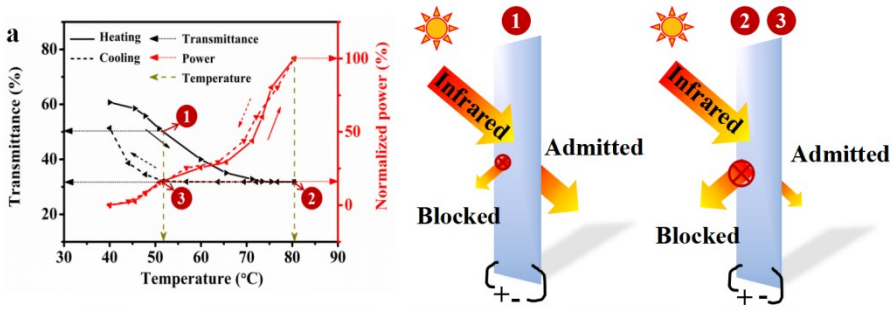
Figure S2 shows the photos of VO_2 films with almost unchanged visible transparency across the MIT.

3. Thermochromic performance of VO_2 nanoparticle films.

Table S1 The integral luminous transmittance (T_{lum}), solar energy modulation ability (ΔT_{sol}), and film thickness of VO_2 nanoparticle films with different solid contents.

Solid content of VO_2 (wt. %)	T_{lum} (%)		T_{sol} (%)		ΔT_{sol} (%)	Film thickness (nm)
	25 ºC	90 ºC	25 ºC	90 ºC		
0.5	87.3	87.6	87.4	81.9	5.5	972
1.0	74.0	74.7	75.1	66.8	8.3	1042
2.0	57.3	55.5	60.2	46.4	13.8	1132
3.0	44.2	42.3	48.2	33.4	14.8	1238
3.5	36.2	34.4	41.0	26.5	14.5	1327

4. The schematic diagram of infrared transmission of VO_2 films at ambient temperature of 52 ºC.



Parameters \ Type	1	2	3
$T_{ambient}$ (ºC)		52	
T_{VO2} (ºC)	52	80.4	52
T_{1200} (%)	49.7	31.5	31.5
Normalized Power (%)	0	100	0

Figure S3 Schematic diagram of infrared transmission of VO_2 films at ambient temperature of 52 ºC (Sites ①, ②, ③).

5. The stability of hysteresis loops of transmittance at 1200nm (T_{1200}) of VO_2 nanoparticle films.

The stability of the transmittance-temperature hysteresis loop at 1200nm of VO_2 film was explored in **Figure S4**. After 100 cycles, both the routine hysteresis loop (20

ºC - 80 ºC - 20 ºC, red and blue curves) and the working loop in practical application (80 ºC - 40 ºC - 80 ºC, dark yellow curves) were observed to be comparably stable, without obvious variations.

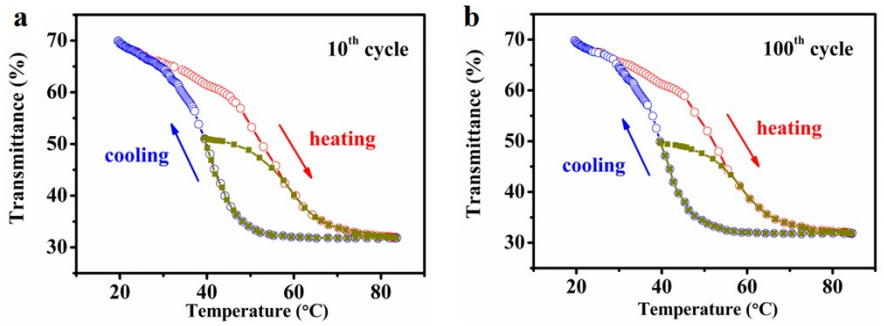


Figure S4 The T_{1200}-temperature hysteresis loops in 10th (a) and 100th (b) cycle. Red and blue curves stand for T_{1200} in the heating (20 ºC to 80 ºC) and cooling (80 ºC to 20 ºC) processes, respectively. Dark yellow curves in each cycle denotes T_{1200} in an unconventional cycle, where the temperature initially declines from 80 ºC to 40 ºC and then returns back to 80 ºC.

6. The calculation method of curvature radius and the induced strain.

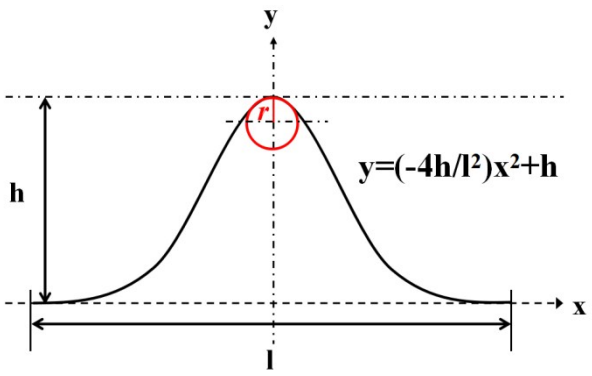


Figure S5 The parabolic model used for estimating the radius of curvature at the vertex of parabolic curve.

The radius of curvature was calculated from the equation below

$$r = \left| (1+y'^2)^{3/2}/y'' \right|$$

where y' and y'' are first-order and second-order differential derivations of the parabolic function.

The strain (%) was calculated from the equation below[1]

$$Strain(\%) = \frac{Total\ thickness\ of\ film}{2 \times radius\ of\ curvature} \times 100$$

According to the above equations, the radius of curvature and strain were calculated, as shown in **Table S2**. The minimum *r* and maximum strain are found when the length of VO_2 film under bending test decreased to 16mm. This was chosen to conduct different bending cycles for the mechanical flexibility in this study.

7. The evaluated radius of curvature, strain and strain rate of flexible VO_2 film

Table S2 The estimated radius of curvature (*r*) according to *h* and *l*, the strain and strain rate of flexible VO_2 film upon bending.

l (mm)	*h* (mm)	*r* (mm)	Strain (%)	Strain rate (%/s)
35	0	∞	0	0
30	7.0	16	0.6	0.12
25	11	7.1	1.2	0.12
22	12	5.0	1.8	0.2
19	13	3.5	2.5	0.23
16	14	2.3	3.8	0.43

Reference

1. Y. Ji, Y. Yang, S. K. Lee, G. Ruan, T. W. Kim, H. Fei, S. H. Lee, D. Y. Kim, J. Yoon and J. M. Tour, *ACS Nano*, 2016, **10**, 7598-7603.