Supporting information

Segregation-controlled Self-assembly of Silver Nanowire Networks using a Template-free Solution-based Process

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Results and discussion (Supplementary Material)

Morphology of SGAgNW-coated PET film. Fig. S8 shows the snapshot images of the AgNW conducting thin films on PET that were connected with copper electrodes (Dimension: 7 cm × 9 cm) with a high optical transparency. The film transparency is slightly darker with higher AgNW content, whereas the university emblem located behind the film is clearly visible.

The coating thickness was estimated to be one or two wire sizes using cross-sectional TEM images and EDS mapping of Pt and Ag (Fig. S9). A total of 40–50 nm of AgNW was coated on the PET film—except for the Pt coating layer—for high-resolution TEM measurements; the nanowires overlapped.

Heating performance: Temperature distribution. Fig. S10 shows the time-dependent temperature profiles of the SGAgNW-based transparent thin-film heater on the PET film with respect to the applied voltage. A constant DC bias voltage was applied to the two ends of the electrode; the temperature distribution was investigated using temperature probes. The TE film heater exhibits a heating property proportional to the applied voltage. In addition, a fast response time of less than 3 min was observed to achieve the saturated temperature (0.8 Ts) under all conditions while maintaining a stable temperature. The heat generation reached 34.5 °C, 46.0 °C, and 64.3 °C under the application of 3 V, 5 V, and 7 V, respectively; This could then increase to 94.5 °C when a DC voltage of 10 V was applied. This verifies that the present film heater can achieve a well-controlled heating property controlled by the electrical voltage. According to Joule heating, the following equation can determine the electro-to-thermal power, where I denotes the electric current flowing through a conductor, *V* represents the applied voltage, and *R* represents the electrical resistance of the heater [1, 2]. As described in equation (3), a lower electrical resistance can generate a better heating performance.

$$P = IV = \frac{V^2}{R}, \tag{3}$$

Thermal stability: Heating and cooling cycles. The reliability and thermal stability of the transparent thin-film heaters were evaluated using heating and cooling cycles. The temperature distribution was investigated under five repeated cycles for five times with an operating time of 20 min (Fig. S11). Considering the return time to reach the initial state, the cooling interval was set to 20 min at 5 V, and the turn-off time was set to 40 min at 7 V. The temperature profiles were maintained at a maximum steady-state temperature similar to the initial saturated temperature. The heating and cooling rates were measured by plotting the derivative of the temperature versus time. As shown in the slope graph, the heating performance appears identically during the test, which confirms that the AgNW-coated heaters on the PET film can repetitive operation with superior thermal stability at a low input voltage below 10 V.

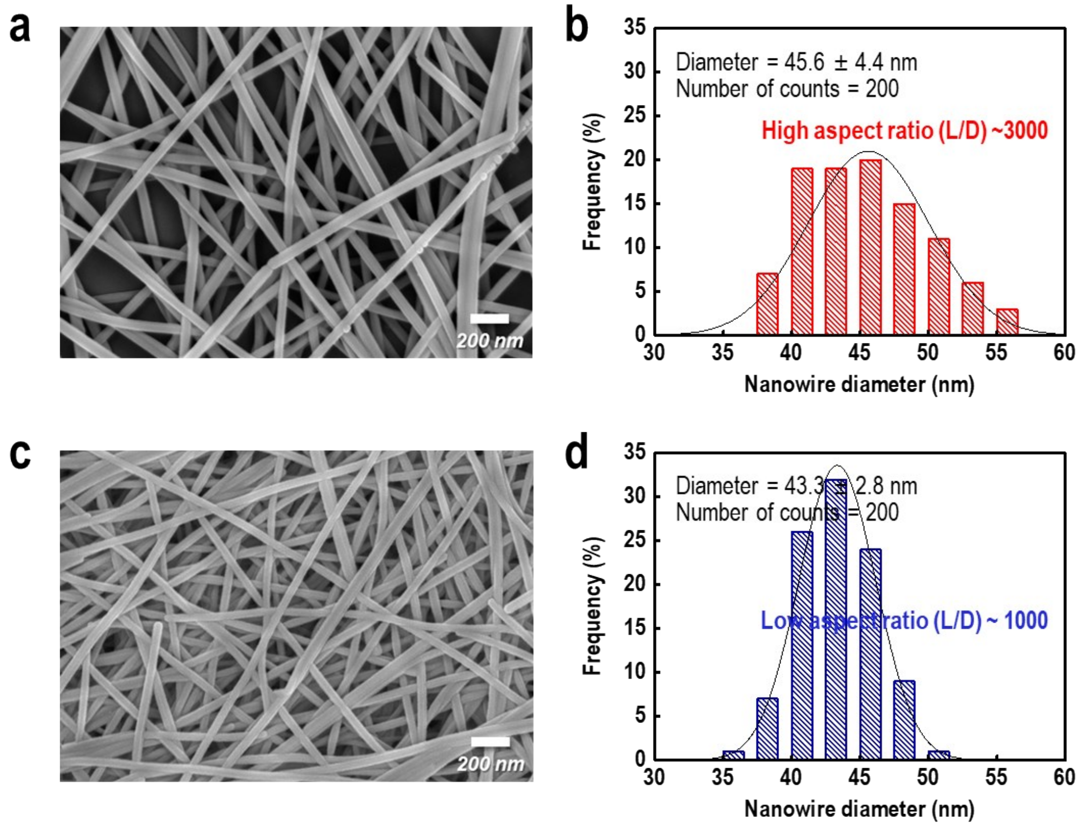
Reference (Supplementary Material)

1. De, S.; Higgins, T. M.; Lyons, P. E.; Doherty, E. M.; Nirmalraj, P. N.; Blau, W. J.; Boland, J. J.; Coleman, J. N., Silver Nanowire Networks as Flexible, Transparent, Conducting Films: Extremely High DC to Optical Conductivity Ratios. *ACS nano* **2009,** *3* (7), 1767-1774.
2. Kim, D.-H.; Cho, K.-S.; Kim, H.-K., Thermally evaporated indium-free, transparent, flexible SnO2/AgPdCu/SnO2 electrodes for flexible and transparent thin film heaters. *Scientific Reports* **2017,** *7* (1), 2550.

List of Supporting Figures and Tables

List of Supporting Tables

Figure S1.



a
200 nm
b
Diameter = 45.6 ± 4.4 nm
Number of counts = 200
High aspect ratio (L/D) ~3000
Frequency (%)
Nanowire diameter (nm)
c
200 nm
d
Diameter = 43.3 ± 2.8 nm
Number of counts = 200
Low aspect ratio (L/D) ~ 1000
Frequency (%)
Nanowire diameter (nm)

Figure S2.

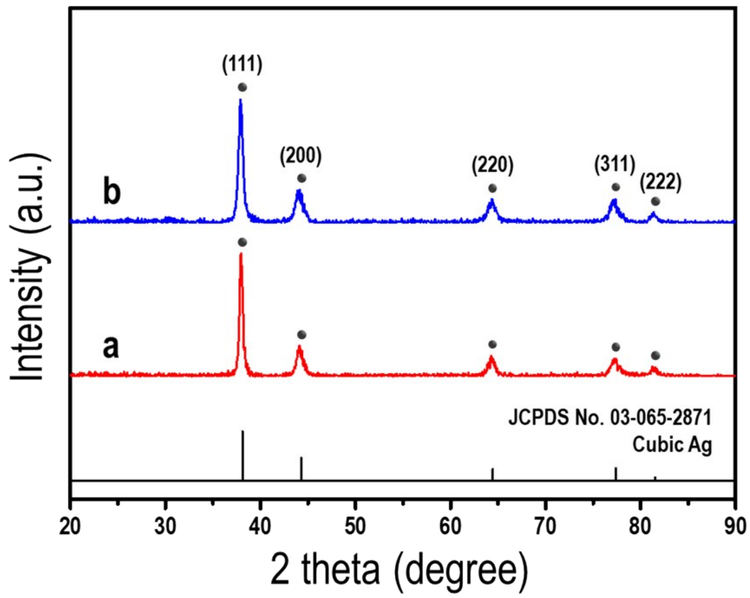


Figure S3.

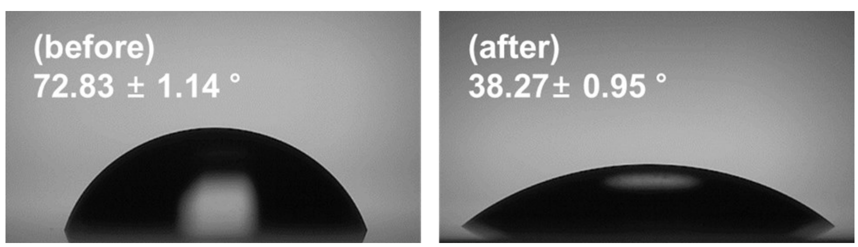


Figure S4.

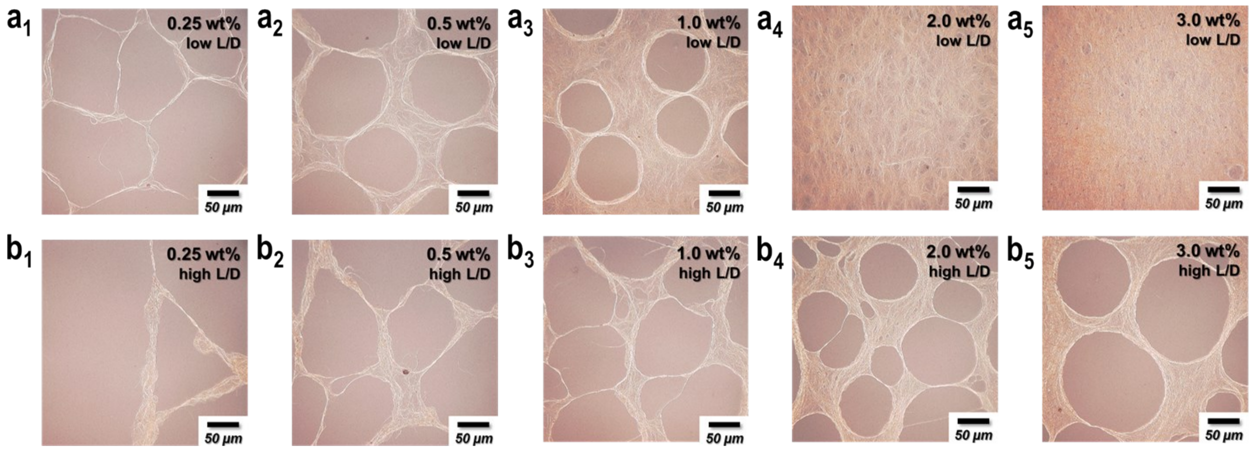

a1
0.25 wt%
low L/D
50 μm
a2
0.5 wt%
low L/D
50 μm
a3
1.0 wt%
low L/D
50 μm
a4
2.0 wt%
low L/D
50 μm
a5
3.0 wt%
low L/D
50 μm
b1
0.25 wt%
high L/D
50 μm
b2
0.5 wt%
high L/D
50 μm
b3
1.0 wt%
high L/D
50 μm
b4
2.0 wt%
high L/D
50 μm
b5
3.0 wt%
high L/D
50 μm

Figure S5.

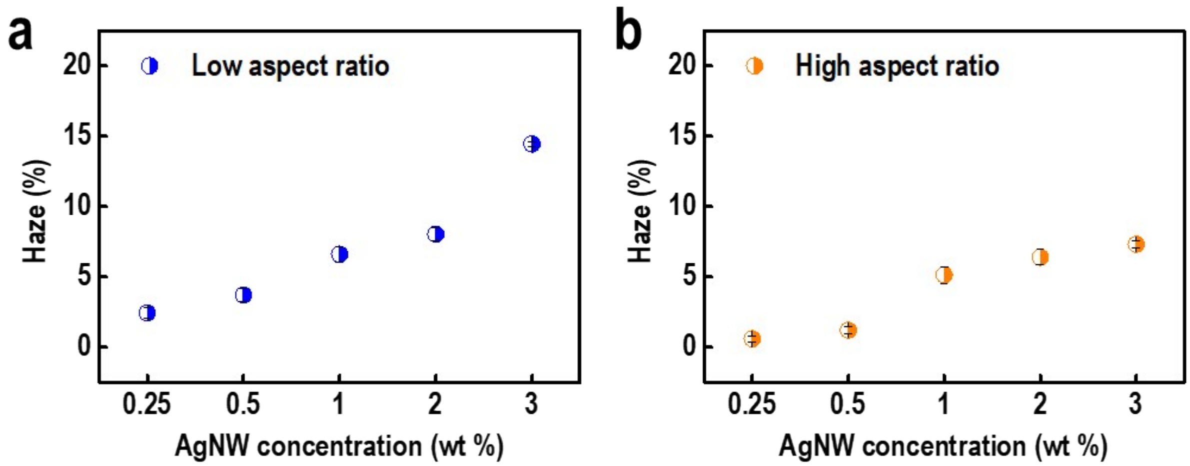


Figure S6.

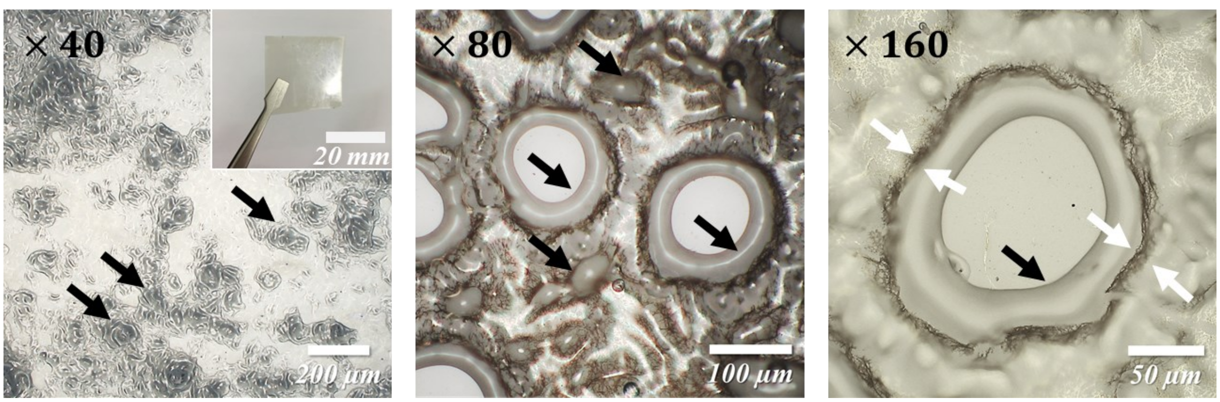


Figure S7.

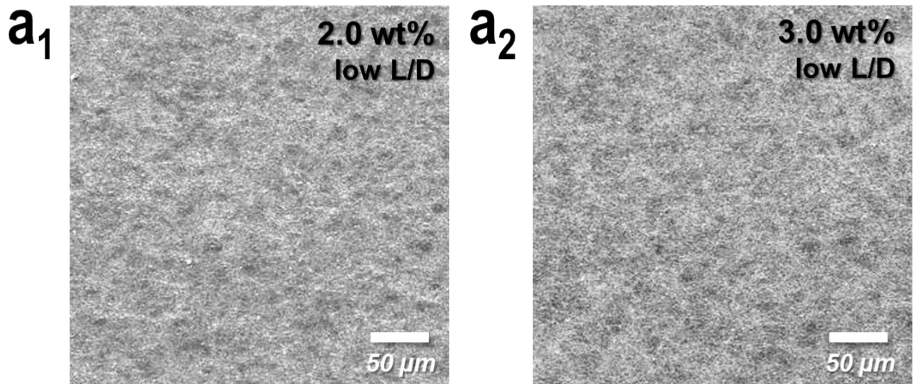


Figure S8.

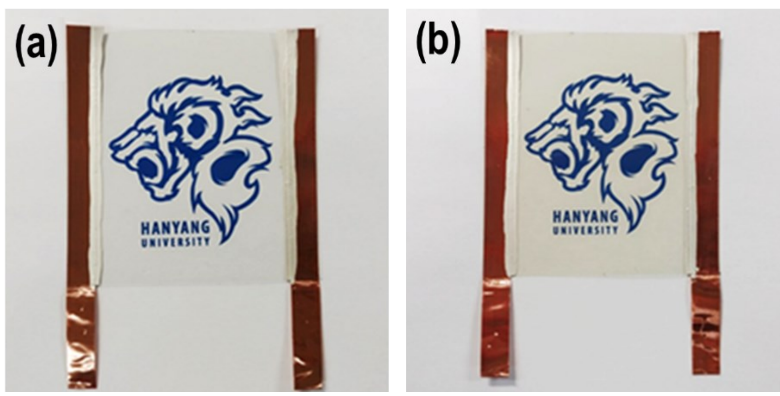


Figure S9.

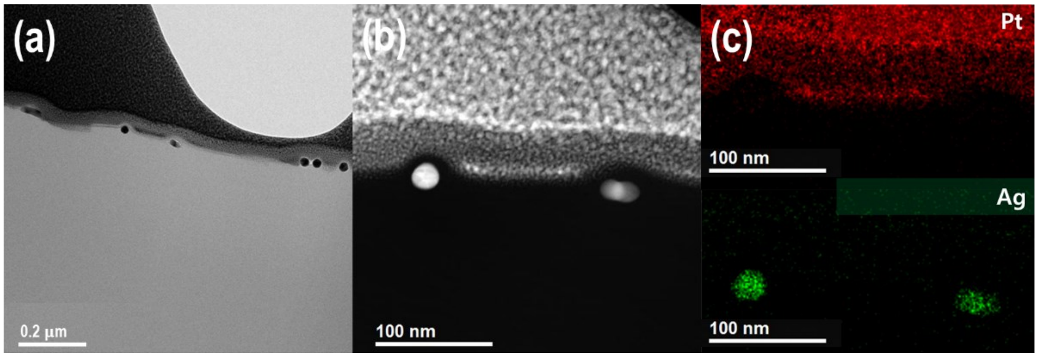


Figure S10.

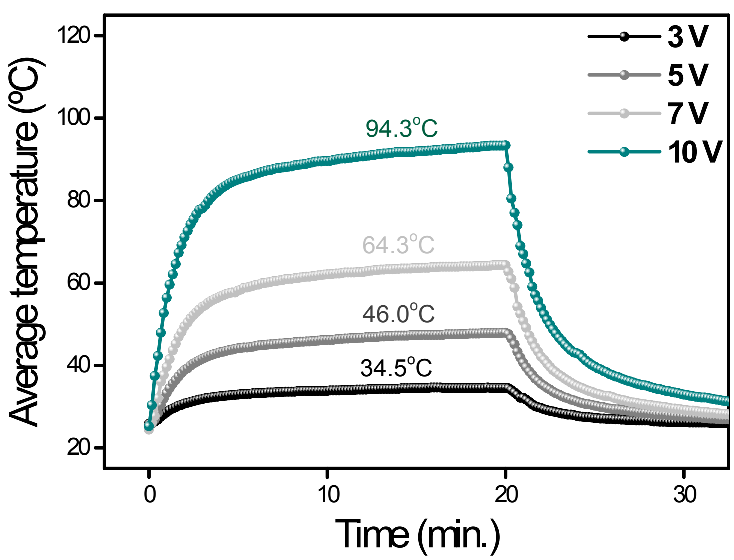
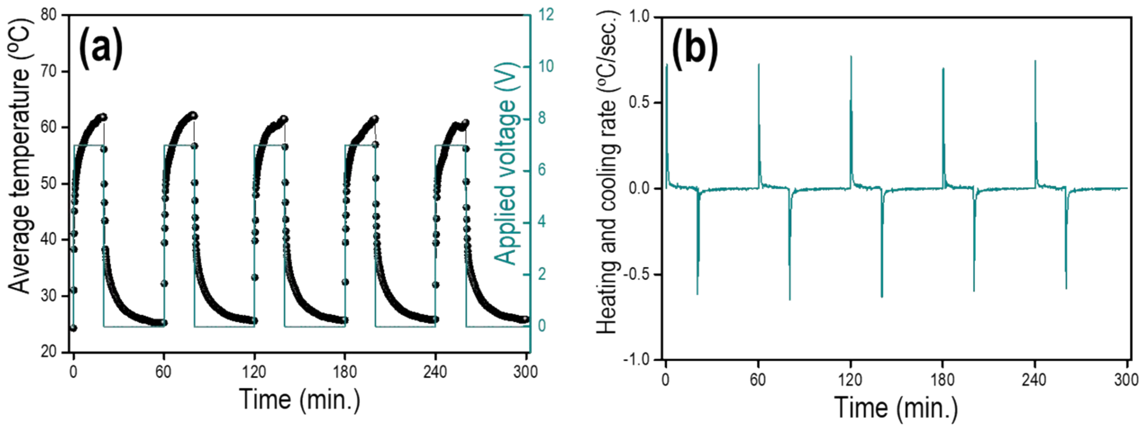


Figure S11.



(a)
Average temperature (°C)
Applied voltage (V)
Time (min.)
(b)
Heating and cooling rate (°C/sec.)
Time (min.)

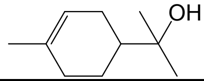
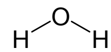
Table S1.

	Ag (wt %)	Cell size (μm)	Cell-to-cell distance (μm)	Transmittance at 550 nm (%)	Haze (%)	R_s (Ω/□)
a. Low aspect ratio	0.25	200.32 ± 38.17	15.81 ± 4.25	95.03	2.44 ± 0.34	1951.98±840.26
	0.5	145.38 ± 27.31	22.37 ± 9.39	87.08	3.71 ± 0.48	21.36±3.24
	1.0	126.08 ± 21.96	70.85 ± 36.17	81.13	6.61 ± 0.57	20.26±8.06
	2.0	3.89 ± 1.00	22.55 ± 6.93	74.83	8.03 ± 0.43	7.70±0.18
	3.0	1.27 ± 0.34	25.32 ± 7.76	54.83	14.44 ± 0.18	2.95±0.12
b. High aspect ratio	0.25	344.68 ± 159.98	15.12 ± 6.39	98.68	0.60 ± 0.21	-
	0.5	121.90 ± 32.65	13.95 ± 6.53	96.46	1.21 ± 0.22	2165.28±1425.87
	1.0	78.96 ± 20.22	20.17 ± 8.87	89.56	5.13 ± 0.61	1506.76±540.40
	2.0	84.41 ± 34.76	36.56 ± 13.70	88.42	6.40 ± 0.53	25.44±6.15
	3.0	106.09 ± 39.02	43.88 ± 19.20	82.96	7.31 ± 0.26	9.71±0.16

Table S2.

Coating method	Material	%T (%)	R_s (ohm/sq)	Figure of merit	Sintering condition	Haze (%)	Reference [year]
Nanoimprinting	AuNW	68	29	30.6	Plasma sintering (5% H_2 in Ar, 15 min.)	2.7	Ref. 10 [2019]
		92	227	19.5		1.6	
Recrystallized ice crystal	AgNW	~ 78	18.8	75.8	80 ˚C/30 min.		Ref. 22 [2018]
		~ 88	192.4	14.8			
Air-water interface	AuNW	~ 92	130.1	34.0	Plasma treatment (Ar, 20 min.)		Ref. 24 [2013]
Nanosecond laser ablation	Cu	83	17.48	110.4			Ref. 25 [2009]
Random crack	AgNW	85	92	24.2			Ref. 27 [2017]
PDMS template	CNT	78	264	5.4	50 ˚C/4 h.		Ref. 28 [2016]
Laser sintering	AgNP	85	30	74.2			Ref. 29 [2016]
Template-free self-assembly	AgNW	87.08	21.36	123	IPL sintering (1000 kW, 2000 μs)	3.71	This work
		88.42	25.44	117		6.40	

Table S3.

	α-terpineol	Water	Methanol
Molecular structure			$H_3C—OH$
Viscosity (at 20°C) [mPa.s]	67	1.001	0.594
Solubility in water [g/L]	2.42	-	miscible
Boiling point [°C]	220	99.98	64.7
Vapor pressure (at 25°C) [kPa]	0.0037	3.169	13.02