Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information

Floating compression of Ag nanowire networks for effective strain release of stretchable transparent electrodes

Jun Beom Pyo,‡[a] Byoung Soo Kim,‡[ab] Hyunchul Park,[c] Tae Ann Kim,[a] Chong Min Koo,[c] Jonghwi Lee,[b] Jeong Gon Son,[a] Sang-Soo Lee,*[ad] and Jong Hyuk Park*[a]

[a.] Photo-Electronic Hybrids Research Center, Korea Institute of Science and Technology, Seoul 136-791, Republic of Korea.

[b.] Department of Chemical Engineering and Materials Science, Chung-Ang University, Seoul 156-756, Republic of Korea.

[c.] Center for Materials Architecturing, Korea Institute of Science and Technology, Seoul 136-791, Republic of Korea.

[d.] KU-KIST Graduate School of Converging Science and Technology, Korea University, Seoul 136-701, Republic of Korea.

† Electronic Supplementary Information (ESI) available: A supporting document with additional technical details is included as a separate PDF file. See DOI: 10.1039/c5nr03814f

‡ Both authors contributed equally to this work.

* Corresponding author.

E-mail: hyuk0326@kist.re.kr (J. H. Park) and s-slee@kist.re.kr (S.-S. Lee)

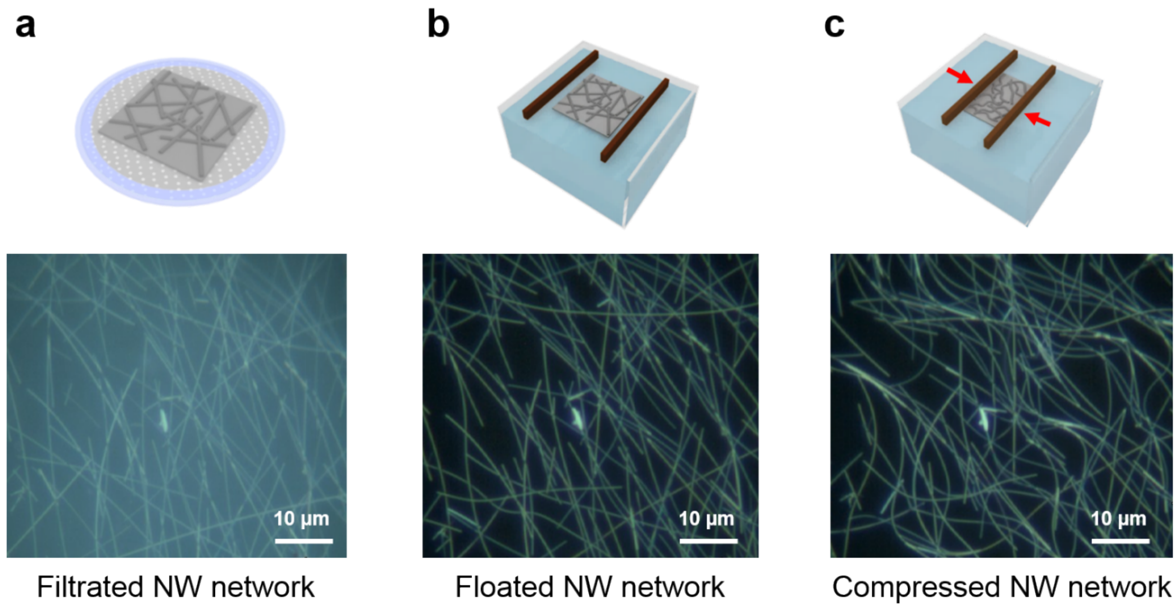

Fig. S1 Schematic for the fabrication steps of Ag nanowire (NW) networks and the corresponding optical microscope images: (a) Ag NW networks deposited on an anodized aluminum oxide membrane, (b) the networks after floating on water, and (c) the networks after compressing.

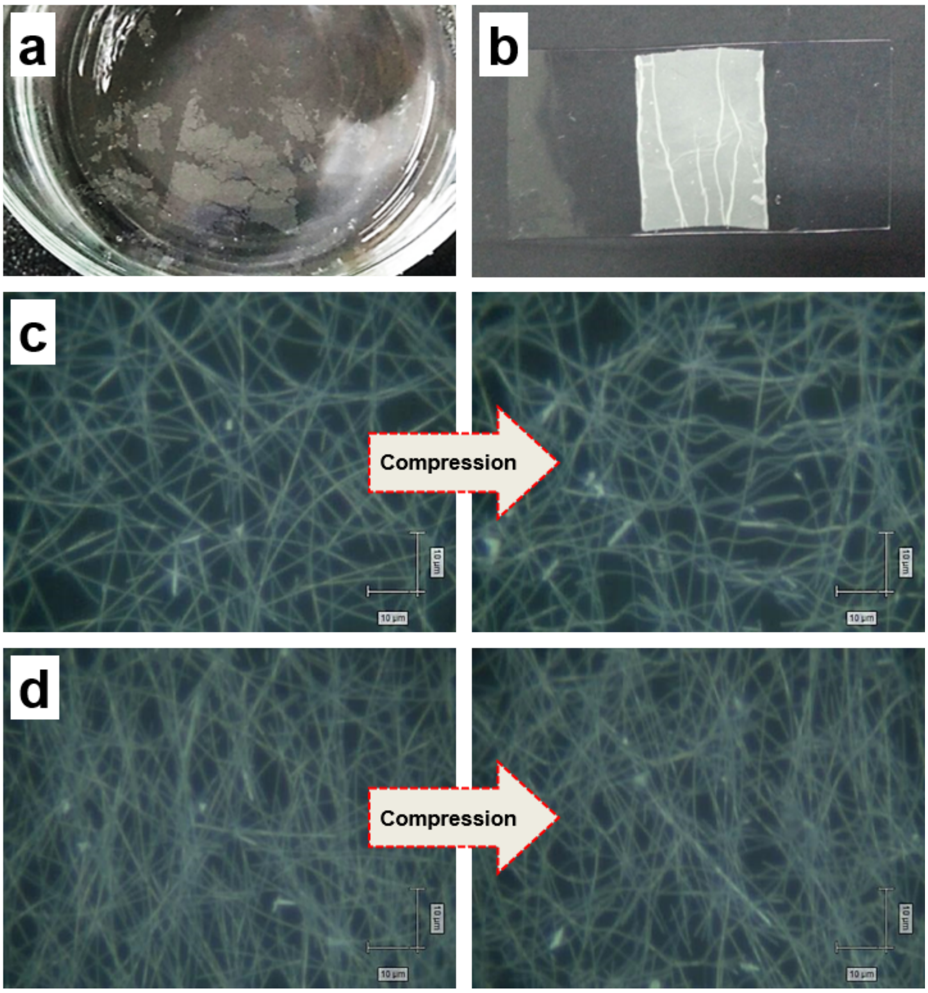

Fig. S2 Photographs of (a) sparse NW networks with an area density of 0.044 μg/mm^2 after floating on water and (b) dense NW networks with an area density of 0.176 μg/mm^2 after compressing with a degree of compression (Δ) of 30%. On the basis of these photographs, it is confirmed that the area density of NWs in the networks needs to be controlled. Applying the floating compression method to very sparse or dense NW networks is challenging. Optical microscope images of Ag NW networks with an area density of (c) 0.132 μg/mm^2 and (d) 0.176 μg/mm^2 before and after compressing with Δ of 30%. The NW networks with a higher area density show a smaller waviness of NWs. It is because the binding between NWs at the junction points disturbs the bending of NWs. In other words, the large number of junction points restricts the motion of NWs, resulting in less wavy structure.

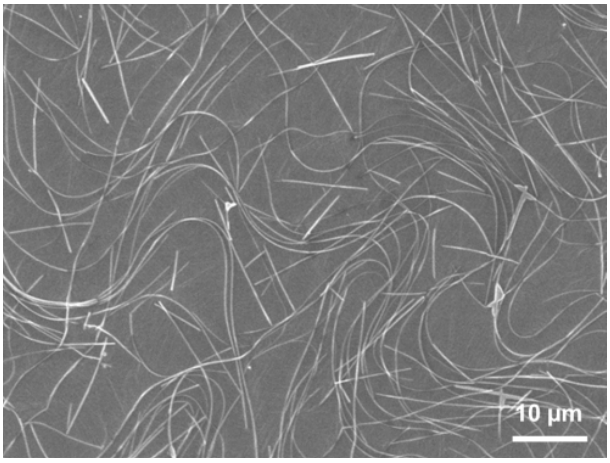

Fig. S3 A scanning electron microscope image for wavy-configured networks consisting of NWs with an average diameter of 25 nm and an average length of 20 μm.

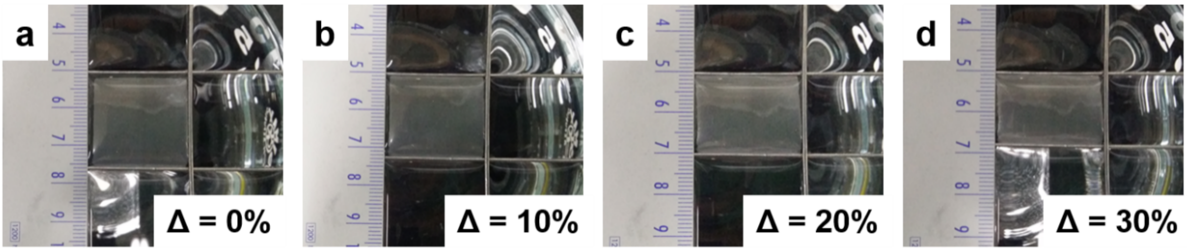

Fig. S4 Photographs of Ag NW networks (a) before compression and after compressing with Δ of (b) 10%, (c) 20%, and (d) 30%. The compressed length with Δ of 10%, 20%, and 30% indicates 2.5, 5.0, and 7.5 mm, respectively.

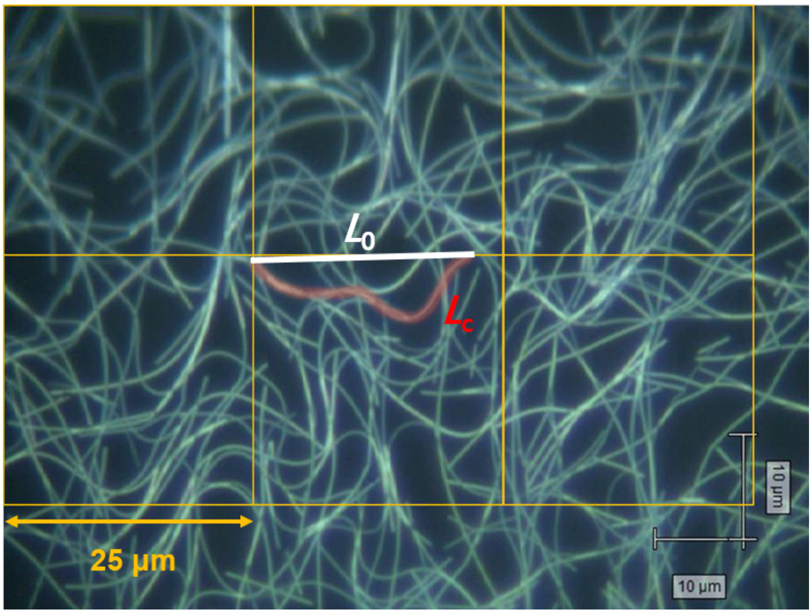

Fig. S5 Contour length (L_c) and end-to-end distance (L_0) of individual nanowires. Square grids of 25 × 25 µm^2 were drawn on the optical microscope images of nanowire networks to determine L_c and L_0. Nanowires crossing at least two edges of a square grid were chosen for the measurement of L_c and L_0.

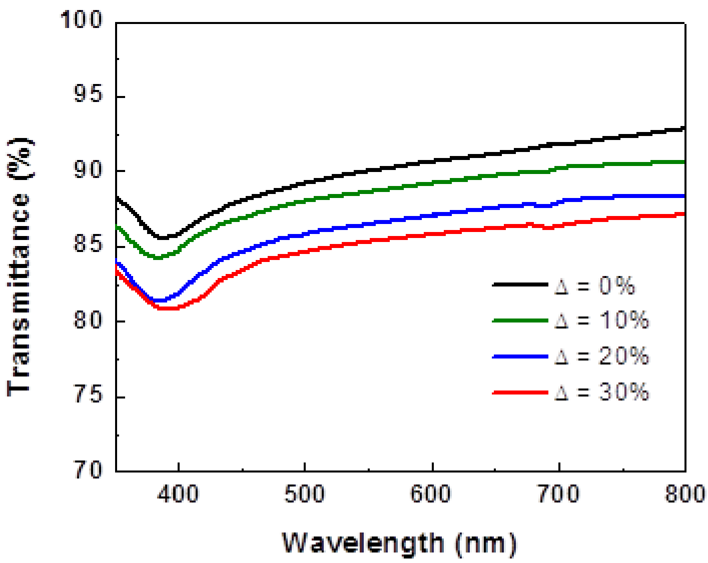

Fig. S6 Optical transmittance spectra of Ag NW networks with different degrees of compression (Δ).

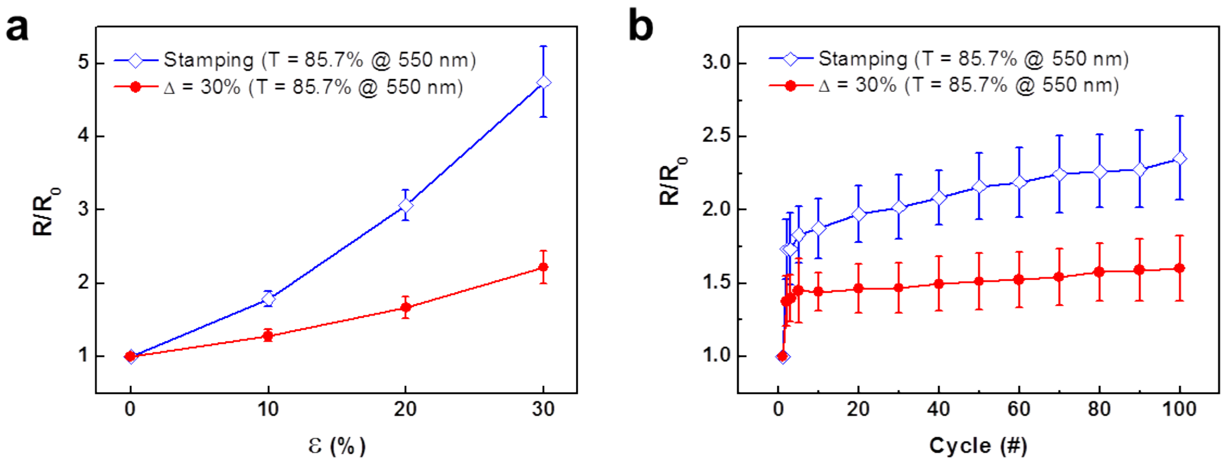

Fig. S7 Electromechanical stability for Ag NW networks with controlled transmittance. (a) Variation in resistance as a function of strain (ε). The strain was uniaxially applied to the substrates. (b) Variation in resistance as a function of cycle number. A 10% strain was repeatedly applied to the network. The NW networks were transferred onto PDMS substrates by a conventional stamping method, resulting in a straight configuration of NW network.[S1–S3] The curve for the NW network prepared with a degree of compression (Δ) of 30% was presented for comparison. We assumed that the identical optical transmittance of NW networks indicates the identical population of NWs. Some error bars are not shown because they are smaller than the size of the data points.

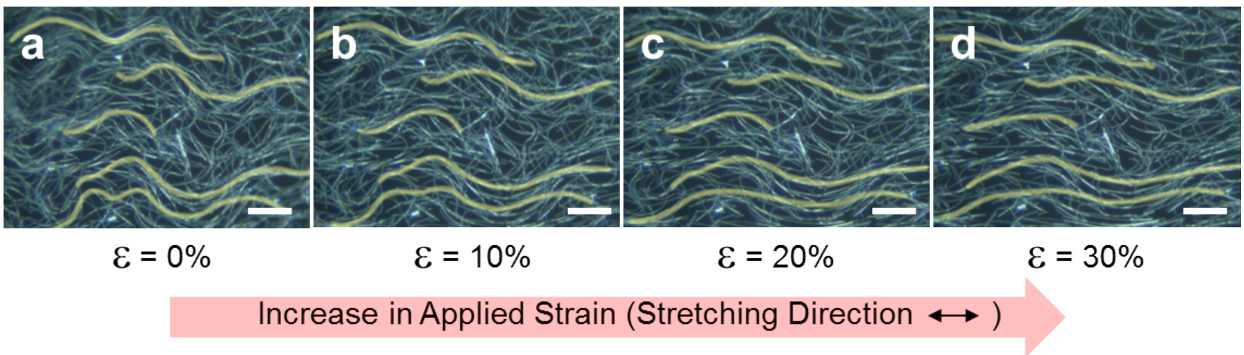

Fig. S8 Optical microscope images of the NW network when strains of (a) 0%, (b) 10%, (c) 20% and (d) 30% were applied. The NW network was prepared with the degree of compression of 30%. The strain was uniaxially applied to the substrate in the same direction as the compression. The scale bars in the images are 20 μm.

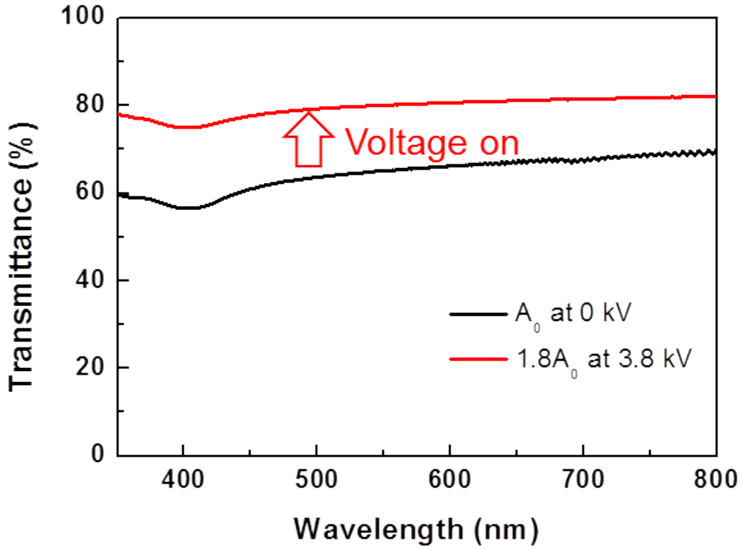

Fig. S9 Optical transmittance spectra of the dielectric elastomer actuators prepared with the wavy-configured Ag NW networks before and after applying voltages.

REFERENCES

1. S. De, T. M. Higgins, P. E. Lyons, E. M. Doherty, P. N. Nirmalraj, W. J. Blau, J. J. Boland and J. N. Coleman, *ACS Nano*, 2009, **3**, 1767–1774.
2. P. Lee, J. Lee, H. Lee, J. Yeo, S. Hong, K. H. Nam, D. Lee, S. S. Lee and S. H. Ko, *Adv. Mater.*, 2012, **24**, 3326–3332.
3. J. Y. Woo, K. K. Kim, J. Lee, J. T. Kim and C.-S. Han, *Nanotechnology*, 2014, **25**, 285203.