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Supplementary Information

# Highly Stretchable and Conductive Silver Nanowire Thin Films by Soldering Nanomesh Junctions

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**Contents**

## 1. Experimental section

Silver nanowire (AgNW, 60 nm in diameter, $10 \pm 3$ μm long, 0.785 g/mL in isopropanol) suspension was purchased from Sigma-Aldrich. To prepare conductive films with different transparency, the AgNW suspension was diluted into various concentrations. The thermal sensitive silver precursor ink[28] was prepared as follows. First, 3.15 g diethanolamine (DEA, Sigma-Aldrich, USA) was added into 1.85 mL DI water. A silver nitrate solution was prepared by adding 1.7 of silver nitrate (MACRON chemicals, USA) in 5 mL DI water. Then, the DEA aqueous solution was mixed with $AgNO_3$ aqueous solution at equal volume ratio (1:1) to form the Ag precursor ink. The stretchable conductive thin film was prepared as follows. 80 μL of the prepared AgNW suspension was deposited on a 3 cm × 1 cm glass plate and put on a spin coater at 700 rpm for 30 s. The resulted thin film on glass was baked on a hotplate at 80 $^{o}$C for 5 minutes to remove unwanted solvents. 200 μL reactive Ag precursor ink was then deposited over the AgNW thin film on the glass plate, and heated at 100 $^{o}$C on a hotplate for 10 minutes. After thermal treatment, the reacted coatings were rinsed with DI water to remove non-reactive chemical residues. Finally, the silver nano-composite films were coated with a polyurethane solution (First Chemical Co., Taiwan), which dried after 10 hr. The dried samples were then peeled off carefully from the glass plate as a free-standing composite conductive film. Microstructures of thin films were examined with scanning electron microscopy (Nova NanoSEM 230, FEI, USA). The transmittance of the prepared conductive thin films was measured by a UV-Vis spectrometer (V-670, Jasco Inc., USA). The sheet resistance of the AgNW thin films was measured with a multimeter (model 2000, Keithley, USA) on four probe mode. For electrical resistance measurements in stretching process, conductive composite AgNW thin films were first cut into stripes 30 mm long and 10 mm wide. The sample was loaded and clamped onto a linear motorized stage (Tanlien Inc., Taiwan) with sample holders on both ends, leaving the central area of 10 mm × 10 mm. Conductive copper tapes were attached on the two moving holders to act as the leads and were wired to a multimeter. The apparent sheet resistances of samples were calculated by the original sample dimension (1cm by 1 cm). A linear motion signal was applied to trigger a uniaxial stretching process, and the resistance profile of the sample was recorded simultaneously by a computer. For resistance profiles under cyclic stretching/releasing, the same protocol was used except that a repeated triangular strain signal was used instead of a linear one.

## 2. Optical transmittance AgNW and AgNW/NP nano-soldering thin films

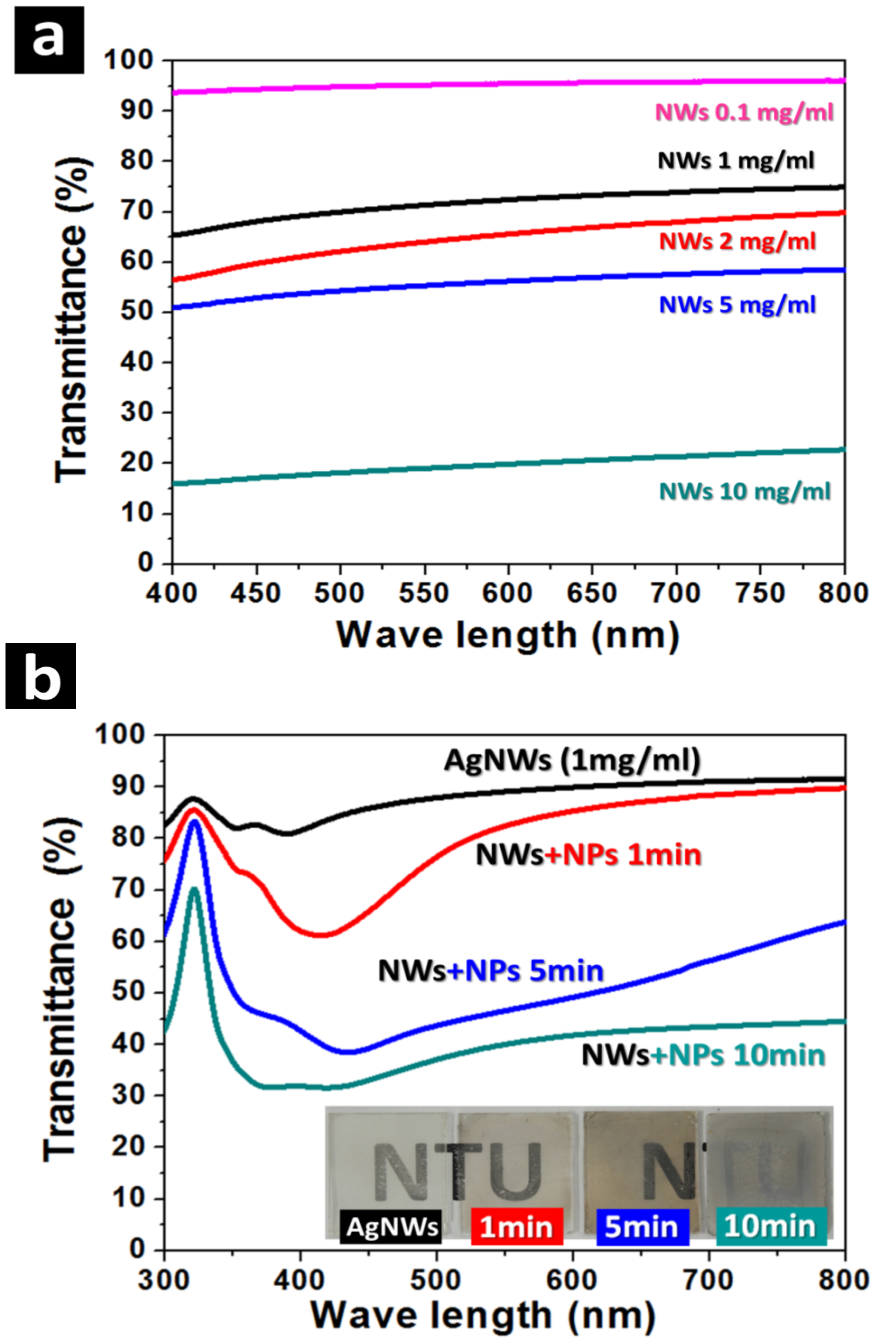


**Figure S1** (a) Optical transmittance spectra of the pristine AgNW thin films at various concentrations. (b) Optical transmittance spectra and digital image of the composite films where AgNWs are soldered for different reaction times by silver ink. All the samples were prepared with AgNW concentration of 1 mg/ml.

## 3. Diameter growth data for AgNW soldering

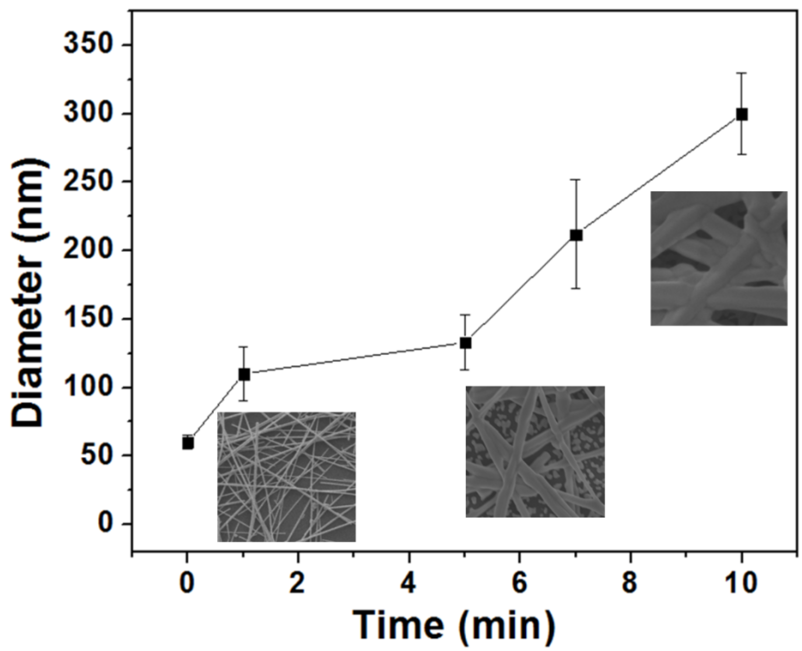


**Figure S2** Variation in AgNW diameters with reaction times for nano-soldering AgNW thin films before transfer to PU substrates.

## 4. Resistance responses of the sintered AgNW films under elongation cycles

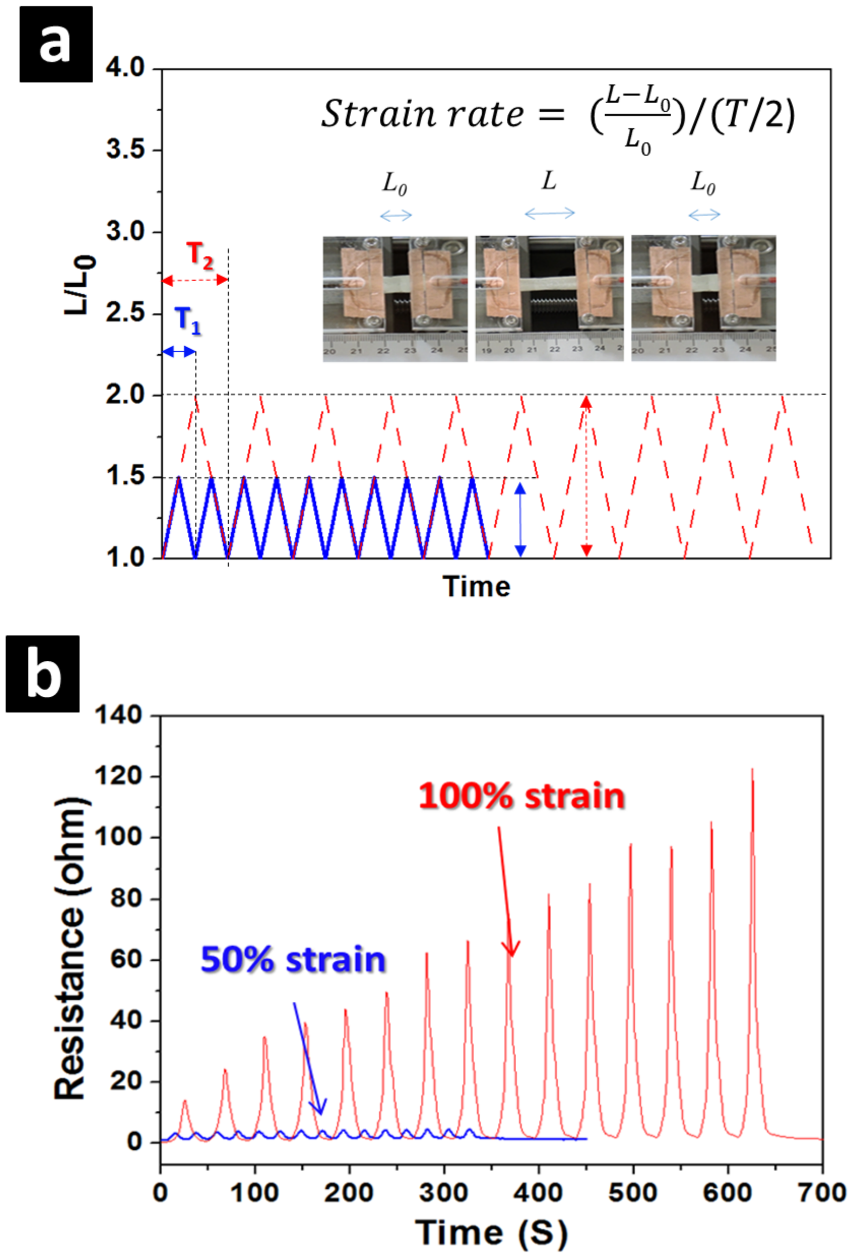


**Figure S3** (a) Schematic diagram for the mechanical stability test with elongation cycles. A triangular waveform with a linear strain rate is used for the film elongation. (b) Resistance responses of stretching films under elongation cycles with strain amplitudes of 50 and 100%. A linear pulsating strain rate of 0.05 $s^{-1}$ was used. The stretched samples were prepared with 1 mg/ml AgNW solution, reacted for 10 minutes with the silver ink, and were all embedded in PU substrates.

## 5. Exemplar Applications

The stretchable thin film can also endure the large strain in twisting process. **Figure S4** shows a stretchable conductive ribbon made by this chemical soldering process. The ribbon is twisted into a coil and stretched along the axial direction. Along the stretching process (~100% strain), the brightness of the LED lights remains nearly the same, indicating little resistance change in the twisting/elongation process. This also shows that the AgNW thin film remain conductive under multiple directional strains. The great strain endurance and high conductivity of the chemically soldered AgNW films can be utilized to fabricate various devices under strong deformation conditions, such as bending, twisting and elongation. **Figure S5** demonstrates an exemplar push button device using the stretchable AgNW film. An electrode made of copper tape was placed below the AgNW film. Once being pressed by a glass plate, the AgNW film stretched to reach the vicinity of bottom electrode. One can also slide the glass plate to ensure the contact between the AgNW film and copper electrode. Because of the strong adhesion of AgNWs in PU, the film remains highly conductive despite the large local strain and abrasion caused by the sliding process. One can also make AgNW patterns with this chemical soldering method (**Figure S6**). Because the AgNW films adhere firmly on PU, one cannot remove them easily with tapes. Those patterned thin films can be used for electronic applications, such as stretchable interconnects or RFIDs in the future.

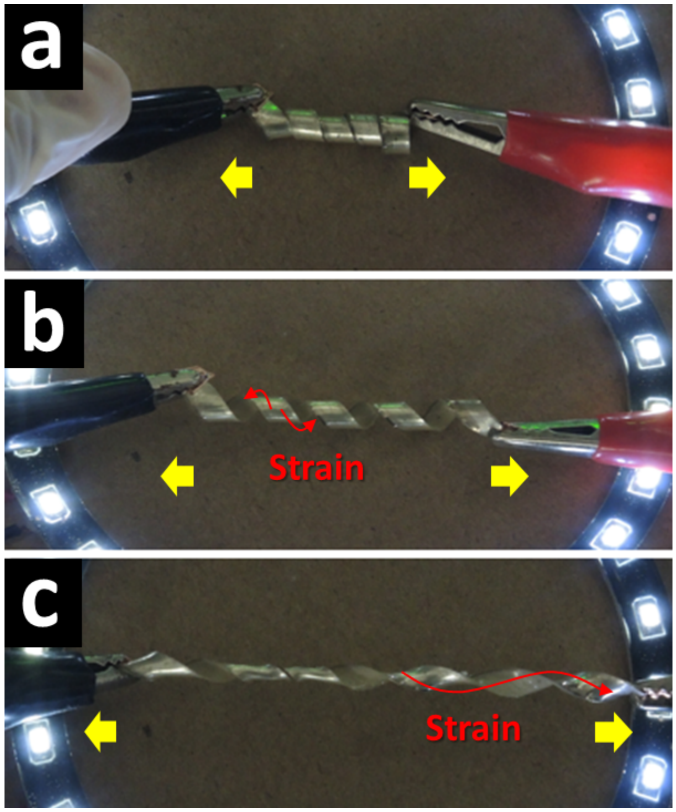


**Figure S4** Optical images of a LED circuit connected with a spiral ribbon made of AgNW/AgNP thin film. Stretching the spiral ribbon leads to non-isotropic strains in both twisting and elongation directions. Along the stretching process (~100%), the brightness of the LED lights remains nearly the same in the twisting/elongation process, indicating that the stretchable conductor is mechanically stable to strains from all directions.

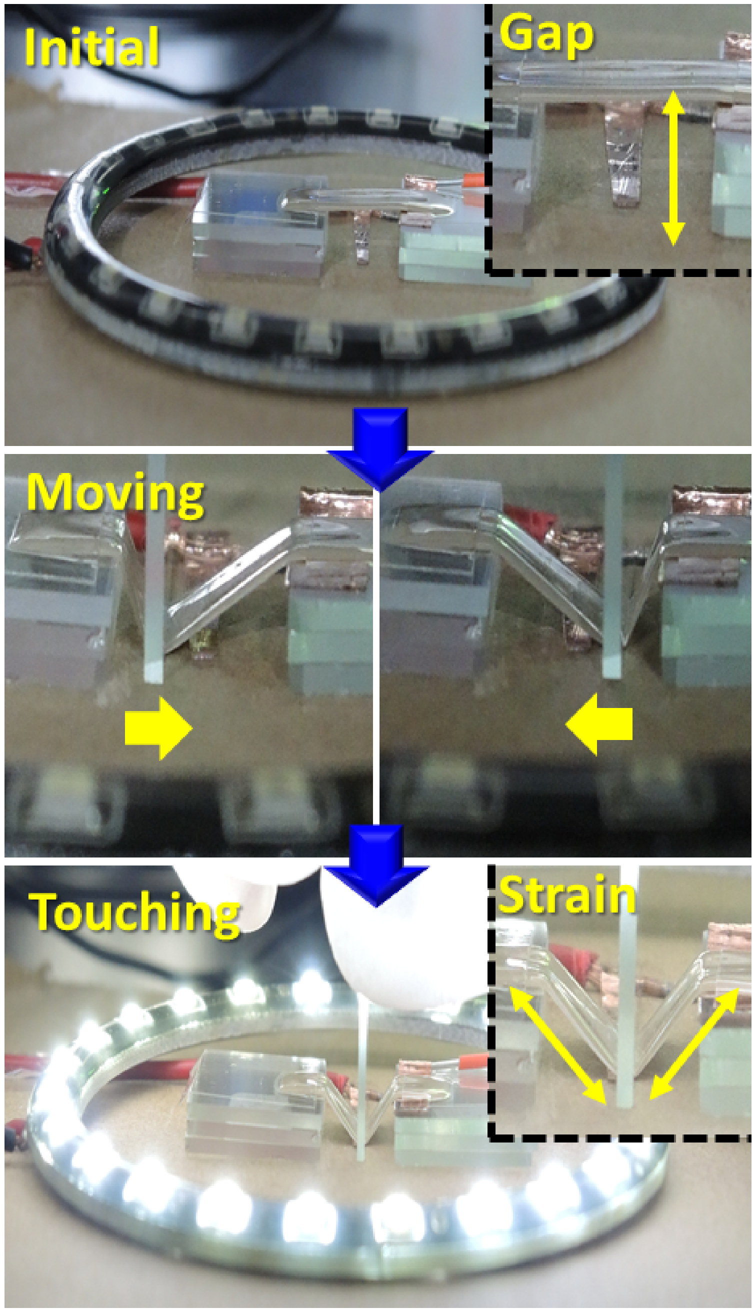


**Figure S5** Optical images of an LED-integrated circuit with a simulating touch control device. When a glass plate slides over the stretchable Ag-NPs/NWs electrode, on/off signals can be generated by the contact between the bottom and stretchable electrodes. These images show that the prepared stretchable electrode can resist large local strains and is mechanically robust to abrasion.

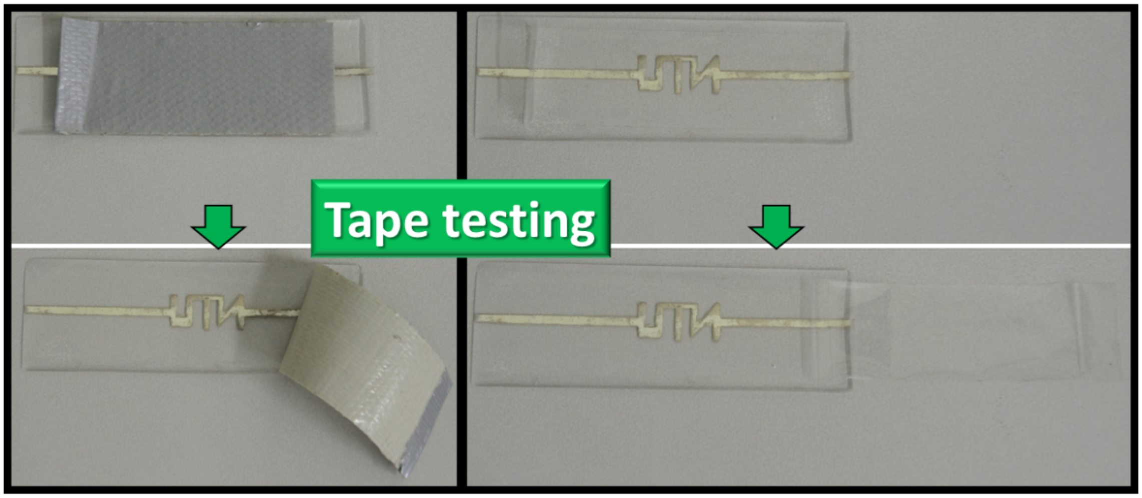


**Figure S6** Tape tests with two tapes of different adhesion strengths: 3M duct tape (left) and Scotch Cat. 600 tape (right). A patterned silver nanowires/nanoparticles hybrid film was used in the tests.