Supplementary Information for

A General Gelation Strategy for 1D Nanowires: Dynamically Stable Functional Gels for 3D Printing Flexible Electronics

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Experimental Section

Synthesis of MXene. To synthesize the single-layer $Ti_3C_2T_x$ MXene, 2 g of lithium fluoride (LiF) was first added to 20 mL of 9 M HCl and was stirred with a Teflon magnetic stir bar. Subsequently, 2 g of Ti_3AlC_2 was slowly added to the LiF/HCl mixture, followed by stirring for 24 h at 35 °C. Then, the suspension was washed by repeated centrifugation (3500 rpm for 10 min) and decantation of the acidic supernatant until the pH reached ~6. 100 mL of deionized water was then added to the sediment, followed by sonicating for 30 min to delaminate the multilayer $Ti_3C_2T_x$ into single layers. Finally, the solution was centrifuged at 3500 rpm for 1 h to separate the single-layer flakes from the multilayer MXene and unreacted MAX phase. The supernatant after centrifugation contained single-layer $Ti_3C_2T_x$, and the solid single-layer $Ti_3C_2T_x$ was obtained by freeze-drying the supernatant. AFM measurement shown in Figure S1 indicates that the thickness and average lateral size of the single-layer MXene about 1.5 nm and 2 μm, respectively

Characterization. Rheological behavior of the nanowire gels was probed using a DHR-2 rheometer (TA Instruments) with a 20 mm plate system and 900 μm gap. All measurements were probed at room temperature. A preconditioning step at a shear rate of 0.1 s^{-1} for 10 s was applied before each test. The steady-state flow step test was performed to measure the shear viscosity of the gels at shear rates of 0.1-1,000 s^{-1}, and the PHS test was performed with constant shear rates in three intervals (0.1 s^{-1} shear rate for 30 s, 200 s^{-1} for 30 s, and 0.1 s^{-1} for 100 s) to simulate the extrusion printing process. The SSS test was performed with oscillation stress of 1–1,000 Pa at a frequency of 1 Hz. Transistor electrical characterization was performed with two Keithley 2400 source meters. The measurement sequences were controlled by a custom-made LabView code. All the transistor measurements were tested under ambient atmospheric conditions. The SEM characterizations were carried out using field-emission scanning electron microscopy (JSM-7800) at an accelerating voltage of 5.0 kV. All electrochemical measurements were carried out in a two-electrode system using an electrochemical workstation (CHI 660D, CH Instruments, Inc.) at room temperature. All the electronic and optoelectronic property tests for UV sensors were performed using the Keithley 2400 under ambient atmospheric conditions. The light source was a 300 W xenon arc lamp (PLS-SXE300) equipped with a 350 nm optical filter.

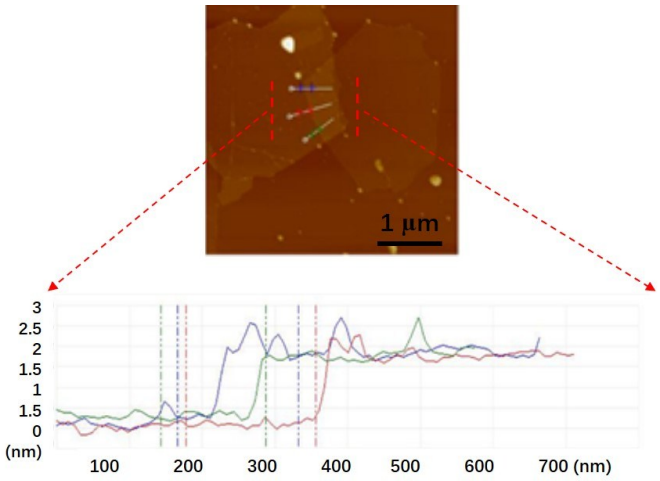

Figure S1. AFM image showing that the thickness and average lateral size of the single-layer MXene about 1.5 nm and 2 µm, respectively

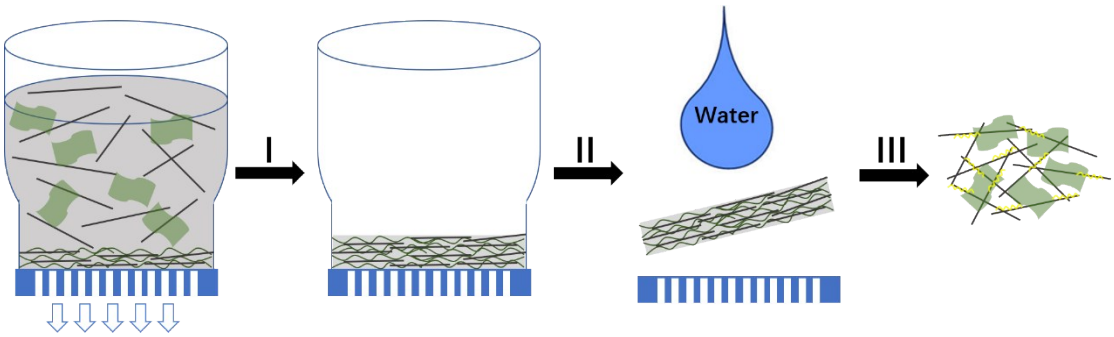

Figure S2. (a) Schematic of the preparation of AgNW gel: I) vacuum-filtering diluted AgNW and GO mixture to obtain AgNW-GO hydrogel; II) peeling off AgNW-GO hydrogel and mixing with certain amount of DI-water; III) agitating to obtain final gel

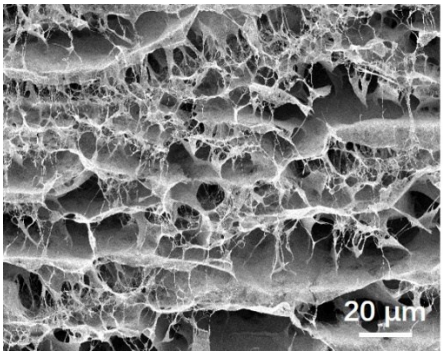

Figure S3. Cross-sectional SEM image of the freeze-dried AgNW-GO hydrogel.

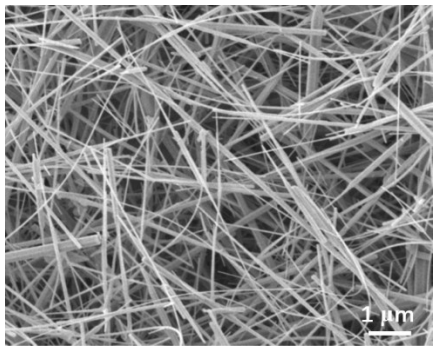

Figure S4. SEM image of ZONW.

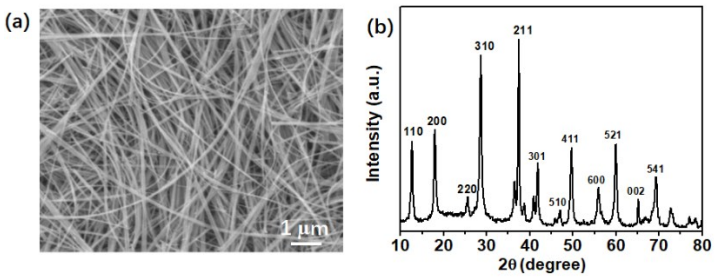

Figure S5. (a) SEM image and (b) XRD pattern of MONW.

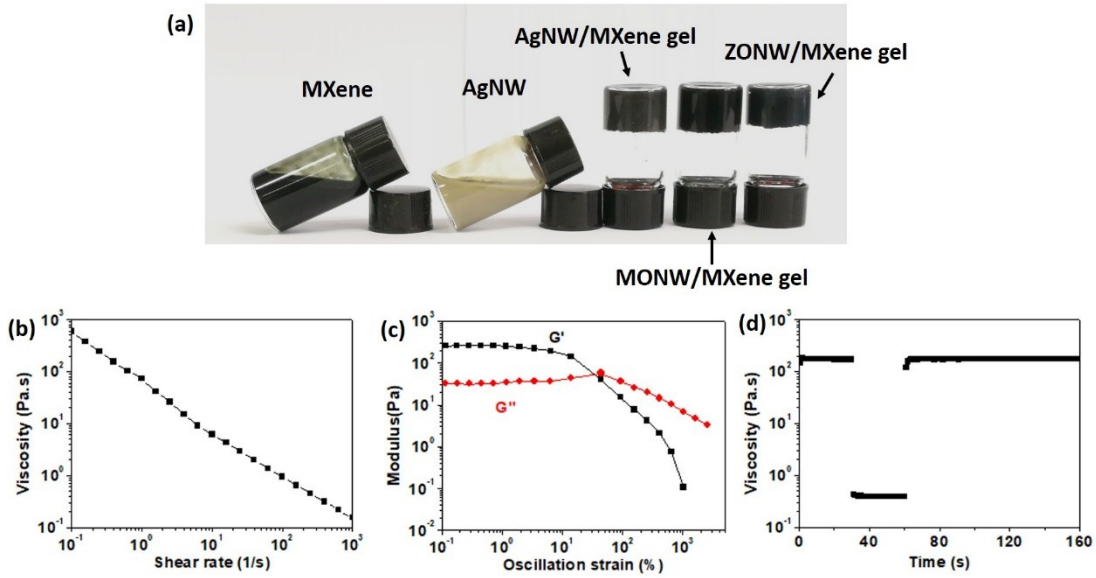

Figure S6. (a) Photographs of aqueous MXene solution (0.66 vol%), AgNW/PVP suspension (1.07 vol% of AgNW, 23 vol% of PVP), AgNW gel (1.07 vol% of AgNW, 0.66 vol% of MXene), ZONW gel (1.61 vol% of ZONW, 0.71 vol% of MXene), MONW gel (1.45 vol% of MONW, 0.71 vol% of MXene). (b) Viscosity as a function of shear rate, (c) Storage (*G'*) and loss (*G"*) moduli, and (d) Rheological behavior during extrusion printing for the AgNW-MXene gel (1.07 vol% of AgNW, 0.66 vol% of MXene).

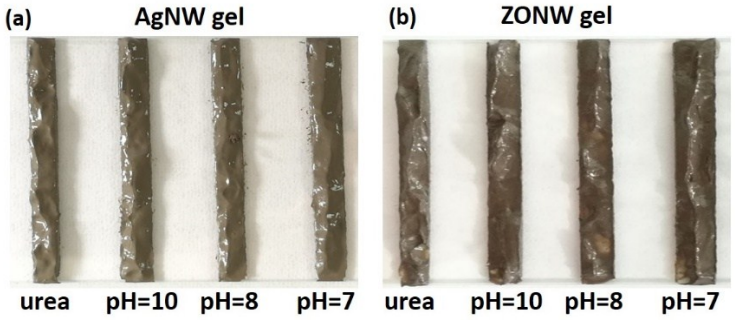

Figure S7. (a) Photograph showing the well-maintained gelation state of AgNW gel under pH value of 7, 8, and 10, and mixing with urea (6 M). (b) Photograph showing the well-maintained gelation state of ZONW gel under pH value of 7, 8, and 10, and mixing with urea (6 M).

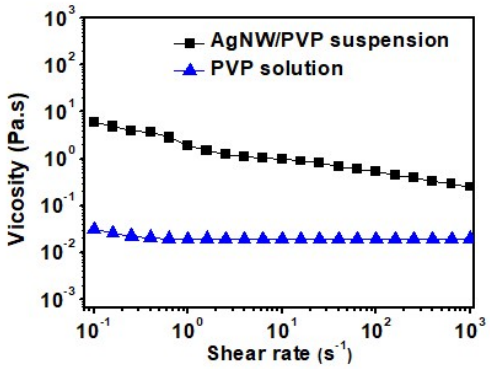

Figure S8. Viscosity as a function of shear rate for pure PVP solution (23 vol% PVP in DI-water) and AgNW/PVP suspension (1.19 vol% AgNW, 23 vol% PVP).

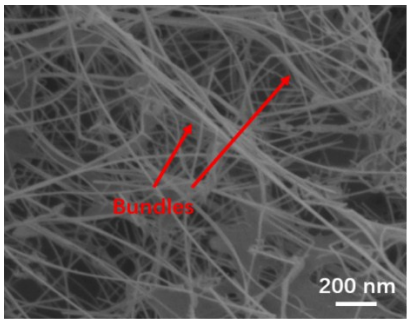

Figure S9. SEM image of AgNW network in AgNW-GO suspension with 0.67 vol% of GO and 1.8 vol% of AgNW.

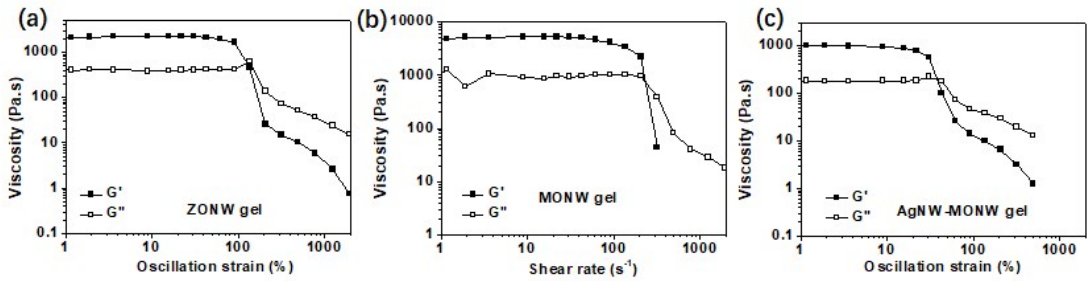

Figure S10. Storage (*G'*) and loss (*G"*) moduli for (a) ZONW gel (1.64 vol% of ZONW, 0.73 vol% of GO), (b) MONW gel (1.47 vol% of MONW, 0.73 vol% of GO), and (c) AgNW-MONW gel (0.89 vol% of AgNW, 0.28 vol% MONW, 0.67 vol% of GO) at the frequency of 1 Hz at different oscillation strains.

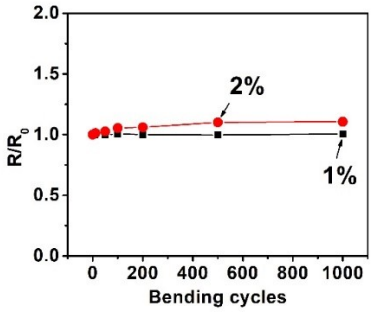

Figure S11. Relative resistance of the 3D-printed AgNW-based microfibers dried under ambient condition for 10 min on PET substrates over 1000 bending cycles with 1% and 2% tensile strain, respectively.

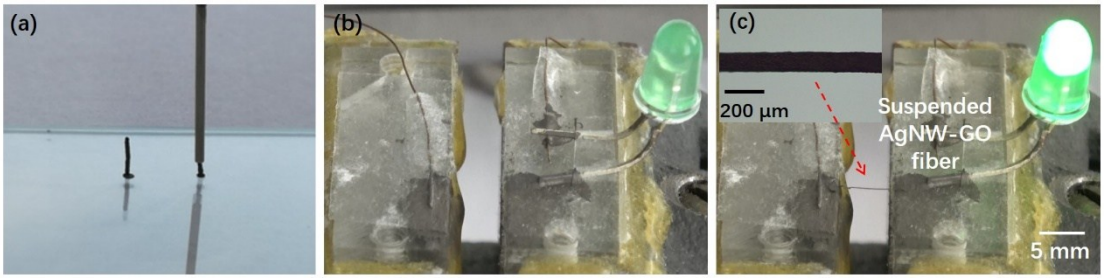

Figure S12. (a) Digital images showing 3D-printing the upright structures using AgNW gel (AgNW:GO:water = 8:1:48) with high viscosity. The inner diameter of the micronozzle was 400 μm and the height of the upright structure was about 4 mm. (b) and (c) Photographs showing the LED circuit connected by a 3D-printed suspended AgNW-based microfiber. The inset optical microscopy image showing the diameter of the suspended AgNW-based

microfiber.

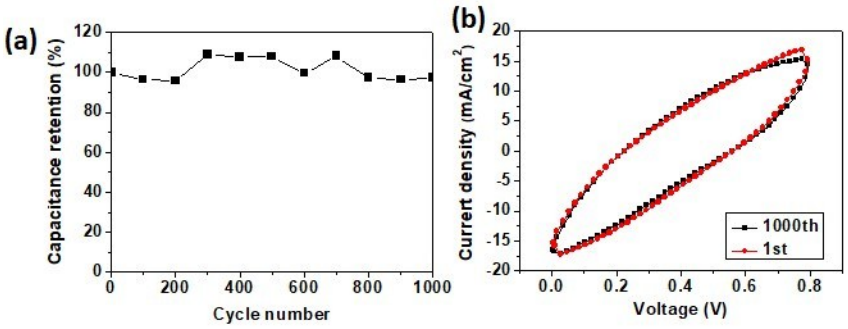

Figure S13. Cycling stability performance of 3D-printed MONW-based MSC under a fixed scan rate of 200 mV/s.

Table S1. Zeta potential of AgNW gel, ZONM gel and MONW gel under different pH value

	Zeta potential of AgNW gel (mV)	Zeta potential of ZONW gel (mV)	Zeta potential of MONW gel (mV)
pH=10	-32.4	-47	-54.8
pH=8	-38.2	-41.9	-46.5
pH=7	-21.8	-28.7	-36.8