Supporting information

Transparent Low-Voltage-Driven Soft Actuators with Silver Nanowire Joule Heaters

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Keywords. Transparent, soft actuators, electro-thermal, liquid crystal, silver nanowire.

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Synthesis of ethyl 4-(allyloxy)benzoate. But-3-en-1-ol (2.9 g, 40 mmol), 4-hydroxybenzoic acid ethyl ester (6.7 g, 41 mmol) and triphenyl phosphate (10.9 g, 40.0 mmol) were dissolved in 30 mL of dried THF. 20 mL of THF solution contained DEAD (7 mL, 40.0 mmol) was added dropwise into the above solution in an ice bath. The reaction mixture was stirred overnight at the room temperature under protection of nitrogen atmosphere. After filtering the produced white precipitate, solvent was removed via vacuum evaporation, then the obtained crude product was purified by silica flash column chromatography with hexane: EtOAc=20:1 as eluent to afford colorless oil (7.1 g, yield: 80%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.02 (d, 2H), 6.92 (d, 2H), 5.85-5.98 (m, 1H), 5.12-5.24 (m, 2H), 4.33-4.40 (m, 2H), 4.06-4.12 (m, 2H), 1.40 (t, 3H).

Synthesis of 4-(allyloxy)benzoic acid. Compound 1 (7.7 g, 29 mmol) and excess sodium hydroxide were mixed and dissolved in mixed solution of ethanol/water (v/v, 1/1). The mixture solution was heated to reflux for 12 h. After cooling to room temperature, 1 M hydrochloric acid solution was added into solution to adjust pH to ~ 2. The resulted white precipitate was collected by filtration and washed with water for twice. The crude product was recrystallized from ethanol to give the white solid (6.1 g, yield: 90%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07 (d, 2H), 6.97 (d, 2H), 5.85-6.0 (m, 1H), 5.12-5.26 (m, 2H),2.56-2.64 (m, 2H).

^{1}H NMR (300 MHz, DMSO-d_6): δ 12.59 (s, 1H) 7.86 (d, 2H), 7.0 (d, 2H), 5.84-5.92 (m, 1H), 5.04-5.23 (m, 2H), 4.05-4.26 (m, 2H).

Synthesis of 4-methoxyphenyl-4-(but-3-en-1-yloxy)benzoate. Compound 2 (3.25 g, 17 mmol), 4-methoxyphenol (2.3 g, 18.6 mmol), DMAP (1.05 g, 8.3 mmol) and DIC (2.6 g, 20.2 mmol) were dissolved in dried dichloromethane. The mixture solution was reacted for 24 h at ambient temperature. After filtering the produced white precipitate and evaporating to remove the solvent, the afforded crude solid was purified by flash column chromatography on silica gel using CH_2Cl_2: hexane=1:20 as the eluent to obtain white solid. (4 g, yield: 78%).

^{1}H NMR (300 MHz, DMSO-d_6): δ 8.06 (d, 2H), 7.08–7.20 (m, 4H), 6.97-7.02 (m, 2H), 5.84-5.96 (m, 1H), 5.08-5.24 (m, 2H), 4.13-4.19 (m, 2H), 3.76-3.81 (m, 3H), 2.60 (q, 2H).

Synthesis of crosslinker 11UB (Compound 4). Hydroquinone (1.1 g, 10 mmol) and potassium carbonate (4.8 g, 35 mmol) were dissolved in ethanol. After dropwise adding 11-chloro-1-undecene (4.5 g, 24 mmol) into the above mixture over 30 minutes, the mixture solution was heated to reflux for 18 h. The reaction mixture was poured into iced water and extracted three times with ether. After evaporation of solvents, the residue was purified by flash column chromatography on silica gel using petroleum ether/ethyl acetate (10:1) as the eluent to give the desired product 11UB (4.6 g, yield 60%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 6.85 (s, 4H), 5.78-5.90 (m, 2H), 4.93-5.06 (m, 4H), 3.92 (t, 4H), 2.03-2.11 (m, 4H), 1.72-1.82 (m, 4H), 1.27-1.5 (m,24H).

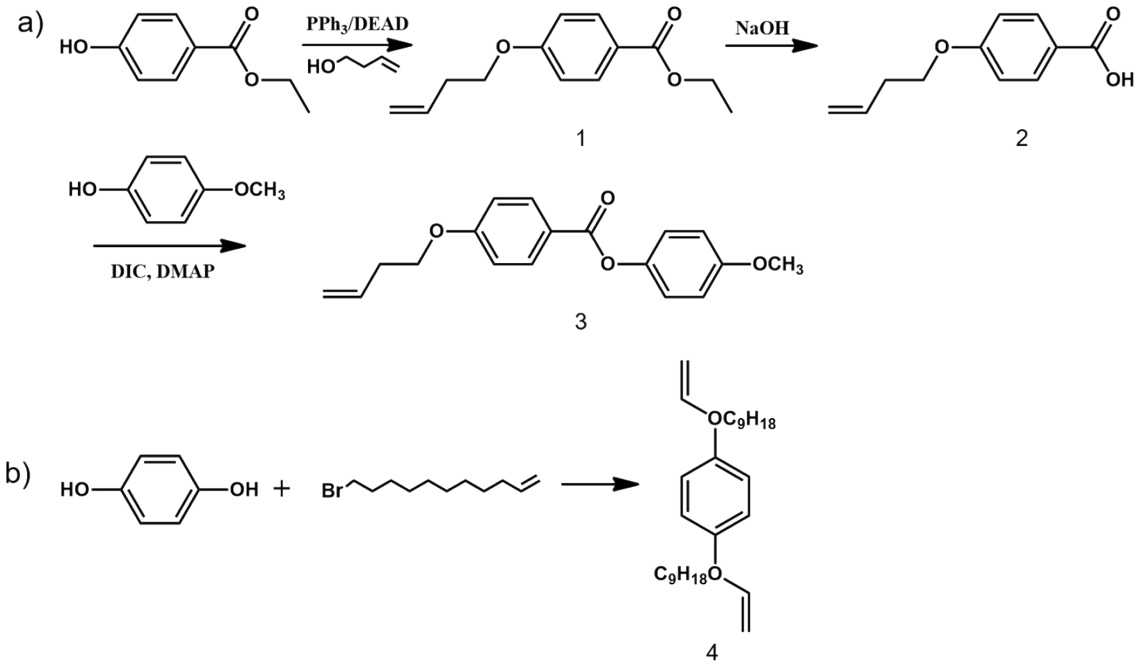

Figure S1. Synthesis routine of designed compound

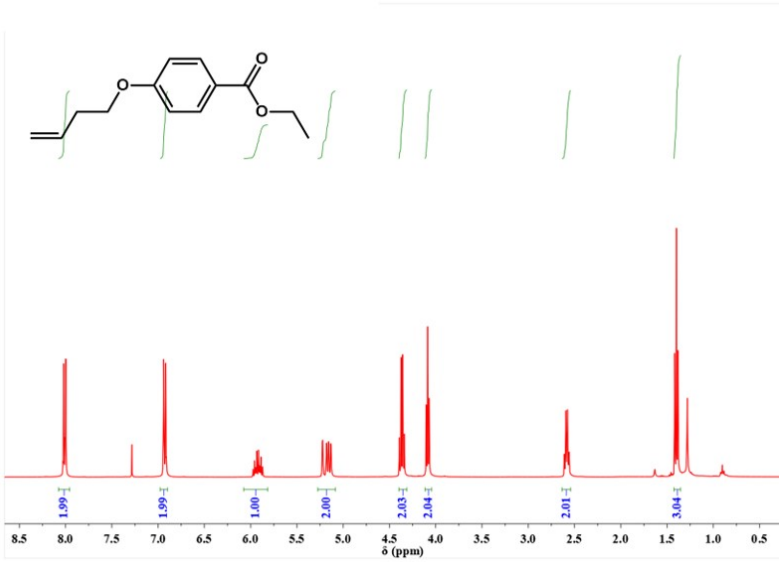

Figure S2. ^{1}H NMR spectra of compound 1

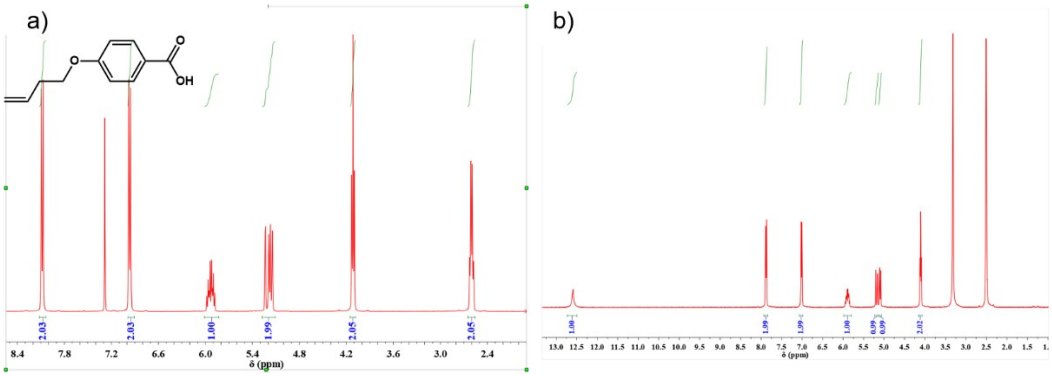

Figure S3. ^{1}H NMR spectra of compound 2 in a) $CDCl_3$ and b) DMSO-d_6.

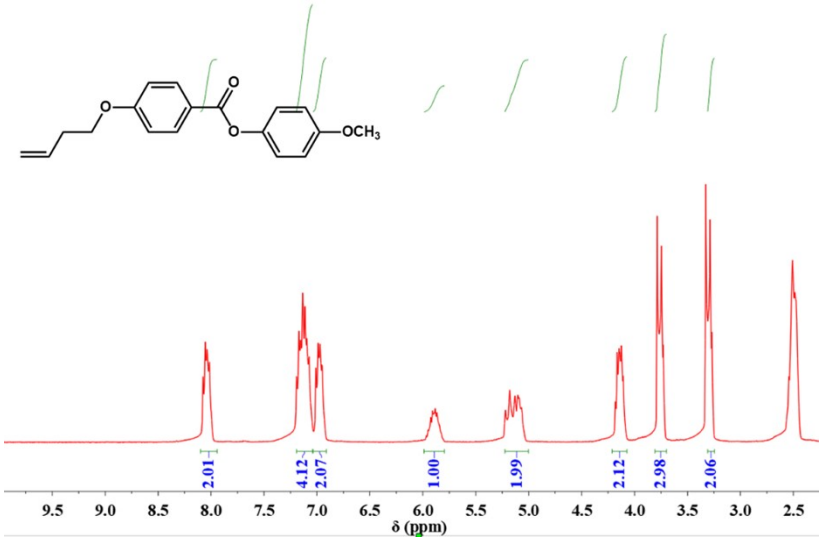

Figure S4. ^{1}H NMR spectra of compound 3 in DMSO-d_6.

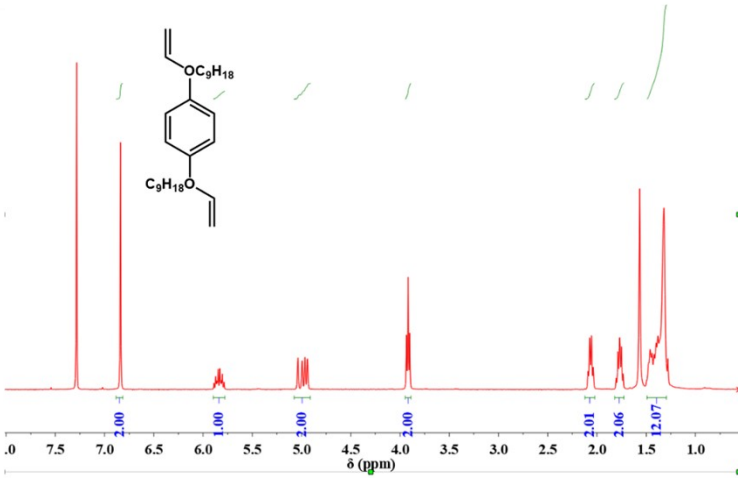

Figure S5. ^{1}H NMR spectra of compound 4 in DMSO-d_6.

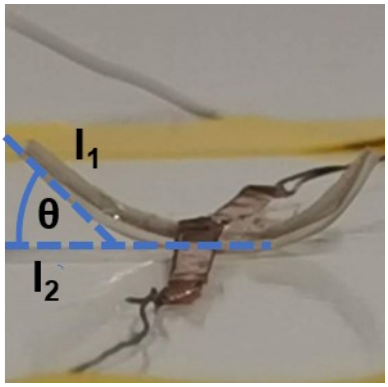

Figure S6. The schematic description of tangent angle θ.

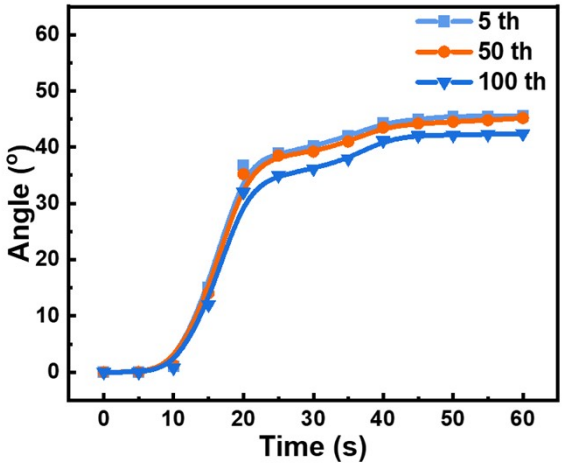

Figure S7. The durability test of voltage application time vs tangent angle θ of the actuator; the applied voltage is 6 V.

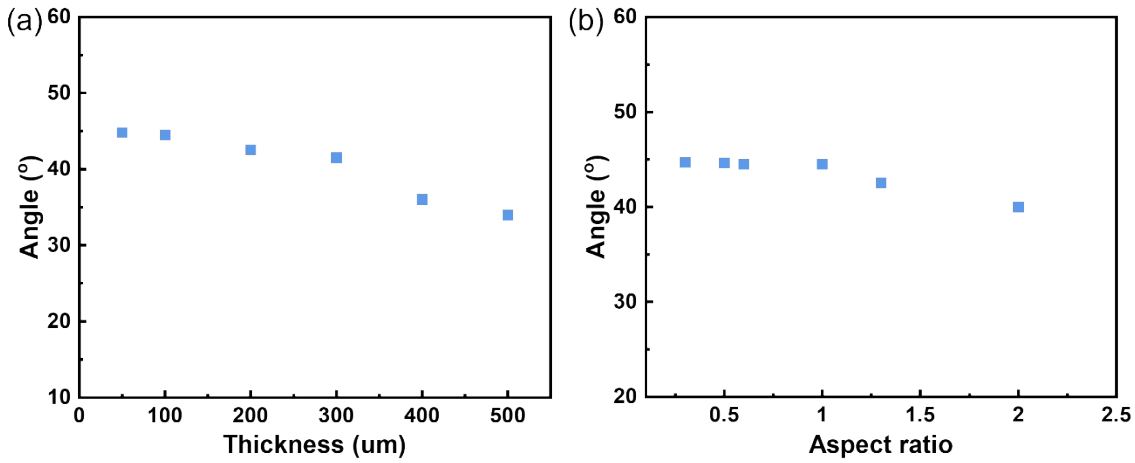

Figure S8. a) The tangent angle θ vs thickness of PDMS layer of the actuator (the thickness of LCE layer is about 200 um) and b) the tangent angle θ vs aspect ratio of the actuator, the thickness of LCE and PDMS layer is 200 and 100 um, respectively.

Table S1. Response time along with the thickness of PDMS layer

Thickness of PDMS (um)	50	100	200	300	400	500
Response time (s)	37	40	43	43.5	45	46