Supplementary Materials for

Optically addressable dielectric elastomer actuator arrays using embedded percolative networks of zinc oxide nanowires

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PDF file includes:

Supplementary Materials and Methods

Supplementary Figures S1-S3

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Caption for Supplementary Codes S1 and S2

Other Supplementary Material for this manuscript includes the following:

Movies S1 and S2

Codes S1 and S2

Supplementary Materials and Methods:

Fabrication of carbon nanotube (CNT) electrodes: the CNT electrodes were formed by vacuum filtration of a dispersion of CNTs in deionized water through a porous filter and stamping onto an elastomer substrate, following the procedure described in the appendix of (*1*).

Fabrication of elastomer layers: the elastomer substrate was made of urethane acrylate precursor, consisting of 99.5% CN9028 (Sartomer Arkema Group) and 0.5% Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (Sigma-Aldrich) as the photoinitiator, spin coated at 3000 rpm for 1 min and cured using ultraviolet light and nitrogen-filled environment for 100 s.

Fabrication of zinc oxide channels: the percolating network of zinc oxide nanowires were made using a similar method as the CNT electrodes; first, 80 mg of zinc oxide nanowires (with diameter of 50 nm to 150 nm and length of 5 μm to 50 μm, SKU: NWZO01A5, ACS Material LLC) were suspended in 80 g of isopropanol using ultrasonication for 8 min at 80% power (Branson 450 Digital Sonifier attached to a one-half inch tapped stepped disruptor horn through a 102C convertor), followed by vacuum filtration of 4.0 g of the dispersion through a porous filter with 0.2 μm pore sizes (T020A090C, Advantec, Dublin, CA), forming percolating networks of zinc oxide nanowires with density of 1.0 $\mu g.mm^{-1}$. Then, the photoconductive electrical channels were made by stamping the filters onto elastomer substrates. The shape and dimensions of the channel were defined by placing masks between the elastomer and the filter, which were cut from a clear silicone release film (CRP41082, Drytac, Richmond, VA) using a desktop cutting machine (Silhouette Cameo, Silhouette America, Inc., Lindon, Utah). The masks and stamps were then removed, and an encapsulating layer of elastomer was formed on top of the CNT electrodes and zinc oxide channel, using the same material and method as for the substrate.

Supplementary Figures:

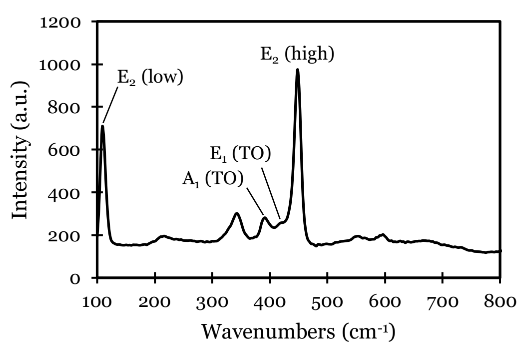

Figure S1. Raman spectrum of zinc oxide nanowires powders on silicon wafer substrate excited using a 532 nm laser.

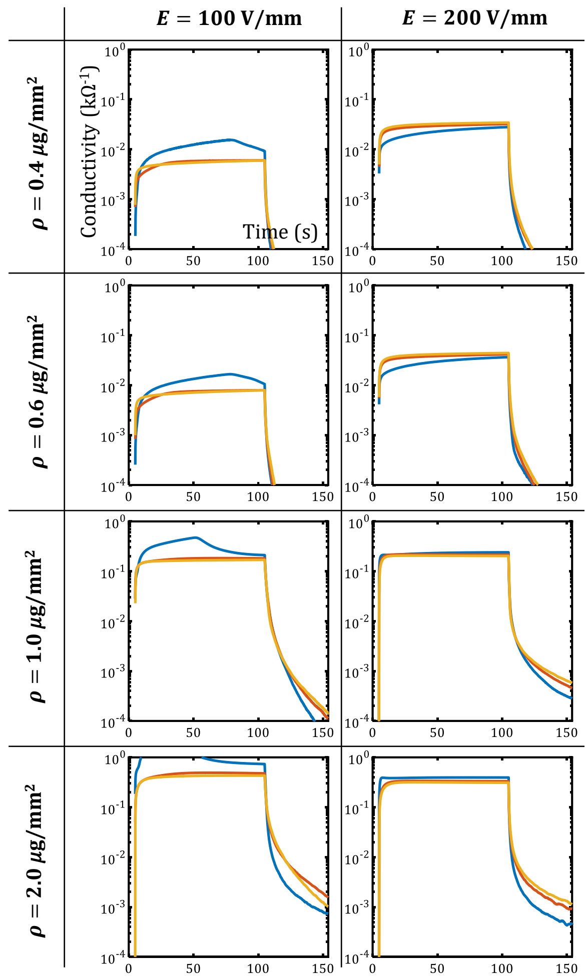

Figure S2. Photoconductivity of the zinc oxide nanowires channels under 100 seconds of UV exposure with 3.41 mW.mm^{-2} intensity, and 100 V and 200 V bias voltages (left and right columns, respectively), for zinc oxide nanowires densities of 0.4, 0.6, 1.0, and 2.0 μg.mm^{-2} (rows one to four, respectively). Blue, red, and yellow curves in each graph represent the first, second, and third cycles, respectively.

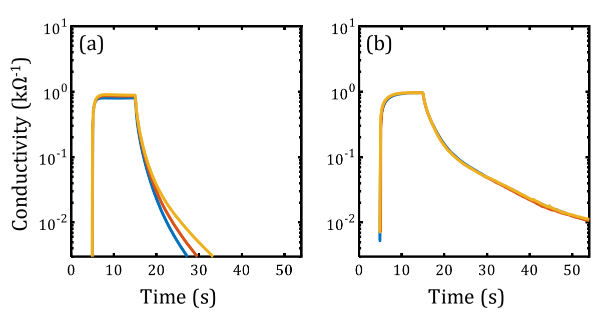

Figure 3. Photocurrent of a zinc oxide nanowires channel with 1.0 μg.mm^{-2} density without the top encapsulating elastomer layer and exposed to air under 10 seconds of UV exposure with 3.41 mW.mm^{-2} intensity and 100 V bias voltage, before and after 10 minutes of UV exposures in the absence of the bias voltage, shown in (a) and (b), respectively.

Caption for Supplementary Movie S1: Real-time cyclic actuation of a dielectric elastomer actuators using solid state relays and embedded electrical channels of percolating networks of zinc oxide nanowires. The ground electrode of the DEA is connected to the ground terminal of the power supply. The actuation sequence is as follows: the actuator is first activated for 500 ms using a solid-state relay, connecting the high-voltage electrode of the DEA to the high-voltage terminal of the power supply at 1.5 kV. The first relay is turned off and the actuation is removed by activating the second relay for 500 ms, connecting the high-voltage electrode of the DEA to the ground terminal of the power supply. After 1000 ms the process is repeated but this time using the zinc oxide nanowire channels: first set of LEDs are turned on activating the first zinc oxide nanowire channel for 500 ms, followed by activating the second zinc oxide nanowire channel for 500 ms using the second set of LEDs. The projected laser line in red is used to measure the out of plane displacement of the DEAs.

Caption for Supplementary Movie S2: Actuation of individual dielectric elastomer actuators in a 6×6 array with embedded electrical channels of percolating networks of zinc oxide nanowires, addressed by activating pairs of ultraviolet light emitting diodes using a Bluetooth Low Energy module, controlled by a custom-made smartphone app. The movie shows real-time actuation of the entire device, followed by magnified view of the actuators array at 4x speed.

Caption for Supplementary Code S1: a smartphone app developed using Xcode, connecting wirelessly to the Bluetooth Low Energy module and communicating the activated pairs of light emitting diodes to address individual dielectric elastomer actuators in the 6×6 array. The app is implemented on an iPhone SE 2016 edition.

Caption for Supplementary Code S2: a program developed using PSoC Creator for the CYBLE-212006-01 (Cypress Semiconductor) Bluetooth Low Energy module, activating the pairs of light emitting diodes to address individual dielectric elastomer actuators in the 6×6 array.

Reference:

1. E. Hajiesmaili, D. R. Clarke, Dielectric elastomer actuators. *Journal of Applied Physics* **129**, 151102 (2021).