Supplementary data

Twisting patterning: Electrochemical Deposition of Stretchable Spiral Metallic Conductor on Elastic Polymer Threads

Yu Chang[1,2,3], Tingrui Pan[2] and Zhenguo Yang[1]**

1. Department of Materials Science, Fudan University, 200433, China
2. Micro-Nano Innovations (MINI) Laboratory, Department of Biomedical Engineering, University of California Davis, 95616, USA
3. Institute of Biomedical and Health Engineering, Shenzhen Institutes of Advanced Technology, Chinese Academy of Science, 518055, China

Corresponding Author:

*Prof. Z. Yang: zgyang@fudan.edu.cn, *Prof. T. Pan: trpan@ucdavis.edu;

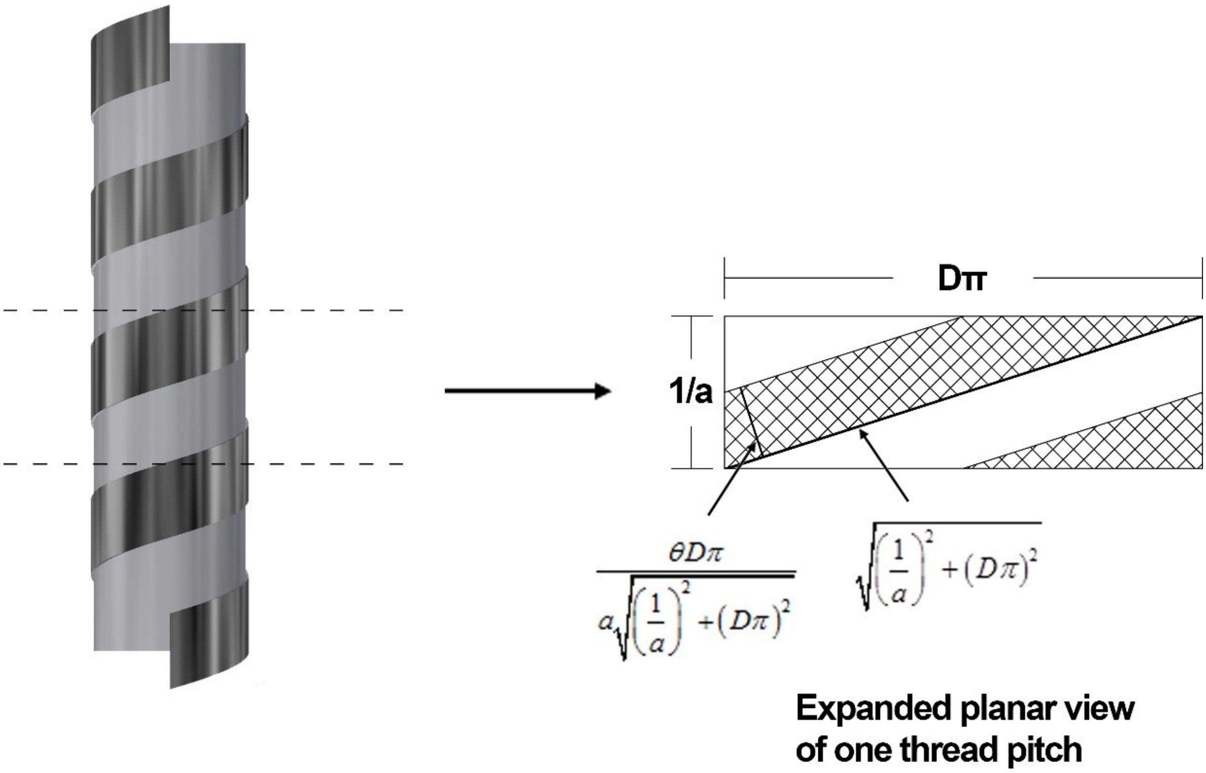

Figure S1. It is possible to derive the spiral length and width equations using known parameters, thus more properties of the 3D spiral, such as resistance, can be calculated. The derivation model starts by expanding one pitch of the spiral to planar with a length of Dπ and a width of 1/a. So the length equation of the spiral is:

$$L = a\sqrt{\left(\frac{1}{a}\right)^2 + (D\pi)^2} \quad (1)$$

While L is spiral length over one centimeter thread, a means spiral cycles per centimeter, so 1/a is spiral pitch, D refers to thread diameter. According to Pythagorean theorem, the width of the spiral is deduced to be.

$$b = \frac{\theta D\pi}{a\sqrt{\left(\frac{1}{a}\right)^2 + (D\pi)^2}} \quad (2)$$

While b is metal spiral width, θ means the ratio between the metal spiral width with the width of one pitch, and can also be interpreted as the coverage rate of catalyst during spraying. The value of θ is 0.5 using single spiral conductor preparation process theoretically, but a more precise value can be obtained by optical measurement. θ value of the 3D spiral conductor prepared by double-spirals conductor process, in which masks are used during catalyst spraying, is related to the slot width on the mask:

$$\theta = \frac{\sin^{-1}\left(\frac{c}{D}\right)}{\pi}$$

(3)

While c is slot width on mask, and the equation works when c is smaller than D. With all the equation above, the resistance of the 3D spiral conductor can be calculated:

$$R = \frac{\rho(a^2D^2\pi^2 + 1)}{\pi D\theta d}$$

(4)

While R is thread resistance per centimeter, ρ is resistivity of the metal spiral. As more than one kind of metal is deposited in the spiral, the real resistivity of the metal spiral is different with the resistivity of nickel, which is used in theoretical calculation.

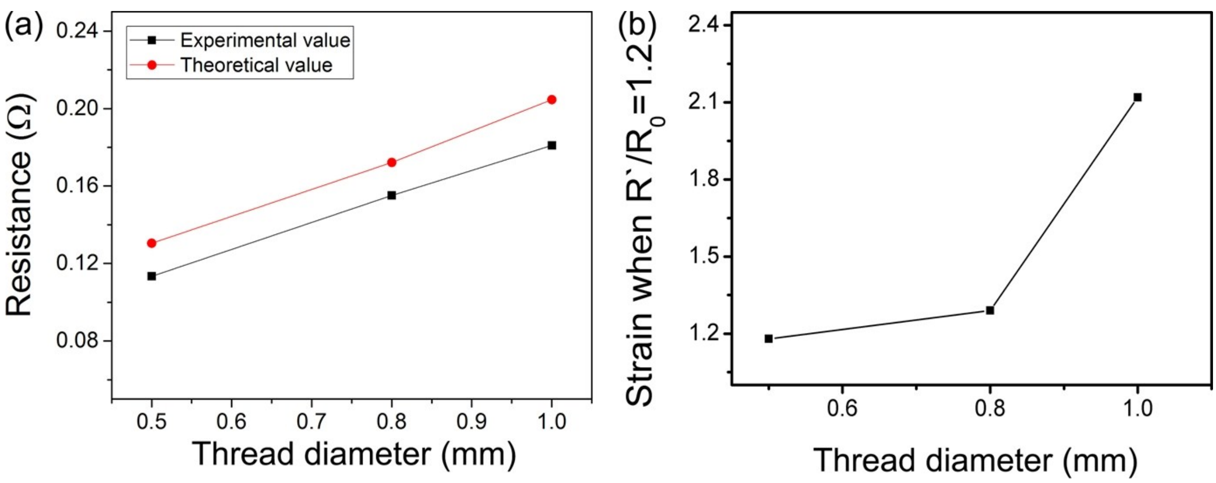

Figure S2. a) resistances (1 cm) of spiral conductors with different thread diameters, nickel thickness is 20 um, spiral cycles is 10 cm^{-1} and θ is 0.6; b) resistance stability of spiral conductors with different thread diameters, nickel thickness is 20 um, spiral cycles is 10 cm^{-1} and θ is 0.6.

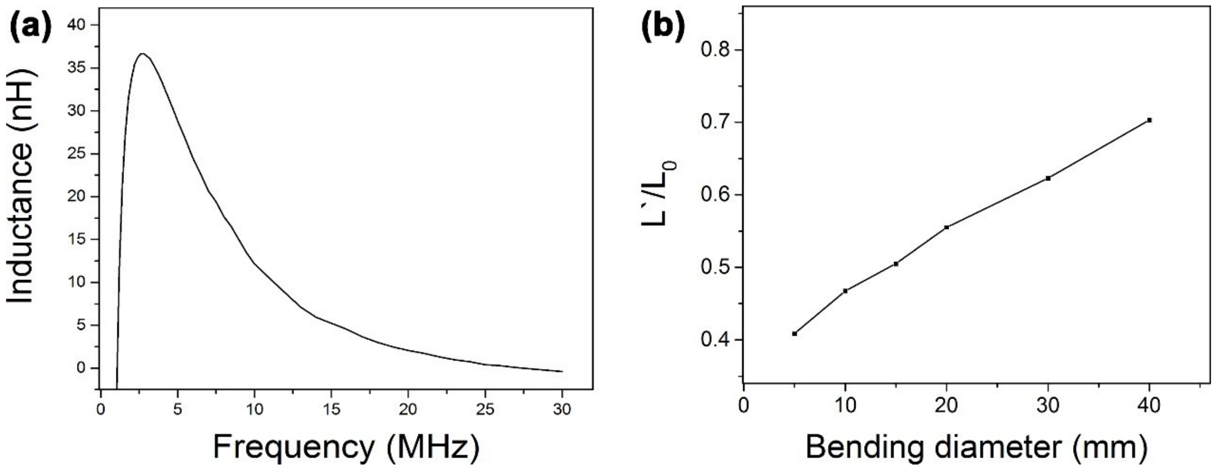

Figure S3. a) inductance (1 cm) of spiral conductor at different frequencies; b) inductance of spiral conductor with different bending diameter, bending angle is 180°, thread diameter: 1200 um, thread length: 60 mm, spiral cycles: 10 cm^{-1}, spiral thickness: 20 um. The phenomena that the inductance of spiral conductor is related to its bending angle and bending diameter can be explained as follows. When the alternating current flows through the inductor, the time-varying magnetic field induces a reverse voltage which has a 90° advance compared to original voltage in phase angle in the conductor, inductance is thus generated and impedance is increased. In the case of spiral conductor, when the thread is straight, only self-inducted electromotive force exists in the spiral, the induced voltage is 90° advance in phase angle to the original voltage, inductance has a largest value. When bending the spiral, two ends of the spiral approach gradually, leading to the increase of mutual induction electromotive force to each other. The closer two ends of the spiral are, the larger mutual induction electromotive force will be. The mutual induced voltage has a same phase angle with the origin voltage in the spiral, thus increasing the current in the spiral. Therefore, the measured impedance has a fall, which means the inductance of the 3D spiral conductor decreases.

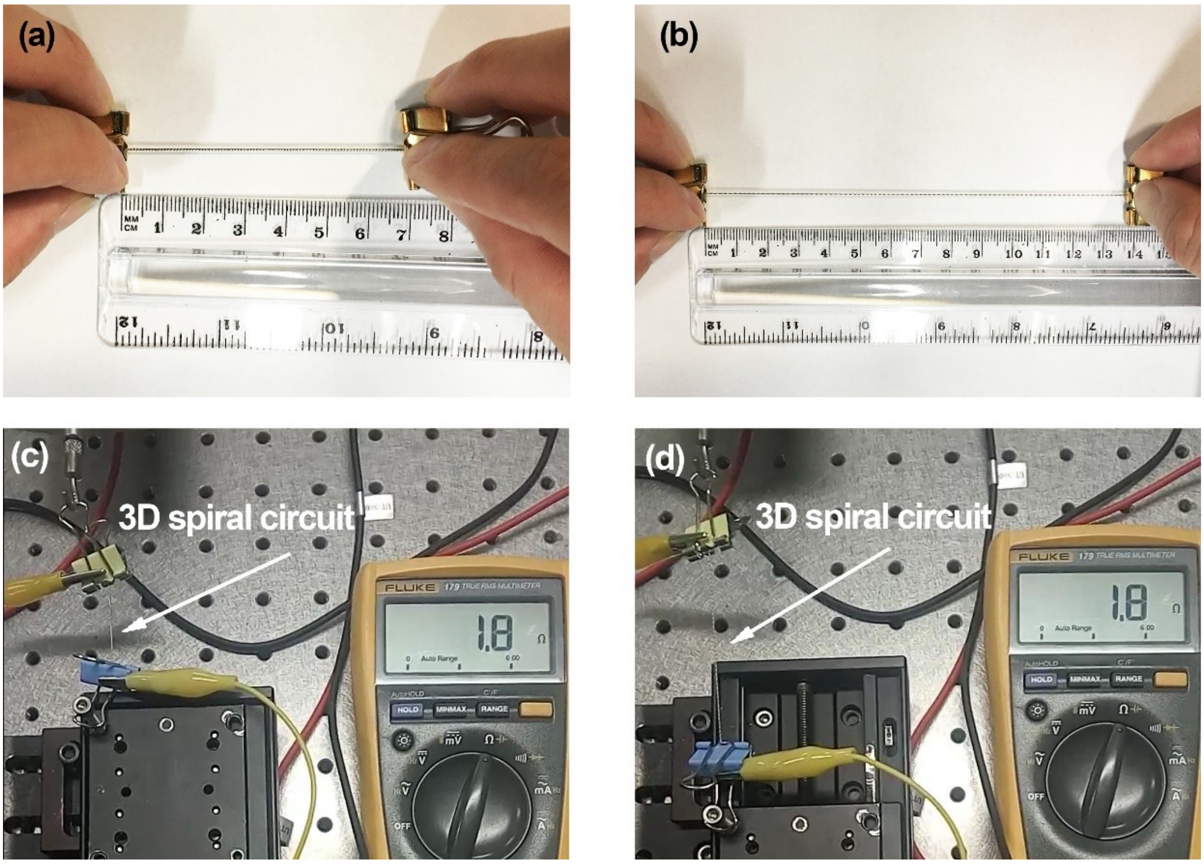

Figure S4. spiral conductor (a) before and (b) after 100% strain, resistance measurement of spiral conductor before (c) and (d) after 120% strain, no change in resistance was measured.