Ultrasensitive, Stretchable Strain Sensors Based on Fragmented Carbon Nanotube Papers

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ABSTRACT

It is now common to design flexible strain sensors using metallic nanoparticles and nanowires, carbon nanotubes (CNTs) or graphene-based materials. However, the pursuit to design reliable strain sensors that feature high stretchability (up to 50%), high sensitivity and durability continues. The sensitivity of a strain sensor is usually quantified by its gauge factor (GF), which is the relative change in resistance ($\Delta R/R_0$) per unit applied strain ($\varepsilon$), in which $\Delta R$ and $R_0$ are the resistance change and the initial resistance, respectively. CNT-based strain sensors (films or fibers) have been shown to have moderate sensitivity, with the highest GF approaching 360. Their sensitivity can be improved by either reducing the initial resistance or by increasing the change in resistance. This latter point is more challenging and a novel method is needed to amplify the change in resistance.

Cracks are normally considered detrimental to the overall mechanical and electrical properties of materials. However, if these cracks can be controlled, they also have the potential for use in mechanical sensing applications. Strain sensors made of cracked silver nanoparticle thin film coated on PDMS substrates can be stretched to 20% with GF=7. This change in resistance is attributed to the opening and closing of microcracks.[1] Ultrasensitive (GF>2000) strain sensors based on the formation of nanocracks in a brittle platinum thin film deposited on the top of stretchable layers have been reported; however, they had only 2% stretchability. This mechanism was based on the disconnection-reconnection process of nanoscale crack junctions under strain or vibration at the nanoscale.[2,3]

Here, we introduce initial fragmentation to papers made of randomly distributed SWCNTs embedded in poly (dimethylsiloxane) (PDMS) by stretching them above their crack onset strain [4]. The entangled networks of SWCNTs bridging the fragments throughout the cracks play a key role toward enlarging the change in electrical resistance of the strip (from 5 $\Omega$ to 30 M$\Omega$). The sensor can measure a strain up to 50%, with a GF of 107. This technology is robust, whereby the performance remains unchanged up to 10000 cycles at 20% strain. We start by describing the sensing strategy that equips our sensor with ultrahigh sensitivity and high stretchability. We identify the key parameters used to create an optimized structure by initiating cracks in the SWCNT papers. Then we show the strain sensing properties as well as their sensing mechanisms. Our concept could readily be extended to other conductive nanomaterials, paving the way for developing high-performance strain sensors.

REFERENCES


