

Using new materials to make more reliable nanoelectromechanical systems

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Given their outstanding mechanical and electrical properties, carbon nanotubes are attractive building blocks for next-generation nanoelectromechanical devices, including high-performance sensors, logic devices, and memory elements. However, manufacturing challenges associated with creating well-ordered arrays of individual carbon nanotubes and the nanotube-devices' prevalent failure modes have prevented any large-scale commercial use.

Now, researchers at Northwestern University, the Center for Integrated Nanotechnologies at Sandia and Los Alamos National Laboratories, and Binghamton University have found a way to dramatically improve the reliability of carbon nanotube-based nanoelectromechanical systems. Their results are published in the journal *Small*.

"Depending on their geometry, these devices have a tendency to stick shut, burn or fracture after only a few cycles," said Horacio Espinosa, James N. and Nancy J. Professor in the McCormick School of Engineering at Northwestern University. "This significantly limits any practical application of such nano devices. Our discovery may be a key to advancing carbon nanotube-based nanoelectromechanical systems from laboratory-scale demonstrations to viable and attractive alternatives to many of our current microelectronic devices."

To date, carbon nanotube-based nanoelectromechanical devices have ubiquitously used metal, thin-film [electrodes](#). The Northwestern University group in collaboration with SANDIA investigators replaced

these electrodes with electrodes made from diamond-like carbon (an electrically-conductive and mechanical robust material), which suppressed the onset of failure. This enabled them to demonstrate the first example of nanoelectromechanical devices constructed from individual CNTs switching reliably over numerous cycles and apply this functionality to memory elements that store binary states.

"This represents a significant step in the maturation of carbon nanotube-based device technology," Espinosa said.

The team used a carbon nanotube-based nanoelectromechanical switch as a platform to study failure modes and investigate potential solutions.

"This switch shares operating principles, and thus failure modes, with numerous reported devices," said Owen Loh, a graduate student in Espinosa's lab. "In this way, we hope the results will be broadly applicable."

First, the team conducted a parametric study of the design space of devices using conventional metal electrodes. This enabled identification of the point of onset of the various failure modes within the design space and highlighted the highly limited region in which the devices would function reliably without failure. They then used computational models to explain the underlying mechanisms for the experimentally-observed modes of failure.

"Using these models, we can replicate the geometry of the devices tested and ultimately explain why they fail," said Xiaoding Wei, a post-doctoral fellow in Espinosa's lab.

The team then demonstrated that using alternative electrode materials like diamond-like carbon could greatly improve the reliability of these devices. They repeated a similar parametric study using diamond-like

carbon electrodes rather than metal thin films and found a dramatic improvement in device robustness. This enabled reliable switching of the carbon nanotube-based devices through numerous cycles, as well as application to the volatile storage of binary "0" and "1" states.

Provided by Northwestern University

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