Biomimetic engineering design will help create efficient heat dissipation in NEMS sensors

**PROBLEM**
Nanoelectromechanical systems (NEMS) devices have the potential to revolutionize the world of sensors: motion, chemical, temperature, etc. But taking electromechanical devices from the micro scale down to the nano requires finding a means to dissipate the heat output of this tiny gadgetry. NEMS devices are characterized by high-density, point-load heat sources that can’t be cooled by traditional means. Even the microelectromechanical systems (MEMS) devices used in automobiles and electronics are hard to cool, because conventional thermal management strategies such as fans, fluids, pastes and wiring often don’t work at these small scales; heat buildup in MEMS frequently leads to catastrophic device failure, which limits the reliability of larger systems.

**APPROACH**
MIT’s Professor Markus Buehler studies protein-based materials at the nano and atomistic scales with the goal of mimicking those natural structures in human-made materials. He has found that in these natural materials, the prevention of failure in response to load is often attributable to a built-in redundancy: the existence of hierarchical arrangements of just a few simple types of tiny lightweight building blocks, each of which features exceptional performance. A similar hierarchical structure also accounts for a living cell’s ability to communicate efficiently with its outermost regions or areas beyond through a series of branching protein networks. Based on this knowledge of the structures of natural materials, Buehler and postdoctoral associate Zhiping Xu applied biomimetic engineering principles to the design of novel materials at the nanoscale to create a template for highly efficient thermal materials that can be used in nanotechnology applications, such as NEMS sensors.

**FINDINGS**
The number of heat-conducting fibers or carbon nanotubes (CNTs) that can be connected to the point-load heat source at the center of a NEMS device is limited by the physical size of the heat source itself. Buehler and Xu designed a simple, hierarchical arrangement of CNTs that optimizes the few fibers that can be directly connected to the heat source. By solving the heat transfer equations in the hierarchical structure through theoretical analysis and numerical modeling based on finite difference methods, the researchers demonstrated that the geometric structure—a branched-tree hierarchy of at least two branches sprouting from each previous branch—is far more effective at heat dissipation than the non-hierarchical “spaghetti” of most existing CNT-based materials. For instance, a single fiber connected to the heat source with 99 additional branched links between it and the heat sink will provide the same dissipation effect as if 50 long fibers were connected directly to the heat source. If five carbon nanotubes are arranged in direct connection to the heat source using this structure, the heat dissipation will be the equivalent of 250 direct connections to the heat source. This design repetition creates a redundant pattern that serves to quickly disperse the heat to an external sink.

**IMPACT**
This research provides a breakthrough in the understanding of the implications of using biomimetics to create an engineered hierarchical design template for NEMS devices. The results could radically change the approach to nanodevice design, which in turn may enable us to more effectively monitor the natural environment, as well as better maintain our nation’s infrastructure through development of sensors for bridges, buildings and telecommunications networks.

**MORE**
Buehler and Xu wrote a paper about this research in the March 26 issue of Nano Letters. The work was funded by DARPA and the MIT Energy Initiative. Buehler and Xu are currently working on the design of heat-conducting fibers that will self-assemble in response to heat by means of heat-sensing particles at the ends of carbon nanotubes.