Tantalizing tantalum: Improving MEMS thermal actuators and sensors

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Carnegie Mellon University researchers explore an efficient substitute material for use in microelectromechanical system (MEMS) thermal actuators and sensors. Credit: De Boer Laboratory, Carnegie Mellon University

Accelerometers in mobile phones, microprocessors in laptops, and gyroscopes that balance drones each rely on microelectromechanical systems, or MEMS for short. Within these small systems are even smaller devices, called actuators and sensors, that perform various physical functions.

One type is a thermal actuator which transforms energy into motion by the expansion and contraction of materials due to temperature changes. You'll find MEMS thermal actuators inside computer disk drives, scanning probes, and microengines.

Currently, these thermal actuators rely on polysilicon, a material that requires high temperatures and consumes a considerable amount of power during the fabrication process. While working on related research, investigators at Carnegie Mellon University's College of Engineering realized they had found an efficient substitute.

Led by Maarten de Boer, professor of mechanical engineering, the team created microelectromechanical thermal actuators with tantalum instead of polysilicon. This lowered both the operating temperature and energy consumption that would be necessary for a given amount of actuation. The results were published in *Nature Microsystems & Nanoengineering*. Further research resulted in an additional paper published in the *Journal of Microelectromechanical Systems.*

Tantalum is a rare, refractory metal, often used in alloys to increase strength and durability. The researchers theorized that tantalum thermal actuators—due to the metal's large coefficient of thermal expansion compared to the silicon substrate on which it is made—would require less than half the power input for the same force and displacement than those made with polysilicon.

Operating at a lower voltage than other thermal actuators, the tantalum ones are directly compatible with complementary metal oxide semiconductor (CMOS) circuits. The tantalum devices could also be processed nearly at room temperature.

"In principle, this work demonstrates the viability of using tantalum not only to fabricate thermoactuators but also many sensors for use in a wide range of integrated nanoelectronics," said de Boer.

During the fabrication process of a microprocessor, phone, or other device, manufacturers typically place a MEMS component on one chip and electronic CMOS components on a second chip.

De Boer's team believes that tantalum as a MEMS structural material can eliminate both the need for two separate chips and the extra wiring that sends signals between them. This will result in more efficient devices made with less material, which will cost less to manufacture and result in higher performance.

Although other researchers have explored ways to eliminate the second chip, they found the high temperatures needed to fabricate MEMS to be a roadblock. De Boer's team has solved this issue.

The second paper, published in the *Journal of Microelectromechanical Systems*, explored the use of aluminum nitride to maintain a low temperature during the MEMS fabrication process. This could increase the viability of developing both MEMS and CMOS on the same chip in a "MEMS-last" approach that may be of interest both to foundries and to so-called fabless MEMS companies.

"Regarding the CMOS integration, it would be quite exciting as it lends itself to use of full CMOS under the MEMS," observed Gary Fedder, a professor of electrical and computer engineering. "Tantalum density is about seven times larger than silicon, so it will be excellent as a proof mass. That is a big deal as a similar sensitivity transducer can be seven times smaller!"

The results could have future impact on a range of industries that require sensing technologies, like aerospace, healthcare, optical networks, and robotics. De Boer and his students have filed three provisional patents in the areas of processing tantalum for MEMS.

Additional authors on the technical papers and provisional patents include Longchang Ni and Ryan Pocratsky, both Ph.D. students in the Department of Mechanical Engineering.

More information: Ni, L., Pocratsky, R.M. & de Boer, M.P. Demonstration of tantalum as a structural material for MEMS thermal actuators. *Microsyst Nanoeng* (2021). DOI: 10.1038/s41378-020-00232-z

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