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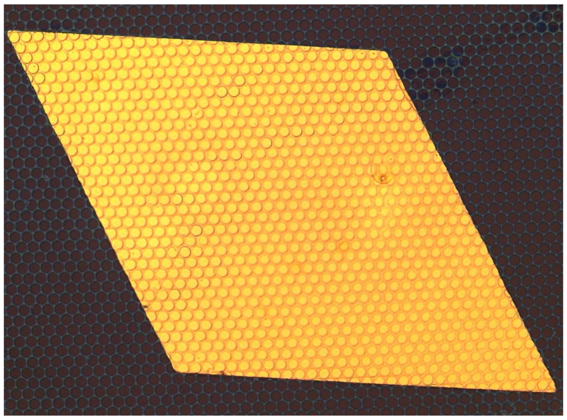
Contact-Printed Nano-Membrane Transducers for Sound Production



Optical microscopy image of an electrostatic microspeaker with a parallelogram-shaped gold membrane transfer-printed atop a cavity-patterned silicon dioxide substrate. The gold membrane shown is approximately 1 mm in length on each side and 125 nanometers thick.

The Challenge: Speakers make sound by moving a membrane to displace air repeatedly. Prevalent speakers use magnets and moving coils to produce a force to vibrate a thick diaphragm. These speakers come with significant disadvantages for both the quality of sound produced and the energy needed to produce it because of power losses in the moving coil and the larger mass of both the vibrating diaphragm and the coil. Conventional speakers increasingly use rare-earth magnets, which are environmentally unfriendly due to rare-earth mining.

Micro-electromechanical systems (MEMS) could offer a viable alternative for sound production in energy-critical and sound quality-critical applications such as hearing aids, where limited battery life often frustrates users. However, due to material limitations and associated processing challenges, there are no electrostatic MEMS microspeakers that use suspended thin films to produce sound efficiently at low voltages.

In addition, an additive ultra-thin-membrane MEMS fabrication process that would enable low-voltage electrostatic speakers could be extended to other large-area applications, such as sensor skins on flexible substrates. These flexible substrates generally break down when exposed to the harsh chemical treatments and high temperatures that are currently used in making microsensors and actuators. Restricting potential substrate materials and areas constrains the types of products that could be manufactured, especially as large-area, scalable, flexible sheets.

The Solution: Among Apoorva's inventions are nano-membrane electrostatic microspeakers and a fabrication process to additively contact-transfer print these nano-membranes atop various substrate materials. His microspeakers consist of a gold membrane suspended over thousands of cavities in an underlying substrate such as glass or silicon. These electrostatic microspeakers move the nano-membrane diaphragm to produce sound using only electric fields, and, as a result, obviate the magnets, moving coils, and thicker diaphragms of conventional sound sources. Electric power wasted as heat in the moving coil of traditional speakers is also eliminated, contributing to higher power efficiency and extended battery life. The elimination of permanent magnets reduces dependence on rare-earth metals, a factor that benefits the environment.

The negligible mass of Apoorva's microspeaker nano-membrane, coupled with its elastic characteristics, enables higher-fidelity sound reproduction at lower power consumption as compared to conventional moving-coil microspeakers. The contact-transfer printing process additively suspends the nano-membranes over shallow sub-micron deep gaps in the underlying substrate, enabling the actuation of these speakers at voltages much lower than those used for prior electrostatic sound sources, thus enhancing their portability. Multiple membranes can be printed as arrays on the same substrate die to increase the sound output, and these arrays could be electrically phased to enable directional sound sources.

That all adds up to high-fidelity sound at lower power, resulting in lighter, longer-lasting, and better-sounding microspeakers for hearing aids and other consumer electronics. Moreover, the contact-transfer printing process can be employed to similarly fabricate nano-membrane MEMS devices on both rigid and flexible substrates for other applications such as sound detection, pressure sensing, and ultrasound imaging.

Application and Commercialization: Printed mechanically-active nano-structured membranes have potential uses ranging from energy-efficient, high-fidelity microspeakers and microphones for consumer electronics to biomedical ultrasound devices. They might even be used for flexible "sensor skins" for distributed pressure-sensing in wind-tunnel testing and in robotics. Market research and industry collaborators have recommended hearing aids as a market-entry application and the printed membrane MEMS devices are currently being optimized for in-ear sound production. Along with Dr. Brian Anthony, of the MIT Institute for Medical Engineering & Science and mechanical engineering PhD candidate Megan Roberts, Apoorva is also investigating the use of these MEMS structures as ultrasound transmitters and receivers for portable, point-of-care medical imaging. He has also engaged a collaborator to explore commercialization. Ultimately, Apoorva envisions himself launching a company to design, manufacture, and market nano-membrane transducers and integrate them into various consumer products.