Graphene sheets enable ultrasound transmitters

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A canyon or pipistrelle bat, a common Northern California species of bat recorded with the new ultrasonic microphone. Credit: Wikicommons photo

University of California, Berkeley, physicists have used graphene to build lightweight ultrasonic loudspeakers and microphones, enabling people to mimic bats or dolphins' ability to use sound to communicate and gauge the distance and speed of objects around them.

More practically, the wireless ultrasound devices complement standard radio transmission using electromagnetic waves in areas where radio is impractical, such as underwater, but with far greater fidelity than current ultrasound or sonar devices. They can also be used to communicate through objects, such as steel, that electromagnetic waves can't penetrate.

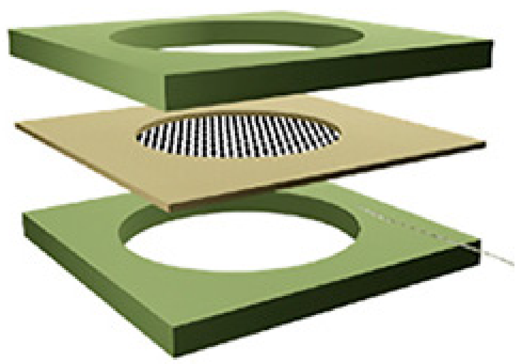
"Sea mammals and bats use high-frequency sound for echolocation and communication, but humans just haven't fully exploited that before, in my opinion, because the technology has not been there," said UC Berkeley physicist Alex Zettl. "Until now, we have not had good wideband ultrasound transmitters or receivers. These new devices are a technology opportunity."

Speakers and microphones both use diaphragms, typically made of paper or plastic, that vibrate to produce or detect sound, respectively. The diaphragms in the new devices are graphene sheets a mere one atom thick that have the right combination of stiffness, strength and light weight to respond to frequencies ranging from subsonic (below 20 hertz) to ultrasonic (above 20 kilohertz). Humans can hear from 20 hertz up to 20,000 hertz, whereas bats hear only in the kilohertz range, from 9 to 200 kilohertz. The grapheme loudspeakers and microphones operate from well below 20 hertz to over 500 kilohertz.

Graphene consists of carbon atoms laid out in a hexagonal, chicken-wire arrangement, which creates a tough, lightweight sheet with unique electronic properties that have excited the physics world for the past 20 or more years.

"There's a lot of talk about using graphene in electronics and small nanoscale devices, but they're all a ways away," said Zettl, who is a senior scientist at Lawrence Berkeley National Laboratory and a member of the Kavli Energy NanoSciences Institute, operated jointly by UC Berkeley and Berkeley Lab. "The microphone and loudspeaker are some of the closest devices to commercial viability, because we've worked out how to make the graphene and mount it, and it's easy to scale up."

Zettl, UC Berkeley postdoctoral fellow Qin Zhou and colleagues describe their graphene microphone and ultrasonic radio in a paper appearing online this week in the *Proceedings of the National Academy of Sciences*.



An atom-thick layer of carbon atoms, called graphene (black mesh), provides the vibrating diaphragm for both an ultrasonic microphone and loudspeaker. Credit: UC Berkeley image.

Radios and rangefinders

Two years ago, Zhou built loudspeakers using a sheet of graphene for the diaphragm, and since then has been developing the electronic circuitry to build a microphone with a similar graphene diaphragm.

One big advantage of graphene is that the atom-thick sheet is so lightweight that it responds immediately to an electronic pulse, unlike today's piezoelectric microphones and speakers. This comes in handy when using ultrasonic transmitters and receivers to transmit large amounts of information through many different frequency channels simultaneously, or to measure distance, as in sonar applications.

"Because our membrane is so light, it has an extremely wide frequency response and is able to generate sharp pulses and measure distance much more accurately than traditional methods," Zhou said.

Graphene membranes are also more efficient, converting over 99 percent of the energy driving the device into sound, whereas today's conventional loudspeakers and headphones convert only 8 percent into sound. Zettl anticipates that in the future, communications devices like cellphones will utilize not only electromagnetic waves – radio – but also acoustic or ultrasonic sound, which can be highly directional and long-range.

"Graphene is a magical material; it hits all the sweet spots for a communications device," he said.

Bat chirps

When Zhou told his wife, Jinglin Zheng, about the ultrasound microphone, she suggested he try to capture the sound of bats chirping at frequencies too high for humans to hear. So they hauled the microphone to a park in Livermore and turned it on. When they slowed down the recording to one-tenth normal speed, converting the high frequencies to an audio range humans can hear, they were amazed at the quality and fidelity of the bat vocalizations.

"This is lightweight enough to mount on a bat and record what the bat can hear," Zhou said.

Bat expert Michael Yartsev, a newly hired UC Berkeley assistant professor of bioengineering and member of the Helen Wills

Neuroscience Institute, said, "These new microphones will be incredibly valuable for studying auditory signals at high frequencies, such as the ones used by bats. The use of graphene allows the authors to obtain very flat frequency responses in a wide range of frequencies, including ultrasound, and will permit a detailed study of the auditory pulses that are used by bats."

Zettl noted that audiophiles would also appreciate the graphene loudspeakers and headphones, which have a flat response across the entire audible frequency range.

"A number of years ago, this device would have been darn near impossible to build because of the difficulty of making free-standing graphene sheets," Zettl said. "But over the past decade the graphene community has come together to develop techniques to grow, transport and mount graphene, so building a device like this is now very straightforward; the design is simple."

More information: "Graphene electrostatic microphone and ultrasonic radio." *PNAS* 2015 ; published ahead of print July 6, 2015, DOI: 10.1073/pnas.1505800112

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