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Paraphrasing from Wikipedia, Graphene is a form (allotrope is the more precise technical term) of carbon in a two-dimensional, one atom thick film. Graphene is the basic structural element of other carbon variants (allotropes), including graphite, charcoal, and carbon nanotubes. It is more than 200 times stronger than high-strength (high-carbon) steel. It efficiently conducts heat and electricity, and carbon materials typically have good acoustical properties.

It was originally observed using electron microscopes in 1962 and characterized in 2004 by Andre Geim and Konstantin Novoselov at the University of Manchester. This work resulted in their Nobel Prize in Physics in 2010 “for groundbreaking experiments regarding the two-dimensional material graphene.”

The Tip of the Spear

So how is graphene used in headphones and speakers and why does it matter? The first audio products to be commercialized with a graphene-derivative material are from ORA Sound (ORA Graphene Audio, Inc.), an early-stage start-up that has announced, but not yet released a product. ORA has devised traditional cone drivers from a composite material called GrapheneQ (graphite oxide). Its low density and high stiffness enable potentially higher output drivers.

ORA was conceived at the engineering labs of McGill University. Dr. Robert-Eric Gaskell headed research into how the properties of graphene oxide could be tuned to create the conditions for high-quality sound. Shortly after producing the first prototype audio transducer based on graphene oxide technology, Gaskell joined TandemLaunch, an incubator for university research and assembled the ORA team. If ORA was going to succeed where other commercial endeavors of graphene had failed, they would have to put manufacturability at the forefront. Turning to Northwestern University, they found the research of Professor SonBinh Nguyen,
Dr. Robert-Eric Gaskell introduced a prototype of a GrapheneQ speaker at the ALMA International Symposium and Expo (AISE) 2017. ORA Sound was the first company to bring to market its development of GrapheneQ, a graphene oxide it is commercializing in composite speaker diaphragms.

The team made its graphene oxide by reducing graphene and then adding a proprietary blend of cross linkers to create the composite. The intrinsically high tan delta means that it requires less damping mass (especially at low frequencies) than commercial devices to prevent unwanted spurious breakup response characteristics. Less damping at lower frequencies also means that the bass and treble response are both extended, which ideally results in faster transient response and quicker settling times.

GrapheneQ is stiff and distorts very little thanks to its high Young’s Modulus of up to 130 GPa. This enables sound waves to travel quickly through the material, pushing diaphragm “break-up” to beyond audio frequencies where they are more easily damped. The material has a very high thermal conductivity, which enables design for enhanced heat dumping from the voice coil and out from the diaphragm using various techniques. Specifically, the voice coil bobbin can be thermally conductive or in a microspeaker or headphone driver a bobbinless coil can be bonded (using thermally conductive adhesive) directly to the diaphragm.

The ORA researchers hope that GrapheneQ will become a standard material for loudspeaker membranes in the future. They have a Kickstarter crowdfunding program for a headphone and are establishing an OEM program for their diaphragm technology.

In 2016, GraphAudio licensed the graphene audio work and patents from The Lawrence Berkeley National Labs at UC Berkeley. GraphAudio’s goal is to develop a new generation of graphene-based microspeaker transducers with high sensitivity and ultra-low distortion. The image shows a comparison of an 8 mm dynamic speaker and an 8 mm GraphAudio Gen1 transducer.

At the Eureka Park zone during CES 2017, ORA Sound successfully introduced the idea of GrapheneQ-based headphones and provided side-by-side comparisons with their first prototypes and well-established over ear models.

An earlier prototype speaker membrane formed from a Graphene composite material (GrapheneQ) from ORA Sound who had a way to manufacture graphene sheets in a simple process that could be easily scaled to production quantities. Then the focus was on tuning GrapheneQ into a high-performance diaphragm material for audio.

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But graphene’s promise is that not only can it be used as an additive for speaker diaphragms in traditional moving coil, magnetic dynamic speakers, such as ORA is doing, but also theoretically as a speaker itself.
**More Research and Development**

In 2012 at the Lawrence Berkeley National Labs (LBNL) at the University of California, Berkeley, Dr. Alex Zettl and Dr. Qin Zhou were researching graphene for audio applications. About a year later, a proof-of-concept graphene earphone, consisting of a graphene diaphragm sandwiched between electrodes to create the electrical field, was demonstrated and received a lot of press coverage. Now the LBNL technology has been exclusively licensed by GraphAudio to be developed into commercialized audio products.

GraphAudio is developing a complete implementation of a true electrostatic driver where the pure graphene diaphragm functions as part of the “motor.” The in-canal earphones consisted of a graphene diaphragm sandwiched between electrodes that created the electrical field. When this field oscillates due to the audio signal, it causes the graphene to vibrate in a physical analogy to the audio electrical signal and this generates sound. It’s essentially an electrostatic speaker; but instead of a metalized polymer film diaphragm, graphene is used. The graphene diaphragms are very thin and light with a small spring constant so that the air itself damps its motion. The air-damped graphene converts almost all of its energy into sound and so is potentially extremely efficient. Scholarly work has continued but a number of practical challenges remain before graphene can emerge as a viable—and game changing—alternative for established transducer technologies.

As mentioned, in 2016, GraphAudio exclusively licensed the graphene audio work and patents from The Lawrence Berkeley National Labs at UC Berkeley. With both the rights to the audio work and IP as well as the original research team of Zettl and Zhou, they began to hire other specialists and continue the path to commercialization. Business Co-Founders are Fred Goldring, CEO, and Frederick Wells, Chief Business Development Officer. Lorance (Lonnie) Wilson, CTO and VP Engineering, has much experience in semiconductor processing and commercialization of new technologies at Fairchild, AMD, and Intel, and leads the development efforts.

GraphAudio’s goal is to develop a new generation of graphene-based micro audio componentry that potentially will outperform the current generation and open new capabilities. GraphAudio’s patent-pending true graphene transducer delivers an electrostatic micro speaker that promises high-resolution audio with high sensitivity and ultra-low distortion.

The obvious targets for graphene-based audio components range from speakers (e.g., tweeters...
and microspeakers) to earphones/headphones and microphones. The promise for audio enthusiasts is that graphene’s high strength allows for the relatively large, free-standing diaphragms necessary for effective low-frequency response, assuming traditional planar dipole configuration. Due to the intrinsically low moving mass and high Young’s modulus, achieving high-resolution audio is a given. The symmetrical push-pull electrostatic drive has been the core technology of the finest audiophile headphones and speakers and studio microphones. (Most readers are familiar with the reputation of the Sennheiser Orpheus and Stax electrostatic headphones, Neumann studio condenser mics, and a number of legendary electrostatic speakers.)

**Going Smaller**

The development work being done by GraphAudio is integrating pure graphene diaphragms for higher sensitivity with much better form factors than current electrostatic implementations using polymer film (metalized or otherwise conductive coating diaphragms).

The ability to power graphene earphones and speakers using conventional mobile battery power expands their application from just the boutique end of the market. Batteries (or supercapacitors) for the DC bias, work for graphene since they source only voltage and virtually no current. Since the power is tiny, there is no need for high current and small batteries suffice. GraphAudio’s innovative work on the drive electronics are highly efficient as well.

In theory, graphene transducers can be economically produced in high volume utilizing automated fabrication techniques. With any new technology, moving from laboratory into the real world is the challenge. Just understanding and learning how to control the fabrication processes for optimization of the usual parameters are the hurdles GraphAudio is just beginning to get under control. The measurement and full characterization of the transducer is where much of their focus lies, including optimization of amplifier parameters, bias voltage, as well as transducer excursion, response, tensioning and sensitivity trade-offs. The low-hanging fruit are microphones, tweeters, earphones, and headphones due to the low excursion requirements—but winning the lottery means microspeakers.

Zettl, GraphAudio’ Co-founder, explained that the appeal of pure graphene for earphones and headphones is that the per-area air damping coefficient significantly decreases when the size of the diaphragm falls below the sound wavelength. For
small speakers, a thinner and lower mass density diaphragm is required to continue the dominance of air damping. Such a diaphragm is difficult to realize. If conventional materials such as metalized Mylar are made too thin, they invariably fatigue and break or lose their optimum tensioning. Graphene is an ideal building material for small, efficient, high-quality broadband audio speakers because it satisfies all the above criteria. It is electrically conducting, has extremely small mass density, and

GraphAudio staff uses this Chemical Vapor Deposition (CVD) tool for Graphene development.

Here is a finished run with four 8 mm transducers, which will be diced for testing.
GraphAudio is exploring graphene-based acoustic transmitters and receivers for all applications, including professional microphones. GraphAudio’s Mic1 is its initial proof-of-concept studio mic. Preliminary graphene microphone work from the UC Berkeley technology spin-off was reported in scientific journals in 2015. In the GraphAudio Mic1, a large graphene diaphragm has been fabricated and integrated into an omnidirectional condenser microphone capsule.

can be configured to have very small effective spring constant.

The pure graphene transducer design functions as speaker or microphone, or both, but the diaphragm tensioning, electrode spacing, and bias voltage, among other parameters such as sensitivity vs. Xmax excursion, electrode attach technique, and so forth still must be optimized for full functionality.

Wilson, Co-founder and CTO, comments on GraphAudio’s progress: “We’ve made great strides with the device so far and I’m very proud of our team. It’s been a real pleasure working with such a high-level interdisciplinary group. The process we’ve developed produces robust and stable transducers and we are currently optimizing the device package for performance prior to engineering release. We are starting to work with early adopter customer/partners to help pull us into commercialization soon. It’s really fun to see that as a business, we seem to be experiencing the same push/pull dynamic as our device.”

Goldring, Co-founder and CEO, expressed his passion for the project, “Graphene transducers are the holy grail of audio and our goal is to become the standard for microspeakers and microphones inside every connected device on the planet. With more and more people today (and the vast majority of young people) listening to their music on mobile devices and in-ear buds rather than large bookshelf and floor speakers, our graphene transducers will finally bring high-res audio economically to the masses. GraphAudio’s transducers will introduce the first quantum leap in consumer audio technology since the advent of the moving coil, magnetic, dynamic speaker in 1921. For an entire generation which has been weaned on compressed music heard only through marginal earphones, our graphene transducer technology will be a real ‘ear opener’.”

GraphAudio envisions arrays of these transducers enabling control of directivity and coverage, but also audiophile applications for full range dipole speakers. Certain product categories will be available for licensing while others will be reserved for GraphAudio’s own products.

Resources


Sources
GrapheneQ
ORA Graphene Audio, Inc. | www.ora-sound.com

Patent-pending graphene-based transducer
GraphAudio | www.graphaudio.com