



(51) International Patent Classification:

H04R 7/02 (2006.01) H04R 7/14 (2006.01)
H04R 9/06 (2006.01) H04R 9/04 (2006.01)
H04R 19/02 (2006.01)

(21) International Application Number:

PCT/US2016/043284

(22) International Filing Date:

21 July 2016 (21.07.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/196,860 24 July 2015 (24.07.2015) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

(54) Title: SPEAKER DRIVER INCLUDING CARBON MATERIAL

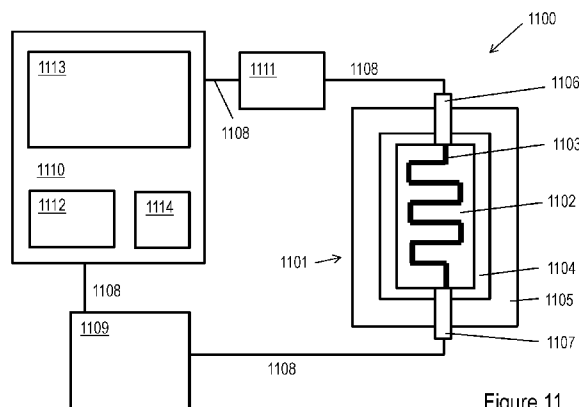


Figure 11

(57) Abstract: Speaker driver devices (1101) including a diaphragm (1102) and one or more electrode (1103) are provided herein. The diaphragms (1102) and electrodes (1103) of the speaker driver devices may each include carbon nanotubes and/or graphene. Also provided herein are methods of generating sound with such speaker driver devices.

SPEAKER DRIVER INCLUDING CARBON MATERIAL

CROSS-REFERENCE TO RELATED APPLICATION

5 **[0001]** This application claims the benefit of United States Provisional Patent Application No. 62/196,860, filed July 24, 2015, which is hereby incorporated by reference in its entirety.

TECHNOLOGY

10 **[0002]** This Application relates to audio equipment. More specifically, embodiments of the subject disclosure include speaker devices for generating sound.

BACKGROUND

15 **[0003]** A speaker, such as a loudspeaker, is a transducer which converts an electrical audio signal into acoustic energy including, for example, sound waves. Speakers, which may include, e.g., tweeters, mid-range speakers, and woofers,
20 have a wide range of shapes, sizes and sound-producing capabilities. For example, speakers are employed in radio and television receivers as well as many forms of music players including headphones. Larger speaker systems are utilized for sound reinforcement in concert venues and theaters as well as in public address systems.

SUMMARY

25 **[0004]** Speaker driver devices including a diaphragm and one or more electrode are provided herein. The diaphragms and electrodes of the speaker driver devices may each or both include, for example, carbon nanotubes and/or graphene.
30 Also provided herein are methods of generating sound with speaker driver devices.

[0005] Embodiments of the speaker driver devices set forth herein have one or more components such as a diaphragm including carbon nanotubes and/or graphene, e.g., only carbon nanotubes, or only graphene. In some versions,

diaphragms include a polymer film, such as polyimide film. The devices may also include a biasing electrode including carbon nanotubes and/or graphene, e.g., only carbon nanotubes, or only graphene, and operably connected to the diaphragm.

[0006] In some versions, the diaphragm and/or the biasing electrode are planar. However, in some versions, a diaphragm includes and/or defines one or more, such as a plurality of, arches. Each of the arches may separate, e.g., lie between, portions of a diaphragm surface which are opposite from one another and/or facing one another. Also, according to various embodiments, a biasing electrode includes or is shaped as a coil, e.g., a cylindrical coil.

[0007] The devices described herein may also include one or more, e.g., two, electrical contacts each including graphene and/or carbon nanotubes and operably connecting to the biasing electrode with a voltage source and/or a signal source, such as an audio signal generation unit. A frame operably connected to and extending around the diaphragm may also be included in embodiments of the devices.

[0008] Diaphragms of the devices may have a thickness of 20 microns or less, such as 15 microns or less, such as 10 microns or less. Diaphragms also may include a cone and/or a former. Embodiments of the diaphragms also are substantially non-electrically conductive.

[0009] Where desired, the devices described herein also include speaker driver devices including a first biasing electrode and a second biasing electrode. Each of the first biasing electrode and the second biasing electrode may include carbon nanotubes and/or graphene. Such devices also may include a diaphragm between, e.g., entirely between, the first biasing electrode and the second biasing electrode, and including carbon nanotubes and/or graphene.

[0010] A variety of methods, including methods of using the disclosed devices, are also set forth herein. Such methods include methods of generating sounds with one or more speaker driver device. In some instances, the methods include applying an electric potential and/or voltage to a biasing electrode of the device in a magnetic field, wherein the biasing electrode includes carbon nanotubes and/or graphene. Such a method may include applying, such as by transmitting, the electric potential and/or voltage to a biasing electrode via, for example, one or more electrical contacts each including carbon nanotubes and/or graphene. Also, in embodiments of the methods wherein a biasing electrode includes carbon nanotubes, applying an

electrical potential and/or voltage to the biasing electrode can include transferring a current across the diaphragm via the carbon nanotubes of the biasing electrode.

[0011] The methods also include moving a diaphragm of a device, such as a diaphragm which includes carbon nanotubes and/or graphene and is operably
5 connected to the biasing electrode. The subject method also include generating sound by, for example, exerting pressure on air with a diaphragm to generate sound waves. Furthermore, in some instances, a device includes a frame operably connected to the diaphragm and defining an opening. In such versions, moving the diaphragm may include moving the biasing electrode within the opening.

[0012] In some variations, a biasing electrode includes or is shaped as a coil and applying an electrical potential and/or voltage to the biasing electrode includes flowing a current through the coil. Flowing a current through a biasing electrode, which may include a coil, may include generating thermal energy in the biasing electrode. As such, the methods also may include conducting the thermal energy
15 away from the biasing electrode via the diaphragm and thereby, for example, cooling the biasing electrode.

[0013] Where appropriate, a diaphragm includes a former defining a central axis therethrough. Also, a biasing electrode may include a coil extending around the former. In such embodiments, moving the diaphragm including moving the coil
20 and/or the diaphragm in one or more direction, e.g., two opposite directions, parallel with the central axis. Furthermore, according to some embodiments of the methods, a former includes a passage and moving the diaphragm includes generating an air flow in the passage and thereby cooling the coil.

[0014] In some instances, the devices have a housing having a first wall
25 including a first magnet and a second wall opposite the first wall and including a second magnet. As such, in some embodiments, moving the diaphragm includes vibrating the diaphragm between the first magnet and the second magnet. Systems and kits according to the subject embodiments are also provided herein.

[0015] These and other objects, advantages, and features of the disclosed
30 subject matter will become apparent to those persons skilled in the art upon reading the details of the devices and methods as more fully described below.

BRIEF DESCRIPTION OF THE FIGURES

[0016] FIG. 1 provides a perspective view of a device including a planar diaphragm according to embodiments of the present disclosure.

5 [0017] FIG. 2 provides a cross-sectional side view of a device including a planar diaphragm according to the subject embodiments.

[0018] FIG. 3 provides a cross-sectional side view of a device with a diaphragm including a cone according to embodiments of the present disclosure.

10 [0019] FIG. 4 provides a cross-sectional side view of a device with a diaphragm including a cone according to embodiments of the present disclosure.

[0020] FIG. 5 provides a cross-sectional side view of a device according to embodiments of the present disclosure.

[0021] FIG. 6 provides a perspective view of a device including an arching diaphragm according to embodiments of the present disclosure.

15 [0022] FIG. 7 provides a cross-sectional side view of a device including an arching diaphragm according to embodiments of the present disclosure.

[0023] FIG. 8 provides a diagram of a device including a plurality of biasing electrodes according to embodiments of the present disclosure.

20 [0024] FIG. 9 provides a perspective view of a device including a plurality of biasing electrodes according to embodiments of the present disclosure.

[0025] FIG. 10 provides a schematic diagram of a device according to embodiments of the present disclosure.

[0026] FIG. 11 provides a schematic diagram of a system according to embodiments of the present disclosure.

25 [0027] FIG. 12 provides a cross-sectional side view of a device including a planar diaphragm according to the subject embodiments.

DESCRIPTION OF EXAMPLE EMBODIMENTS

30 [0028] Speaker driver devices including a diaphragm and one or more electrode are provided herein. The diaphragms and electrodes of the speaker driver devices may each include, for example, carbon nanotubes and/or graphene. Also provided herein are methods of generating sound with speaker driver devices.

[0029] Before embodiments of the invention are described in greater detail, it is to be understood that this disclosed subject matter is not limited to particular embodiments described, and as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the embodiments of the invention will be limited only by the appended claims.

[0030] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the embodiments of the invention. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges and are also encompassed within the embodiments of the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the embodiments of the invention.

[0031] Certain ranges may be presented herein with numerical values being preceded by the term "about." The term "about" is used herein to provide literal support for the exact number that it precedes, as well as a number that is near to or approximately the number that the term precedes. In determining whether a number is near to or approximately a specifically recited number, the near or approximating unrecited number may be a number which, in the context in which it is presented, provides the substantial equivalent of the specifically recited number.

[0032] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the embodiments of the invention belong. Although any methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present embodiments of the invention, representative illustrative methods and materials are now described.

[0033] All publications and patents cited in this specification are herein incorporated by reference as if each individual publication or patent were specifically and individually indicated to be incorporated by reference and are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited. The citation of any publication is for

its disclosure prior to the filing date and should not be construed as an admission that the presently disclosed subject matter is not entitled to antedate such publication by virtue of prior invention. Further, the dates of publication provided may be different from the actual publication dates which may need to be independently confirmed.

[0034] It is noted that, as used herein and in the appended claims, the singular forms “a”, “an”, and “the” include plural referents unless the context clearly dictates otherwise. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as “solely,” “only” and the like in connection with the recitation of claim elements, or use of a “negative” limitation.

[0035] Additionally, certain embodiments of the disclosed devices and/or associated methods can be represented by drawings which may be included in this application. Embodiments of the devices and their specific spatial characteristics and/or abilities include those shown or substantially shown in the drawings or which are reasonably inferable from the drawings. Such characteristics include, for example, one or more (e.g., one, two, three, four, five, six, seven, eight, nine, or ten, etc.) of: symmetries about a plane (e.g., a cross-sectional plane) or axis (e.g., an axis of symmetry), edges, peripheries, surfaces, specific orientations (e.g., proximal; distal), and/or numbers (e.g., three surfaces; four surfaces), or any combinations thereof. Such spatial characteristics also include, for example, the lack (e.g., specific absence of) one or more (e.g., one, two, three, four, five, six, seven, eight, nine, or ten, etc.) of: symmetries about a plane (e.g., a cross-sectional plane) or axis (e.g., an axis of symmetry), edges, peripheries, surfaces, specific orientations (e.g., proximal), and/or numbers (e.g., three surfaces), or any combinations thereof.

[0036] As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the presently disclosed subject matter. Any recited method can be carried out in the order of events recited or in any other order which is logically possible.

[0037] In further describing the instant subject matter, embodiments of devices and systems of the invention are described first in greater detail, followed by a description of methods, including methods of employing the subject devices, as well as a review of certain applications in which the embodiments of the invention find use.

DEVICES

[0038] The present disclosure provides embodiments of speakers or components thereof, such as speaker drivers. As used herein, the term “speaker driver” refers to a single transducer, such as an electroacoustic transducer, which converts electrical energy to sound waves. In other words, a speaker driver converts an electrical signal, e.g., an audio signal, such as a voltage, into sound. As such, a speaker may include one or more, e.g., a plurality, such as two or more, three or more, or five or more, speaker drivers, such as one or more speaker drivers mounted in a speaker housing.

[0039] In some embodiments of the subject disclosure, the devices include speaker driver devices having a diaphragm and an electrode, e.g., a biasing electrode. By “biasing electrode”, as used herein, is meant an electrode which biases the diaphragm to move, such as by exerting a force on the diaphragm, when an electrical potential and/or voltage is applied to, and/or current is flowed through, the biasing electrode in a magnetic field. In some embodiments, the potential and/or voltage applied to the biasing electrode is an audio signal. The diaphragm may, in some versions, be operably connected, e.g., physically attached to, to the electrode so that the biasing electrode and the diaphragm move, e.g., vibrate, together. The movement of the biasing electrode and/or the diaphragm may be proportional to the magnitude of the potential and/or voltage, such as an audio signal, applied thereto. By “operably connected”, “operably coupled”, and “operably attached” as used herein is meant connected in a specific way that allows the disclosed devices to operate and/or methods to be carried out effectively in the manner described herein. More specifically, the phrase “operably connected” can include physically connected, such as physically attached, and/or thermally connected so that thermal energy may be transmitted from one connected element to another, and/or electrically connected so that electrical voltage and/or current may be transmitted from one connected element to another. For example, an electrode operably connected to a contact,

e.g., an electrical contact, may be physically connected to the contact and/or electrically connected to the contact so that an electrical current may flow between the electrode and the contact.

[0040] One embodiment of the subject devices is shown, for example, in FIG.

5 1. FIG. 1 illustrates a speaker driver device 100 including a diaphragm 101 and a biasing electrode 102. The device 100 shown in FIG. 1 also includes a frame 103, a first electrical contact 104 and a second electrical contact 105, the contacts 104, 105, each connected to the biasing electrode. In FIG. 1, diaphragm 101 is shown disposed beneath biasing electrode 102 as well as beneath the first electrical contact
10 104 and the second electrical contact 105.

[0041] Elements of the subject devices including the diaphragm, electrode, e.g., biasing electrode, contacts, and frame may each be composed of a variety of materials. Each component may include a single material or a plurality of materials. For example, embodiments of the devices include a diaphragm including carbon
15 nanotubes and/or graphene. In some versions, a diaphragm includes only carbon nanotubes or only graphene. The subject devices also, in some versions include one or more electrodes each including carbon nanotubes and/or graphene. In some versions, a biasing electrode includes only carbon nanotubes or only graphene. Furthermore, in some versions the devices also include one or more electrical
20 contacts connecting a biasing electrode to a voltage source, such as the contacts 104, 105 illustrated in FIG. 1, each including carbon nanotubes and/or graphene. In some versions, such contacts each include only carbon nanotubes or only graphene.

[0042] Diaphragms and/or other components such as biasing electrodes, frames and/or electrical contacts, may include, for example, any one or combination
25 of: carbon materials; e.g., graphene and/or carbon nanotubes; polymeric materials, e.g., materials having one or more polymers; metallic materials, e.g., materials including one or more metals; and/or ceramic materials; as well as wood, paper and/or cellulose. Such materials may have characteristics of flexibility and/or high strength, e.g., able to withstand significant heat and/or force, such as a force exerted
30 on it by a biasing electrode, without breaking and/or resistant to wear, and/or high fatigue resistance, e.g., able to retain its physical properties for long periods of time regardless of the amount of use or environment. In various embodiments, the material or combination of materials of the diaphragm are formed as a sheet which is flexible and which vibrates to generate sound.

[0043] In some embodiments, polymeric materials of the subject device components, e.g., diaphragms, and/or frames and/or biasing electrodes, e.g., insulation therefor, and/or electrical contacts, include, but are not limited to: glass fiber, polyimide, e.g., polyimide film, e.g., Kapton[®] or Nomex[®], and/or plastics, such as polytetrafluoroethene or polytetrafluoroethylene (PFTE), including expanded polytetrafluoroethylene (e-PFTE), polyester (Dacron[®]), nylon, polypropylene, polyethylene, high-density polyethylene (HDPE), polyurethane, polyepoxide, phenol formaldehyde, etc. In certain embodiments, metallic materials of the subject device components, e.g., diaphragms, and/or frames and/or biasing electrodes, e.g., insulation therefor, and/or electrical contacts, include, but are not limited to: metals e.g., copper, tin, silver, aluminum, bismuth, zinc, indium antimony, stainless steel, gold, titanium, tantalum, etc. and/or metal alloys.

[0044] Where desired, the subject diaphragms include only polyimide, e.g., polyimide film. In some embodiments, the subject diaphragms do not include polymeric materials, such as polyimide. Embodiments of the devices include diaphragms and/or biasing electrodes not including glass fiber. Furthermore, in some embodiments, components such as diaphragms and/or biasing electrodes do not include metallic materials, e.g., aluminum, copper, or alloys thereof. Also, in some embodiments, components such as biasing electrodes and/or electrical contacts only include metallic materials, e.g., aluminum, copper, or alloys thereof, or any of the other metallic materials provided herein. Additionally, in some versions, diaphragms do not include carbon nanotubes or graphene. Also, in some embodiments, biasing electrodes do not include carbon nanotubes or graphene.

[0045] In some variations of the subject embodiments, a diaphragm, e.g., a diaphragm including carbon nanotubes and/or graphene, and/or frame of a device is substantially non-electrically conductive. By “substantially”, as used herein is meant to a great or significant extent, such as entirely. As such, a diaphragm which is substantially non-electrically conductive essentially or entirely does not conduct electrical current, for example, from the biasing electrode to another location, such as the frame.

[0046] As noted above, in some versions, the subject devices include diaphragms and/or electrodes, e.g., biasing electrodes, composed of a plurality of carbon nanotubes. The phrase “carbon nanotube”, is used herein in its conventional sense to refer to an allotrope of carbon wherein the hexagonal lattice of carbon

atoms is shaped as a cylinder. Carbon nanotubes are also referred to herein as “nanotubes”. The subject devices also include one or more electrical contacts connecting a biasing electrode to a voltage source, wherein the electrical contacts are composed of a plurality of carbon nanotubes. Nanotubes may be randomly oriented or substantially aligned. For example, each nanotube has a single axis of symmetry and when multiple nanotubes are aligned, the axes of symmetry of the nanotubes are substantially parallel. Nanotubes may be held together by van der Waals forces, such as by pi-stacking.

[0047] The carbon nanotubes may be single-walled nanotubes (SWNTs), multi-walled nanotubes (MWNTs), or a combination of both. The multi-walled nanotubes may include a plurality, e.g., two or more, three or more, five or more, ten or more, of concentric tubes of carbon sheets, e.g., graphene. As such, the multi-walled nanotubes may be double-walled nanotubes (DWNTs) or triple-walled nanotubes (TWNTs).

[0048] Carbon nanotubes may each be cylindrical and have a first end defining a first opening and a second end opposite the first end defining a second opening. In various instances, the nanotubes have a diameter, e.g., a diameter along a cross section of a cylindrical nanotube extending from a first side of the nanotube to a second side of the nanotube opposite the first side, ranging from, for example, 0.5 nanometer to 2 nanometers, such as 0.5 nanometer to 1.5 nanometers, such as 0.8 nanometers to 1.2 nanometer, inclusive. By “inclusive”, as used herein in association with a range is meant that the values defining the endpoints of the range provided are also included in the range. Even if the term “inclusive” is not specifically recited in association with a range, all the ranges provided herein, including open-ended ranges, are inclusive. Carbon nanotubes as disclosed herein may have a diameter of 1 nanometer or close to 1 nanometer. In embodiments of multi-walled nanotubes, the nanotubes may include one or more nanotubes inside another and separated, for example, by a distance of 0.0003 micrometers.

[0049] Carbon nanotubes or materials thereof included in components of the devices according to the subject embodiments may have a higher tensile strength and/or elastic modulus than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. As such, carbon nanotubes or materials including carbon nanotubes

may be more resistant to physical breakdown such as cracks or breaks and more able to retain their initial shape than such materials. Accordingly, carbon nanotubes or materials including carbon nanotubes may be able to move, such as vibrate, from a first position to a second position and/or back to the first position, for example to produce sound, a higher number of times than materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide, without cracking, breaking or permanently deforming from their initial shape.

[0050] Carbon nanotubes or materials thereof according to the subject embodiments may have a density of, for example, 1 to 1.5 g/cm³, such as 1.3 to 1.4 g/cm³. Such materials may also have a specific strength, e.g., a specific strength in an axial direction, of 48,000 kN·m·kg⁻¹ or lower, such as 40,000 kN·m·kg⁻¹ or 30,000 kN·m·kg⁻¹, such as a specific strength greater than that of high-carbon steel. In some versions, carbon nanotubes have a tensile strength ten or more times that of a steel cable of the same weight. In some embodiments, carbon nanotubes or materials thereof do not undergo a plastic deformation, e.g., a permanent physical deformation, until they undergo an elongation of 3% or greater, such as 4% or greater, such as 5% or greater. In some versions, carbon nanotubes according to the subject embodiments may have a Young's modulus ranging, for example, from 270-950 GPa and/or a tensile strength ranging from 11-63 GPa in an axial direction. Carbon nanotubes according to the subject embodiments may also have a Young's modulus ranging, for example, from 1 to 5 in a radial direction.

[0051] Carbon nanotubes may have a wide variety of electrical conductivity. For example, carbon nanotube structures may be electrically conductive or substantially non-electrically conductive. The electrical conductivity of carbon nanotubes may depend on how the nanotubes are made. For example, carbon nanotubes made as single wall nanotubes may have a different, e.g., higher or lower, electrical conductivity than those made as double wall nanotubes. The amount of non-carbon atoms in a lattice of carbon nanotubes may also affect the electrical conductivity of a carbon nanotubes structure by causing it to be higher or lower. Also, the methods described below may include controlling the electrical and/or thermal conductivity of components including carbon nanotubes and/or graphene by constructing them in a particular manner, e.g., a manner providing high electrical conductivity or a low electrical conductivity.

[0052] In some embodiments, the carbon nanotubes and materials including carbon nanotubes are substantially non-electrically conductive. For example, a diaphragm including carbon nanotubes may be unable or substantially unable to conduct an electrical current away from a biasing electrode, such as from a biasing electrode to a frame. In other words, a diaphragm may be an electrical insulator and may electrically insulate a biasing electrode. In some embodiments, a diaphragm according to various embodiments is not an electrical conductor.

[0053] In some variations of the subject embodiments, carbon nanotubes and materials including carbon nanotubes are electrically conductive. For example, some embodiments, a biasing electrode and/or electrical contacts operably coupled to the biasing electrode, according to various embodiments are electrical conductors. In versions of carbon nanotubes which are conductive, the nanotubes may be semiconducting. Embodiments of the subject nanotubes and materials composed thereof may be able to carry an electric current density of $4 \times 10^9 \text{ A/cm}^2$. Some embodiments of the subject nanotubes and materials composed thereof may be able to carry an electric current density higher, e.g., more than 1000 times higher, than that of copper and/or aluminum. In some embodiments, carbon nanotubes have an electrical conductivity ranging, for example, from 10^5 to 10^7 S/m , such as from 10^6 to 10^7 S/m . Carbon nanotubes or materials thereof included in components of the subject devices may have a higher electrical conductivity than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. In some versions, carbon nanotubes or materials thereof have a specific conductivity greater than that of copper and aluminum. Also, according to some embodiments, components of the devices including carbon nanotubes may also include copper and may be a composite.

[0054] Embodiments of carbon nanotubes and materials including carbon nanotubes may have a higher thermal conductivity than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. Accordingly, for example, diaphragms including carbon nanotubes and materials including carbon nanotubes may be configured to more efficiently conduct heat away from a biasing electrode than diaphragms composed of, e.g., composed entirely of, other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide.

[0055] In some variations, embodiments of carbon nanotubes and materials including carbon nanotubes may have a high thermal conductivity in one direction while also having a low thermal conductivity in a perpendicular direction. As such, diaphragms and/or biasing electrodes, including carbon nanotubes, according to various embodiments, may each have a high thermal conductivity in a first direction, e.g., along its length, and have a low thermal conductivity in a second direction, e.g., along its width, which is perpendicular to the first direction. As such, diaphragms and/or biasing electrodes according to various embodiments, may have a high thermal conductivity, e.g., a thermal conductivity of $1000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or more, such as $2000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or more, such as $3000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or more, in a first direction while being a thermal insulator, e.g., having a thermal conductivity of $1000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or less, such as $500 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or less, such as $100 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or less such as $50 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or less, such as $10 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or less, in a second direction perpendicular to the first direction.

[0056] Where desired, carbon nanotubes and materials including carbon nanotubes may be ballistic conductors. Versions of the carbon nanotubes, such as single-walled nanotubes, may have a room-temperature, e.g., a temperature ranging from 20 to 26 °C, thermal conductivity along its axis ranging from $3200 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ to $3800 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, such as from $3300 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ to $3700 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, such as from $3400 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ to $3600 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, such as a conductivity of $3500 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. In some versions, carbon nanotubes have a high thermal conductivity, such as a thermal conductivity of $3000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or greater. Individual multi-walled nanotubes, may have a room-temperature, e.g., a temperature ranging from 20 to 26 °C, thermal conductivity of $3000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ and above, such as $3500 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ and above, such as $4000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ and above. The carbon nanotubes may have a room-temperature thermal conductivity along its axis greater, such as significantly greater, than that of copper. Carbon nanotubes, according to the embodiments, may also have a room-temperature thermal conductivity across its axis, e.g., in the radial direction, ranging from $1.51 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ to $1.53 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, such as $1.52 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. Carbon nanotubes also may have a temperature stability of up to, and including, 750 °C in air. Also, in some versions of the subject embodiments, the diaphragms include a composite of carbon nanotubes and epoxy, e.g., epoxy resin.

[0057] In some versions of the devices, diaphragms include a sheet of randomly dispersed, e.g., oriented, nanotubes held together, for example, by van der

Waals forces. Such a sheet may be made by suspending the nanotubes in a solvent to create a liquid nanotube/solvent mixture. The nanotube/solvent mixture can then be dispersed on a flat surface. Thereafter, the solvent can be evaporated to leave the sheet of randomly dispersed nanotubes.

5 **[0058]** Also, in some variations, the diaphragms include woven nanotube sheets composed of fine nanotube carbon threads which are woven together. The nanotube threads can be extruded, for example, from nanotubes grown on substrates.

10 **[0059]** Embodiments of the subject devices include diaphragms and/or electrodes, e.g., biasing electrodes, composed of graphene. The term “graphene”, is used herein in its conventional sense to refer to an allotrope of carbon wherein the hexagonal lattice of carbon atoms is shaped as a single-atom thick sheet. In other words, graphene is a two-dimensional, e.g., planar, atomic scale hexagonal lattice of carbon atoms. In various instances, graphene is only one single sheet of carbon
15 atoms or a plurality of such sheets which are not bonded to, e.g., not bonded via van der Waals bonds, to other such sheets. The subject devices also include one or more electrical contacts connecting a biasing electrode to a voltage source, wherein the electrical contacts are composed of graphene. In some embodiments, graphene does not include multiple stacked atomic scale hexagonal lattices of carbon atoms.

20 **[0060]** Graphene or materials including graphene included in components of the devices according to the subject embodiments may have a higher tensile strength and/or elastic modulus than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. As such, graphene or materials including graphene
25 may be more resistant to physical breakdown such as cracks or breaks and more able to retain their initial shape than such materials. Accordingly, graphene or materials including graphene may be able to move, such as vibrate, from a first position to a second position and/or back to the first position, for example to produce sound, a higher number of times than materials such as aluminum, copper, stainless
30 steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide, without cracking, breaking or permanently deforming from their initial shape.

[0061] In some versions, graphene has a Young's modulus of 1TPa and an intrinsic tensile strength of 130 GPa. Embodiments of the subject devices include

graphene having a spring constant ranging from 1 to 5 N/m and/or a stiffness of 0.5 TPa. Graphene, may also have a fracture toughness ranging from 3.8 to 4.2 MPa√m, such as 4.0 MPa√m. Materials including graphene may also have a fracture toughness, for example, ranging from 15 to 50 MPa√m. In some instances, graphene has a tensile strength 100 or more times higher than that of steel and/or Kevlar.

[0062] In some embodiments, materials including graphene are substantially non-electrically conductive. For example, a diaphragm including graphene may be unable or substantially unable to conduct an electrical current away from a biasing electrode, such as from a biasing electrode to a frame.

[0063] Where desired, graphene and materials including graphene are electrically conductive. In versions of graphene materials which are conductive, the materials may be semiconducting.

[0064] In some versions, graphene has an electron mobility of 15000 cm²·V⁻¹·s⁻¹ or higher, such as 40000 cm²·V⁻¹·s⁻¹ or higher, such as 100000 cm²·V⁻¹·s⁻¹ or higher. Graphene may have an electron mobility at room temperature of 200000 cm²·V⁻¹·s⁻¹ or less at a carrier density of 10¹² cm⁻². Graphene may also have a resistivity of 10⁻⁶ Ω·cm or less.

[0065] Graphene or materials thereof included in components of the subject devices may have a higher electrical conductivity than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. In some versions, graphene or materials thereof have a specific conductivity greater than that of copper and aluminum. Also, according to some embodiments, components of the devices including graphene may also include copper and may be a composite.

[0066] Graphene and materials including graphene according to the subject embodiments may have a higher thermal conductivity than other materials such as aluminum, copper, stainless steel, para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide. Accordingly, for example, diaphragms including graphene may be configured to more efficiently conduct heat away from a biasing electrode than diaphragms composed of, e.g., composed entirely of, other materials such as aluminum, copper, stainless steel, glass fiber,

para-aramid synthetic fiber, cellulose, paper, and/or polymeric materials, such as polyimide.

[0067] In some versions, graphene and materials including graphene may be ballistic conductors. Versions of graphene, e.g., suspended single layer graphene, may have a room-temperature, e.g., a temperature ranging from 20 to 26 °C, thermal conductivity along its axis ranging from 1500 W·m⁻¹·K⁻¹ to 5500 W·m⁻¹·K⁻¹, such as from 1500 W·m⁻¹·K⁻¹ to 2500 W·m⁻¹·K⁻¹, such as from 1800 W·m⁻¹·K⁻¹ to 2200 W·m⁻¹·K⁻¹, such as a conductivity of 2000 W·m⁻¹·K⁻¹. Embodiments of graphene, e.g., supported single layer graphene, may have a room-temperature, e.g., a temperature ranging from 20 to 26 °C, thermal conductivity along its axis ranging from 450 W·m⁻¹·K⁻¹ to 650 W·m⁻¹·K⁻¹, such as from 500 W·m⁻¹·K⁻¹ to 600 W·m⁻¹·K⁻¹, such as from 525 W·m⁻¹·K⁻¹ to 575 W·m⁻¹·K⁻¹, such as a conductivity of 550 W·m⁻¹·K⁻¹. Embodiments of graphene may have a thermal conductivity of 1000 W·m⁻¹·K⁻¹ or more, such as 1500 W·m⁻¹·K⁻¹ or more, such as 2000 W·m⁻¹·K⁻¹ or more, such as 3000 W·m⁻¹·K⁻¹ or more. Also, in some versions of the subject embodiments, the diaphragms include a composite of graphene epoxy, e.g., epoxy resin. Furthermore, some embodiments of devices including diaphragms and/or electrodes, e.g., biasing electrodes, composed of graphene or carbon nanotubes do not include graphite.

[0068] In some variations, diaphragms may be composed of, such as entirely composed of polymeric materials. Specific polymeric materials of interest include, but are not limited to: plastics, rubbers, silicones, etc. Polymeric materials may include glass fiber for structural support. In some versions, polymeric materials include polyimide. In some versions, polymeric materials retain their structural and/or thermal and/or electrical integrity across a range of temperatures, for example, from -269 °C to 400 °C, such as from -100 °C to 300 °C, such as from 0 °C to 100 °C. In some aspects, polymeric materials have flexural strengths of 340 MPa and below, such as 300 MPa and below, such as 200 MPa and below. Such materials may have a flexural strength half-life at 249 °C of, for example, 400 hours. The polymeric materials may also have flexural moduli of 21,000 MPa and below, such as 20,000 MPa and below, such as 15,000 MPa and below. Polymeric materials according to the embodiments may have high tensile strength and/or low creep which are maintained at temperatures of 450 °C and below, such as 300 °C and

below, such as 200 °C and below. Polymeric materials, such as polyimide may also have a thermal conductivity ranging, for example, from 0.5 W/(mK) to 0.20 W/(mK), such as from 0.5 W/(mK) to 0.15 W/(mK), such as from 0.10 W/(mK) to 0.15 W/(mK), such as a thermal conductivity of 0.12 W/(mK).

5 [0069] In some instances components, e.g., diaphragms and/or biasing electrodes, of the devices including carbon nanotubes and/or graphene having specific dimensions may be able to conduct a greater amount of electricity without being subject to degradation than components having the same dimensions but not including carbon nanotubes and/or graphene. Accordingly, devices having
10 components, e.g., diaphragms and/or biasing electrodes, including carbon nanotubes and/or graphene, may be more able to receive a higher amount electrical power without degrading and thus produce higher sound levels than devices having components not including such materials.

[0070] As noted above, one embodiment of the subject devices is provided in
15 FIG. 1. In some versions of the devices, including the embodiment shown, the devices are ribbon speakers, e.g., ribbon loudspeakers. Also, in some versions, the subject devices are planar magnetic speakers. A speaker driver device 100 is shown including a diaphragm 101 and a biasing electrode 102. The device 100 provided in FIG. 1 also includes a frame 103, a first electrical contact 104 and a
20 second electrical contact 105, the contacts 104, 105, each connected to the biasing electrode.

[0071] A diaphragm 101 according to the subject embodiments may be a sheet, e.g., a solid sheet, of one or more materials having a thin and/or planar shape. A diaphragm or other components of the subject devices, e.g., a biasing
25 electrode and/or housing, may include a top surface and a bottom surface each defining a parallel plane and separated by a thickness. In various embodiments, a sheet is or includes a uniform layer of a single material, e.g., carbon nanotubes or graphene. A sheet may, in some aspects, have a length, a width and a height, also referred to as a thickness. A thickness of a diaphragm, e.g., a thickness between a
30 first surface and a second surface opposite the first surface, may be 1 mm or less, or 0.1 mm or less, or 50 microns or less, or 20 microns or less, or 15 microns or less, or 10 microns or less, or one micron or less, or 0.5 micron or less. A thickness of a diaphragm may also range for example, from 0.1 micron to 20 microns, such as from 0.1 micron to 15 microns, such as from 0.1 micron to 10 microns, such as from 0.1

micron to 5 microns, or from 0.1 micron to 1mm, such as from 1 micron to 1 mm, such as from 10 microns to 0.1 mm, such as from 20 microns to 0.01 mm, inclusive. Also, a length and/or width of a diaphragm may also range from 1 mm to 2 m, such as from 1 cm to 1 m, such as from 1 cm to 10 cm.

5 **[0072]** Diaphragms may be and/or have an area defining any suitable size or shape including a: circle, semi-circle, oval, rectangle, square, triangle, polygon, quadrilateral, or combination thereof. For example, in embodiments where the diaphragm is a rectangle, the length of the diaphragm is greater than the width.

10 **[0073]** The diaphragm may have three edges, four edges, or more than four edges which define the area of the diaphragm. In various embodiments, the edges meet at corners, e.g., three, four, five, or ten or more corners. In some versions, a first edge of a diaphragm is opposite a second edge of a diaphragm and adjacent to a third and/or fourth edge of a diaphragm. In such an embodiment, the third edge may be opposite a fourth edge and the fourth edge may be adjacent to the first
15 and/or second edge. In various embodiments, all of the edges of the diaphragm are operably, e.g., fixedly, such as adhesively, connected to a frame. In various embodiments, all of the edges of the diaphragm are contained within, e.g., retained in a recess of, a frame.

20 **[0074]** A diaphragm may also be flexible such that it can vibrate to generate sound. In some versions, a diaphragm may be configured to deform from a first configuration to a second configuration and/or from a first configuration to a third configuration a plurality of times. In some versions, diaphragms are biased to retain their initial un-biased shape when one or more forces are exerted thereon which cause the diaphragms to assume, e.g., to temporarily assume, a second “biased”
25 shape. In other words, diaphragms may be elastic. Furthermore, in some versions, a surface, e.g., a top surface and/or a bottom surface of a diaphragm defines a plane when the diaphragm is in an original, unbiased configuration. The diaphragm may be configured to move in a first direction and a second direction which is opposite the first direction. The first and/or second direction may be perpendicular or
30 substantially perpendicular a plane defined by a surface of a diaphragm. Such movement may include moving from a first, e.g., original, configuration to a second configuration and/or a third configuration to generate a sound.

[0075] In some versions, carbon nanotubes and/or graphene, and/or one or more materials made thereof, have a higher damping capacity than other materials,

e.g., metallic materials, such as aluminum, and/or copper; and/or polymeric materials, such as plastic, and/or polyimide. As such, in various embodiments of the devices, diaphragms and/or biasing electrodes, such as those including carbon nanotubes and/or graphene, are configured for damping, e.g., highly effective
5 damping compared to components not including such materials, e.g., polymer films, such as polyimide. In other words, the components, e.g., diaphragms, are highly resistant to storing energy, e.g., kinetic energy, when a stimulus, such as a stimulus to move, e.g., an electrical potential and/or a force from a biasing electrode, is taken away. Such components will absorb and/or effectively disperse such energy in a
10 very short time period. As such, the components, e.g., diaphragms, will not continue moving, e.g., oscillating, e.g., “ring”, and will be substantially resistant to such continued movement when such a stimulus is removed. Accordingly, devices including diaphragms and/or biasing electrodes, such as those including carbon nanotubes and/or graphene, may be self-damping.

15 **[0076]** A biasing electrode 102 according to the subject embodiments may be a length of one or more electrically and/or thermally conductive materials extending, e.g., extending along a length, from a first end to a second end opposite the first end. An electrical potential may be applied to a biasing electrode via, for example, electrical contacts operably coupled to each of the first and second ends of the
20 biasing electrode.

[0077] Biasing electrodes may have any suitable shape, e.g., a flat or cylindrical shape. For example, a cross section taken transversely along a length, e.g., an entire length, of a biasing electrode may have a rectangular, e.g., square, triangular, circular or ovoid shape. In some versions, a biasing electrode is a wire or
25 a conductive, e.g., electrically and/or thermally conductive, trace. In some versions, a biasing electrode, e.g., a biasing electrode which is a trace, may be a sheet, e.g., a solid sheet, of one or more materials having a thin and/or planar shape. In various embodiments, a sheet is or includes a uniform layer of a single material, e.g., carbon nanotubes or graphene. In some versions, a surface of a flat biasing electrode is
30 operably coupled to a surface of a diaphragm.

[0078] A sheet may, in some aspects, have a length, e.g., from a first end to a second end, and a height, also referred to as a thickness. A thickness of a biasing electrode, e.g., a thickness between a first surface and a second surface opposite the first surface, may be 1 mm or less, or 0.1 mm or less, or 50 microns or less, or

20 microns or less, or 15 microns or less, or 10 microns or less, or 5 microns or less, or 1 micron or less. A thickness of a biasing electrode may also range for example, 0.1 micron to 1 mm, such as from 1 micron to 1 mm, such as from 10 microns to 0.1 mm, such as from 15 microns to 0.1 mm, such as from 20 microns to 0.01 mm, inclusive. Also, a length of a biasing electrode may also range from 1 mm to 2 m, such as from 5 mm to 50 cm, such as from 1 cm to 10 cm.

[0079] A biasing electrode may also have a portion extending across a diaphragm, e.g., from a first end of a diaphragm to a second end of a diaphragm opposite the first end. According to various embodiments, biasing electrodes may be suspended by and/or separated from a frame of a device by a diaphragm. In other words, and as addressed herein, a biasing electrode may only be operably coupled to and/or contacting a diaphragm and/or one or more electrical contacts.

[0080] In some versions of the subject embodiments, including the embodiment shown in FIG. 1, a biasing electrode is shaped as a coil. In other words, biasing electrodes may be wound in a sequence of concentric but non-converging full or partial loops between a first end and a second end. In some embodiments, biasing electrodes may have one or more, two or more, three or more, four or more, five or more, ten or more, fifty or more, one-hundred or more, five-hundred or more, or one-thousand or more non-converging full or partial loops. Each of the full or partial loops may have a portion extending across a diaphragm, e.g., from a first end of a diaphragm to a second end of a diaphragm opposite the first end. Each of the full or partial loops may also be electrically insulated from one another.

[0081] In some variations, biasing electrodes have an end, e.g., a first end, contained between at least two other portions of the biasing electrode. For example, an end, e.g., a first end, of a biasing electrode may be within concentric but non-converging loops of the biasing electrode. Also, an end, e.g., a second end, of a biasing electrode may not be within concentric but non-converging loops of the biasing electrode. Non-converging loops of biasing electrodes may be any suitable size or shape including a: circle, semi-circle, oval, rectangle, square, triangle, polygon, quadrilateral, or combination thereof.

[0082] In some versions of the subject devices, a biasing electrode may be a planar coil. As such, embodiments of the devices include a biasing electrode having a first end and a second end opposite the first end and separated therefrom by a

length of conductive, e.g., electrically and thermally conductive, material. In some versions a first end of a biasing electrode and a second end of a biasing electrode are at the same end of a diaphragm and in some versions, they are at opposite ends of a diaphragm. In some aspects, a biasing electrode extends from its first end in a first direction for a first length then in a second direction perpendicular to the first direction for a second length which is shorter than or equal to the first length. From that point, the biasing electrode may extend in a third direction which is parallel to and opposite the first direction for a third length which is equal to the first length and then extend in a fourth direction which is parallel to and opposite the second direction for a fourth length which is shorter than the second length. From that point, the biasing electrode may again extend in the first direction a fifth length which is shorter than the first length before extending a sixth length in the second direction which is shorter than the second length. Such a pattern may be repeated so that the biasing electrode forms, e.g., forms on a planar diaphragm, concentric but non-overlapping coils, such as two or more, three or more, four or more, five or more, ten or more, twenty or more, or fifty or more concentric coils. Such coils or portions thereof may separate the first and second ends of the biasing electrode from one another. For example, a first end of a biasing electrode may be on an exterior coil and a second end of a biasing electrode may be on an interior coil.

[0083] A biasing electrode may also be flexible such that it can vibrate to generate sound. In some versions, a biasing electrode may be configured to deform from a first configuration to a second configuration and/or from a first configuration to a third configuration a plurality of times. In some versions, biasing electrodes are biased to retain their initial un-biased shape when one or more forces are exerted thereon which cause the diaphragms to assume, e.g., to temporarily assume, a second “biased” shape. In other words, biasing electrodes may be elastic. Furthermore, as noted above, a surface, e.g., a top surface and/or a bottom surface of a diaphragm defines a plane when the diaphragm is in an original, unbiased configuration. A biasing electrode may be configured to move in a direction which is perpendicular or substantially perpendicular to such a plane to a second configuration and/or a third configuration when the diaphragm vibrates to generate a sound.

[0084] Where desired, one or more, e.g., a plurality, such as two or more, three or more, five or more, or ten or more, biasing electrodes are operably coupled

to a diaphragm. As such, one or more surface of a biasing electrode, e.g., a top surface and/or a bottom surface, may be attached, e.g., adhesively attached, to one or more surface e.g., a top surface and/or a bottom surface, of a diaphragm. In some versions, a biasing electrode is integral with a diaphragm. In some aspects, a biasing electrode is joined to the diaphragm by a plurality of covalent bonds.

[0085] A biasing electrode may be attached to a diaphragm in a manner that the biasing electrode and the portion of the diaphragm to which the biasing electrode is attached move together. In other words, when a diaphragm moves to generate sound, a biasing electrode operably coupled thereto moves, e.g., moves in the same direction and distance, as well. In some versions, the biasing electrode is connected to the diaphragm in a manner such that the biasing electrode may exert force on the diaphragm and thereby cause, e.g., cause by biasing, the diaphragm to move to generate sound. Such a force may be exerted on the diaphragm in a first direction and/or a second direction opposite the first direction, and/or perpendicular to a plane defined by a surface of the diaphragm in its original, e.g., unbiased, confirmation. Such a force may also be exerted by physically pushing and/or pulling the diaphragm by contacting the diaphragm or pushing or pulling on the diaphragm via an adhesive operably coupling the components.

[0086] In some embodiments, such as the embodiment of the speaker driver device 500 of which a cross-sectional illustration is provided in FIG. 5, a biasing electrode 502 is contained within, such as encapsulated within, a diaphragm 501. In other words, a biasing electrode may entirely be contained between at least two portions of a diaphragm 501, such as a first layer 503 and a second layer 504 which are operably, e.g., adhesively, coupled together. As is illustrated, a diaphragm 501, such as a diaphragm composed of polyimide film, may also be operably coupled to a frame, such as a frame having a first portion 507 operably coupled to a second portion 505. Devices according to the subject embodiments may also include one or more electrical insulators 506 between adjacent lengths of a biasing electrode 502.

[0087] A frame, such as the frame 103 shown in FIG. 1, according to the subject embodiments may be operably, e.g., adhesively, coupled to a diaphragm. A frame may also include one or more sheets, e.g., a solid sheet or two sheets, of one or more materials each having a thin and/or planar shape. In some versions, frames may include two sheets, e.g., a first sheet and a second sheet, operably coupled, e.g., adhesively attached, together. In various embodiments, a sheet is or includes a

uniform layer of a single material. In some versions, frames include one or more outer edges defining the periphery of the frame and one or more inner edges defining an opening in the frame, such as an opening for retaining the diaphragm therein. In some versions, one or more inner edges of a frame may include a
5 recess, e.g., a slot, therein within which a portion, e.g., an edge, of a diaphragm may be retained. Frames may also extend around, e.g., entirely around the edges of, the diaphragm and/or the biasing electrode.

[0088] A sheet may, in some aspects, have a peripheral length, width a height, also referred to as a thickness. A thickness of a frame, e.g., a thickness
10 between a first surface and a second surface opposite the first surface, may be 1 m or less, or 1 cm or less, or 1 mm or 0.1 mm or less, or 50 microns or less, or 20 microns or less, or 10 microns or less. A thickness of a frame may also range for example, 1 micron to 1 m, such as from 1 micron to 1 cm, such as from 1 micron to 1 mm, such as from 10 microns to 0.1 mm, such as from 20 microns to 0.01 mm,
15 inclusive. Also, a length and/or width of a frame may also range from 1 mm to 2 m, such as from 1 cm to 1 m, such as from 1 cm to 10 cm. Frames may also have a width between an inner edge and an outer edge. Such a width may range, for example, from 1 mm to 1m, such as from 5 mm to 10 cm, such as from 1 cm to 5 cm.

[0089] Openings within frames defined by one or more inner edges may also have by a length, and width, which are each dimensions corresponding with the distance across the opening. An opening within a frame may also have a depth, which is a dimension corresponding with the thickness of the frame. A depth of an opening may range from 1 micron to 10 cm, such as from 100 microns to 5 cm, such
25 as from 1 mm to 1 cm. A length and/or width of an opening may extend from, for example, a first inner edge to a second inner edge opposite the first inner edge. As such, a length and/or width of an opening may range from 1 mm to 1.8 m, such as from 1 cm to 1 m, such as from 1 cm to 10 cm.

[0090] Such openings may be configured to contain therein, e.g., entirely
30 contain therein a diaphragm and/or a biasing electrode. In other words, a diaphragm and/or a biasing electrode may be dimensioned such that they may each or both be contained between at least two portions, e.g., a first inner edge and a second inner edge opposite the first inner edge, of a frame. Openings in frames may or may not correspond with the peripheral shape of a frame and may be any suitable size or

shape including a: circle, semi-circle, oval, rectangle, square, triangle, polygon, quadrilateral, or combination thereof.

[0091] An opening in a frame may be defined by three edges, e.g., inner edges, of a frame, four edges, or more than four edges which define the cross-sectional area of the opening. In various embodiments, the edges meet at corners, e.g., three, four, five, or ten or more corners. In some versions, a first edge of a frame defining an opening is opposite a second edge of a frame defining the opening and adjacent to a third and/or fourth edge of the frame defining the opening. In such an embodiment, the third edge may be opposite a fourth edge and the fourth edge may be adjacent to the first and/or second edge. In various embodiments, all of the inner edges of the frame defining an opening are contained within, e.g., located between at least two other portions of, a frame. A frame may also be composed of one or more rigid materials and may remain or substantially remain in its original confirmation when a diaphragm operably coupled thereto is moving to produce sound.

[0092] As noted above, a frame may be operably, e.g., fixedly, such as adhesively, coupled to a diaphragm. In various embodiments, all of the edges of the diaphragm are operably, connected to a frame. In various embodiments, one or more portion, such as one or more edges, such as all of the edges, of the diaphragm are attached at their periphery to a surface, e.g., an inner edge, of a frame or contained within, e.g., retained in a recess of, a frame. In some versions, one or more portions of a diaphragm, e.g., one or more edges, may be contained between a first layer and a second layer of a frame operably, e.g., adhesively, attached to the first layer. In such embodiments, a first frame layer may be operably, e.g., adhesively, coupled to a first surface of a diaphragm and a second frame layer may be operably, e.g., adhesively, coupled to a second surface of the diaphragm opposite the first surface.

[0093] In some versions of the subject devices, the devices do not include a frame. In such instances, the diaphragm is operably coupled, e.g., adhesively coupled, to the housing, e.g., a metallic housing. In such versions, the diaphragm may also be operably coupled to one or more spacer, such as an insulating spacer, such as an electrically insulating spacer, which is in turn operably coupled to the housing. In some versions, a spacer includes a first end operably coupled to a diaphragm and a second end opposite the first end operably coupled to the housing.

[0094] One or more electrical contacts may also be included in the subject devices. Such contacts can include one or more of the electrically conductive materials provided herein, e.g., carbon nanotubes and/or graphene, and may be configured to convey a voltage and/or current, such as a signal, such as an audio signal. Each electrical contact may be operably coupled to an end of a biasing electrode and may operably, e.g., electrically, couple the biasing electrode with a source of an electric potential, such as a voltage source, such as an audio signal generation unit. Each electrical contact may be a length of conductive material, such as a wire and may have a first end and a second end. A first end of an electrical contact may be operably connected to a biasing electrode and a second end may be operably connected to a voltage and/or current source, such as a signal source, a ground, or another component, such as a separate speaker driver device.

[0095] The subject devices including, for example, ribbon speakers, may include one or more housing, which may also be referred to as a case. Such an embodiment is provided by FIG. 2. More specifically, FIG. 2 provides a cross-sectional illustration of a speaker driver device 200 including a diaphragm 201, having a biasing electrode 202 attached on a surface, e.g., an upper surface, thereof. The diaphragm is operably coupled to a frame 203 having a top layer 204 and a bottom layer 213 and may be at least partially between such layers. The frame 203 in turn is operably coupled to the housing 205 and may be contained within, e.g., between at least two portions of, the housing 205. In some versions a housing 205 may have a first portion, e.g., upper portion 206, and a second portion, e.g., lower portion 207. In some instances, a housing 205 or a portion thereof, such as an upper portion 206 may have a first wall operably, e.g., adhesively, coupled to one or more magnets 208. Also, in some versions, a housing 205 or a portion thereof, such as a lower portion 207, may have a second wall operably, e.g., adhesively, coupled to one or more magnets 209. In some versions, the first wall is opposite the second wall and each defines the interior of the housing 205.

[0096] Each magnet may have a polarity as designated by poles labeled “N” and “S” in FIG. 2. As shown in FIG. 2, the magnets within the housing have an alternating polarity. In other words, each magnet on a wall, e.g., a first and/or second wall, may have one of its poles, e.g., a North pole, as designated by “N”, operably coupled to the wall whereas each adjacent magnet on the wall may have its opposite pole, e.g., a South pole, as designated by “S”, operably coupled to the wall.

Furthermore, a pole of a magnet mounted on a first wall which is closest to a pole of a magnet mounted on a second and opposite wall may have the same polarity, e.g., “S”, as the closest pole of the magnet across from which it is mounted. In other words, magnets on different walls opposite each other may each have an orientation
5 such that they have the same type of pole, e.g., “N” or “S”, closest to the opposite magnet as the opposite magnet has. Additionally, devices according to the subject embodiments may include one magnet or a plurality of magnets, such as two, three, four, five, six, or ten or more, or twenty or more or fifty or more magnets. Each magnet or a combination of magnets according to the subject embodiments have a
10 magnetic field strength large enough so that a diaphragm moves to generate sound when a potential is applied to a biasing electrode in the magnetic field provided by the magnets.

[0097] In some embodiments, such as that shown in FIG. 2, the diaphragm 201 has one or more surface defining a plane and the diaphragm 201 is configured
15 to move with the biasing electrode 202 within the housing 205 in a first direction 210 and/or second direction 211 which are each perpendicular or substantially perpendicular to the plane to generate sound. Furthermore, in some embodiments, the housing 205, or a portion thereof, e.g., an upper portion 206, may define one or more opening, e.g., 212, therein. Such openings may allow sound and/or thermal
20 energy to leave the housing 205. Furthermore, in some versions, one or more components such as diaphragms, biasing electrodes, magnets, and/or frames, may be contained within, e.g., between at least two portions of, a housing.

[0098] Another version of a speaker driver device is provided by FIG. 12. More specifically, FIG. 12 provides a cross-sectional illustration of a speaker driver
25 device 1200 including a diaphragm 1201, having a biasing electrode 1202 attached on a surface, e.g., an upper surface, thereof. In some versions, such as the version shown in FIG. 12, the device does not include a frame and the diaphragm 1201 is operably coupled, e.g., adhesively coupled, directly to the upper housing 1206, or the lower housing 1207, (as shown). , e.g., a metallic housing. In such variations,
30 the diaphragm 1201 may be configured to convey thermal energy from, for example the biasing electrode 1202, to the upper housing 1206 or lower housing 1207.

[0099] In some versions of the embodiments, a housing may have a first portion, e.g., upper portion 1206, and a second portion, e.g., lower portion 1207. The upper portion 1206 may be operably coupled to a spacer 1203, which in turn

may be operably coupled to the lower portion 1207. In some versions, the spacer 1203 is an insulating spacer, e.g., an electrically and/or thermally insulating spacer, e.g., a polymeric, such as a plastic spacer. In some embodiments (not shown), the diaphragm is not operably coupled to a spacer. Also, in some versions, a spacer is not included and as such, the housing is a single integrated body of material or an upper portion of the housing is operably, e.g., adhesively, coupled to a lower portion.

[00100] As is shown in FIG. 12, in some instances, a housing, comprising 1206 and 1207, or a portion thereof, such as an upper portion 1206 may have a first wall operably, e.g., adhesively, coupled to one or more magnets 1208. Also, in some versions, a housing, comprising 1206 and 1207, or a portion thereof, such as a lower portion 1207, may have a second wall operably, e.g., adhesively, coupled to one or more magnets 1209. In some versions, the first wall is opposite the second wall and each defines the interior of the housing, comprising 1206 and 1207. Also in some versions, which are not shown, a diaphragm is closer to a first wall or a second wall and may be operably coupled to either a top portion or a bottom portion. In such versions, the distances between each magnet and the diaphragm may be adjusted so that each are equidistant to the others.

[00101] Furthermore, in some versions, the diaphragm 1201 has one or more surface defining a plane and the diaphragm 1201 is configured to move with the biasing electrode 1202 within the housing in a first direction 1210 and/or second direction 1211 which are each perpendicular or substantially perpendicular to the plane to generate sound. Furthermore, in some embodiments, the housing, or a portion thereof, e.g., an upper portion 1206, may define one or more opening, e.g., 1212, therein.

[00102] According to some versions of the embodiments, the disclosed devices may be a moving coil speaker having a diaphragm with a full or partial cone-shaped portion, referred to herein as the “cone”. One such embodiment is shown in FIG. 3. More specifically, FIG. 3 provides a cross-sectional illustration of a speaker driver device 300 including a diaphragm 301 including a cone 304 and a former 305, having a biasing electrode 302 which is shaped as a coil around the former 305 and which is operably coupled thereto. A diaphragm 301 may also include a dome 312 extending, e.g., arcing, from a first side of a cone 304 and/or former 305 to a second side opposite the first side. The diaphragm 301 is also operably coupled to a frame

303. The speaker driver device 300 also includes a pole piece 306 coupled to the frame 303 via magnet 307.

[00103] Embodiments of the devices include a former 305, e.g., a cylindrical former, defining a central axis 309 therethrough. In some versions, the diaphragm and/or the biasing electrode move in a first direction 310 and/or a second direction 311 which are each parallel to the central axis 309 in order to generate sound.

[00104] In some variations, a cone 304 is operably coupled to a frame 303 by a surround 308 and/or a former 305 is operably coupled to a frame by a spider 315. A surround may be a body, e.g., an arching loop, of material, such as any of the polymeric materials provided herein, extending between one or more edge of the diaphragm and one or more portions, e.g., edges, of a frame. In some embodiments, the surround is flexible so that the diaphragm can vibrate to generate sound but also provides enough structural support to suspend the diaphragm so that the diaphragm does not contact the frame or another fixed portion of the device while vibrating. A spider may also be a body of material, such as any of the polymeric materials provided herein, extending between a portion of a former of a diaphragm and a frame. The spider is flexible so that the diaphragm can vibrate to generate sound but also provides enough structural support to suspend the diaphragm so that the diaphragm does not contact the frame or another fixed portion of the device while vibrating. In some versions, the spider and/or the surround is elastic and may be biased to remain in a first configuration when it is placed in a second configuration. As such, the spider and/or the surround may bias the diaphragm to return to an original spatial position when the diaphragm is moved to a second position from the first position. Accordingly, the spider and/or the surround may exert force on the diaphragm in a first direction 310 and/or a second direction 311 which are each parallel to a central axis 309 defined by a former 305.

[00105] As noted above, in some versions, diaphragms have a former, a cone and/or a dome. Any one or combination of these components may be composed of any of the materials described herein, such as carbon nanotubes and/or graphene. In some versions, each of the diaphragm components are composed of the same material or materials and may be integral with one another. In some versions, each of the diaphragm components are composed of different materials.

[00106] Furthermore, a former, and/or a cone, and/or a dome of a diaphragm may be integral with one another, e.g., composed of a single body of material. In

other versions, a former, and/or a cone, and/or a dome of a diaphragm may be operably coupled, e.g., adhesively coupled, to one another.

[00107] A former may be operably, e.g., adhesively, coupled with the biasing electrode. In some versions, the former has a cylindrical shape and the biasing electrode is a coil extending around the exterior of the cylindrical former. The former may have a cross-sectional area which is circular. The former may extend from a first end which may be operably coupled to a cone and/or a dome to a second end. A former maybe attached to a frame at its first end by a spider. The former may also have a length such as a length ranging from, for example, 1 mm to 1 m, such as from 5 mm to 0.5 m, such as from 1 cm to 10 cm, and may define a central axis, e.g., axis of symmetry, therethrough. The former may also have a diameter along any cross-section ranging from, for example, 1 mm to 1 m, such as from 5 mm to 10 cm, such as from 1 cm to 5 cm.

[00108] A cone of a diaphragm may have one or more portions which continuously slope at an angle with respect to and along the central axis defined by the former. The cone may slope from a first cross-sectional diameter at a first end to a second cross-sectional diameter which is larger than the first diameter at a second end. The first end of the cone may be operably coupled to the former and/or the cone and may be integral with one or both of the former and/or the cone. The second end, or a portion thereof, e.g., an edge, may be operably coupled to the surround and the frame via the surround. The cone may also have a cross-sectional area which is circular.

[00109] A dome of a diaphragm may extend from a first portion of a cone to a second portion opposite the first portion. A dome may also be operably coupled to a cone or a portion thereof, e.g., a first end, and/or a former, or a portion thereof, e.g., a first end. A dome may be a rounded and/or continuously sloping body of material and may have an end, e.g., a first end with the same cross-sectional diameter as the former and/or the first end of the diaphragm. The cross-sectional area may be circular and may get smaller toward a second end of the dome which is opposite the first along the central axis defined by the former.

[00110] In some versions of the embodiments, the devices include a biasing electrode which is a coil, e.g., a cylindrical coil, and which may be coiled around a portion of a diaphragm, e.g., a former. In various instances, the biasing electrode is operably, e.g., fixedly, attached to the former by a frictional force and/or by an

adhesive. A biasing electrode which is a cylindrical coil may define the same central axis as the former and may have a diameter along a cross-section of the coil of, for example, 1 mm to 1 m, such as from 5 mm to 10 cm, such as from 1 cm to 5 cm, or any of such ranges plus one or two cross-sectional thicknesses, e.g., diameter, of the biasing electrode. A biasing electrode which is a cylindrical coil may also have a length such as a length ranging from, for example, 1 mm to 1 m, such as from 5 mm to 0.5 m, such as from 1 cm to 10 cm, and may extend from a first end of a former to a second end of a former opposite the first. The biasing electrode may also be operably coupled to one or more electrical contacts, such as any of the contacts described herein. Furthermore, in some versions, a biasing electrode is a solid body of conductive material, e.g., a wire, e.g., a wire having a length and/or circular cross-sectional diameter. In some aspects, as biasing electrode is insulated and may include one or more electrically insulating materials encapsulating it along its length.

[00111] The devices, including moving coil speaker devices, such as that shown in FIG. 3, may also include a frame for suspending the diaphragm. A frame may extend, for example, from a pole piece to a surround and/or a diaphragm connected to the surround and may be operably coupled to each. A frame may include one or more portions, such as a portion between the pole piece and the surround which continuously slopes at an angle with respect to and along the central axis defined by the former. The frame may also contain one or more portions of the diaphragm, e.g., the cone and/or dome therein. In some versions, the frame is also operably coupled to the diaphragm via a spider which is flexible and, along with the surround, suspends the diaphragm away from fixed components so that the diaphragm and/or the biasing electrode can vibrate to generate sound. The frame may also have a cross-sectional area which is circular.

[00112] The subject devices may also include one or more pole piece. A pole piece may be composed of any one or combination of the same materials as the frame provided herein, e.g., one or more metallic materials. In some versions, a pole piece may include In particular, a pole piece may include one or more materials having a high magnetic permeability such as iron, e.g., soft iron, and may direct the magnetic field provided by a magnet.

[00113] A pole piece may be operably coupled to a magnet and/or a frame of a device. A pole piece may also anchor the frame to one or more fixed support. In some versions, one or more portions of a pole piece extends into, e.g., is contained

between at least two opposing portions of, a former and/or a coiled biasing electrode of the device. Furthermore, embodiments of the devices include versions where a former and/or a coiled biasing electrode of the device extends within, e.g., is contained between at least two opposing portions of, a pole piece.

5 [00114] Embodiments of the devices include pole pieces having one or more opening, e.g., cylindrical opening, therein extending along the central axis defined by the former. One version of such a device is shown, for example, in FIG. 4. More specifically, FIG. 4 provides a cross-sectional illustration of a speaker driver device 400 including a diaphragm 401 including a cone 404 and a former 405, having a
10 biasing electrode 402 which is shaped as a coil around the former 405 and which is operably coupled thereto. The speaker driver device 400 also includes a pole piece 406 coupled to the frame 403 via magnet 407. The pole piece 406 includes an opening 413 therein extending from a first end of the pole piece to a second end of the pole piece and allowing air to circulate to a side of the diaphragm 401 adjacent to
15 the frame 403 and the pole piece 406 to cool the diaphragm 401 and the biasing electrode 402 when the diaphragm 401 moves, e.g., moves in a first direction 408 and/or a second direction 409 opposite the first. The diaphragm 401, which includes a dome 411, is also operably coupled to a surround 410 which in turn is operably coupled to the frame 403. The diaphragm 401 is also operably coupled to a spider
20 412 which in turn is operably coupled to the frame 403.

[00115] An opening, e.g., passage, in a pole piece may be a cooling opening and may be configured so that air can pass therethrough and thereby cool the diaphragm and/or the biasing electrode. Such an opening may also have a diameter of, for example, 1 mm to 0.5 m, such as from 5 mm to 10 cm, such as from 1 cm to 5
25 cm. Such an opening may also be defined by a length of the pole piece ranging from, for example, 1 mm to 0.5 m, such as from 5 mm to 0.5 m, such as from 1 cm to 10 cm. An opening in a pole piece may also be shaped as a cylinder and have a circular cross-sectional area.

[00116] In some embodiments, the devices include an interior, e.g., a sealed or
30 substantially sealed interior, defined by the diaphragm, surround, frame, magnet and/or pole piece. Also, in some versions, the devices include an interior which is sealed or substantially sealed but for an opening, e.g., a passage, in a pole piece.

[00117] The devices may also include one or more magnet. A magnet or a combination of magnets according to the subject embodiments have a magnetic field

strength large enough so that a diaphragm moves to generate sound when a potential is applied to a biasing electrode in the magnetic field provided by the magnet or magnets. In some versions, a magnet is operably coupled to a pole piece and may have one or more portions contained within, e.g., between at least two
5 opposing portions of, a pole piece. Also, in some versions of the devices, such as moving coil speaker devices, the devices are low-impedance devices.

[00118] In some variations, the speaker driver devices are air motion transformers. An embodiment of an air motion transformer device 600 is illustrated in FIGS. 6 and 7. The device 600 includes a diaphragm 601, e.g., a diaphragm
10 including carbon nanotubes and/or graphene, and one or more, such as a plurality of biasing electrodes 602, e.g., a plurality of biasing electrodes each including carbon nanotubes and/or graphene. The diaphragm 601 includes a plurality of arches including upward arches 606 and downward arches 607. Each arch separates a first portion, e.g., 608, such as a planar portion, on a surface of a diaphragm which is
15 opposite from a second portion, e.g., 609, such as a planar portion, on the surface of the diaphragm. A diaphragm 601 may be configured to move and push air in an upward, or substantially upward, direction and/or a downward, or substantially downward, direction along the z-axis to produce sound.

[00119] Furthermore, each of the biasing electrodes 602 may have a first
20 electrical contact, e.g., 604, and a second electrical contact, e.g., 605, each operably connected to an end, e.g., a first or second end, of a biasing electrode. However, for the sake of clarity, only a first electrical contact 604 and a second electrical contact 605 are shown.

[00120] The device 600 provided in FIGS. 6 and 7 also includes a frame
25 including lateral supports 612 operably coupled to the diaphragm, as well as a end supports (not shown). The frame may contain, e.g., entirely contain between at least two opposite portions, the diaphragm 601 and/or one or more biasing electrode 602 therein. In some circumstances, the frame may also include one or more optional support elements 610, e.g., top supports and/or bottom supports, for holding the
30 diaphragm 601 and or biasing electrodes 602 between frame portions during operation. Furthermore, the subject devices or components thereof, e.g., a frame, may include one or more magnets, e.g., two magnets on opposite sides of a diaphragm, which provide a magnetic field in a direction aligned with the z-axis, the y-axis or the x-axis.

[00121] In some versions, the devices including air motion transformer devices include a single biasing electrode. One embodiment of components of such a device is shown schematically in FIG. 8. More specifically, FIG. 8 illustrates a top view of a diaphragm 801 in a flattened confirmation having a single biasing electrode 802 operably coupled thereto. The diaphragm 801 is shown in a flattened confirmation for illustrative purposes only. For operation, the diaphragm 801 would be arched a plurality of times and employed in a device having components, e.g., a frame, such as those illustrated in FIGS. 6 and 7. In addition, a biasing electrode 802 may have a first electrical contact 803 and a second electrical contact 804 each operably connected to an end, e.g., a first or second end, of the biasing electrode 802.

[00122] Also, in some versions of the devices, one or more biasing electrodes of a device is encapsulated, e.g., completely encapsulated, within the diaphragm of a device, such as between two opposite portions thereof. In such embodiments, a biasing electrode is electrically insulated, for example from other biasing electrodes and/or other electrical components, by the diaphragm. In such embodiments, for example, the diaphragm may prevent or substantially prevent arcing between biasing electrodes and/or between a biasing electrode and another electrical component and/or between a first portion of a biasing electrode and a second portion of a biasing electrode.

[00123] Embodiments of the subject devices, including air motion transformer devices, include a diaphragm having and/or defining one or more arches, such as a plurality of arches, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more, such as 20 or more such as 50 or more, such as 100 or more, such as 500 or more, such as 1000 or more arches. A diaphragm may also include a number of arches in a range of 1 to 1000, such as from 1 to 100, such as from 1 to 10, such as from 1 to 5, each inclusive. Each arch may face a first direction, e.g., an upward-facing arch, or may face a second direction opposite the first, e.g., a downward-facing arch. In other words, diaphragms may include arches arcing in a first direction along a z-axis, as such an axis is designated in FIG. 6, or in a second direction along the z-axis which is opposite the first. Upward and downward facing arches may alternate along the diaphragm. A diaphragm may have the same number of upward and downward facing arches, a greater number of upward facing arches, or a greater number of downward facing arches.

[00124] Arches may be curves, folds and/or bends in the diaphragm having a radius of curvature and/or a plurality of radii of curvature each lying within a single plane, such as a plane which is perpendicular to the diaphragm or a surface thereof, e.g., a curved surface, at the position of the arch. The arches may shape the diaphragm into a plurality of layers, e.g., layers in a direction along the x-axis as designated in FIG. 6, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more layers, with each layer being defined by a thickness of the diaphragm.

[00125] In some instances, one or more arch may separate, e.g., separate along a surface, a first portion of a surface of a diaphragm and a second portion of a surface of a diaphragm opposite and/or facing the first portion. Such opposite portions of a diaphragm surface may be directly across from one another and/or parallel to one another, e.g., each having a surface defining a plane, wherein the planes are parallel to one another. In some versions, the only medium separating or present between a first portion of a surface of a diaphragm and a second portion of a surface of a diaphragm is air and/or one or more biasing electrode. In various instances, a diaphragm includes one or more biasing electrodes on a first portion of a surface of a diaphragm which is opposite and/or facing a second portion of a surface of the diaphragm.

[00126] In some variations, a first portion, e.g., a flat portion, of a first surface of a diaphragm is opposite a second portion, e.g., a flat portion, of the first surface of the diaphragm and is separated therefrom along the diaphragm by a first arch, such as an upward-facing arch. In such an embodiment, the second portion of the first surface of the diaphragm is separated from a first portion of a second surface of the diaphragm by a single layer of diaphragm material having a thickness, wherein the second surface of the diaphragm is opposite the first surface. The first portion of the second surface of the diaphragm may in turn be opposite and separated from a second portion of the second surface of the diaphragm by a second arch, such as a downward-facing arch. In some versions, such as second arch may be adjacent to the first arch along the diaphragm. Such a pattern of alternately-facing arches and surface portions may be repeated along the diaphragm a plurality of times to form an air motion transformer device diaphragm, such as the diaphragm shown in FIGS. 6 and 7.

[00127] Furthermore, an arches and/or portions, e.g., planar portions, between arches of a diaphragm may be integral with one another, e.g., composed of a single

body of material. In other versions, one or more arches and/or portions, e.g., planar portions, between arches of a diaphragm may be operably coupled, e.g., adhesively coupled, to one another.

[00128] In some embodiments, the speaker driver devices are electrostatic speaker drivers. An electrostatic speaker driver is a speaker driver in which sound is generated by force, e.g., electrostatic force, exerted on a diaphragm suspended in an electrostatic field, such as an electrostatic field between two electrodes, e.g., biasing electrodes. Also, in some versions of the devices, such as electrostatic speaker driver devices, the devices are high-impedance devices.

[00129] One embodiment of an electrostatic speaker driver device 900 is illustrated in FIG. 9. The device 900 includes a diaphragm 901, e.g., a diaphragm including carbon nanotubes and/or graphene. Also included are a first biasing electrode 902 and a second biasing electrode 903, which each or both may include carbon nanotubes and/or graphene. In some versions, the diaphragm 901 is between, e.g., entirely between at least two opposite portions of, the first biasing electrode 902 and the second biasing electrode 903, such as a surface of the first biasing electrode 902 and a surface of the second biasing electrode 903. Each of a diaphragm, a first biasing electrode and/or second biasing electrode may be operably coupled to a frame and/or case of a device, neither of which is shown in FIG. 9. In addition, a first and/or second biasing electrode may include one or a plurality of electrical contacts, e.g., a first electrical contact 904 and/or a second electrical contact 905 operably coupled thereto. Furthermore, a diaphragm may include one or more electrical contact 906, e.g., a first and second electrical contact, operably coupled thereto.

[00130] A diaphragm 901 may also be spaced apart from a first biasing electrode 902 and/or a second biasing electrode 903 by an opening, e.g., an opening filled by air, defined by a distance “d”. Distance “d” is the distance between, for example, a first surface of a diaphragm 901 and a first surface of a first biasing electrode 902 opposite the first surface of the diaphragm 901. Distance “d” also may be the distance between, for example, a second surface of a diaphragm 901 and a first surface of a second biasing electrode opposite the second surface of the diaphragm 901. Force, e.g., electrostatic force, and/or pressure may be exerted by one or more biasing electrode on a diaphragm via the one or more opening between the one or more biasing electrode and the diaphragm.

[00131] In some instances, a diaphragm vibrates between a first biasing electrode and a second biasing electrode to generate sound. In various embodiments of the devices, one or more biasing electrodes of a device, e.g., a first and/or second biasing electrode, do not contact a diaphragm, such as contact the diaphragm when the device operates to generate sound. Additionally, a first biasing electrode may have the same dimensions, e.g., length, width and/or thickness, and/or composition as a second biasing electrode.

[00132] Where appropriate, a diaphragm, e.g., a diaphragm including carbon nanotubes and/or graphene, is configured so that a charge may be accumulated thereon, such as on one or more surfaces thereof. As noted elsewhere herein, a diaphragm may be composed of one or more electrically conductive materials. In some embodiments, a diaphragm includes a polymer film including, e.g., including only, polyimide, polyethylene terephthalate (PET) and/or polyester. In some instances, a diaphragm includes a conductive coating, e.g., a conductive coating including carbon nanotubes and/or graphene.

[00133] Also, in some versions, a diaphragm or one or more portions thereof, moves, e.g., vibrates, in a direction, such as a direction along the x-axis as depicted in FIG. 9, toward and/or away from a first biasing electrode to generate sound. Furthermore, in some versions, a diaphragm moves, e.g., vibrates, in a direction toward and/or away from a second biasing electrode to generate sound in a direction opposite from that which it is moving at a particular time with respect to the first biasing electrode. Also, in various embodiments one or more biasing electrodes, such as a first biasing electrode and/or a second biasing electrode are fixed and do not move, e.g., vibrate when the device operates to generate sound.

[00134] In some versions, a diaphragm is operably coupled, such as electrically coupled to a source of electric potential and/or voltage and/or current. Such as source may be configured to induce an electrical charge in the diaphragm. Such a source or a different source may also be operably coupled to one or more biasing electrode.

[00135] In various embodiments, a diaphragm, a first biasing electrode and/or a second biasing electrode are flat and/or planar. For example a diaphragm, a first biasing electrode and/or a second biasing electrode may each include a first surface defining a first plane, and a second surface opposite the first surface and defining a

second plane, wherein the first plane is parallel to, e.g., never intersects with, the second plane.

[00136] In some variations of the subject embodiments, a biasing electrode, e.g., a first biasing electrode and/or a second biasing electrode, is a solid sheet of one or more materials, e.g., carbon nanotube and/or graphene. In some versions, a
5 biasing electrode is a stator or a stator plate. In other instances, a biasing electrode, e.g., a first biasing electrode and/or a second biasing electrode, define one or more, such as a plurality of openings therethrough. For example in some versions a biasing electrode may be a screen, a grid, and/or or a woven sheet of, for example,
10 wires. Each of such embodiments may be planar and/or flat. In some instances, the one or more openings in a biasing electrode allow air and/or sound therethrough when the device operates to generate sound. In some instances, the one or more, e.g., plurality of, openings in a biasing electrode may extend from a first surface of the electrode to a second surface opposite the first surface. In some versions, a
15 diaphragm may push or pull air through one or more openings in a basing electrode while the diaphragm moves to generate sound.

[00137] A schematic of an electrostatic speaker driver device 1000 is provided by FIG. 10. The device 1000 includes a diaphragm 1001, e.g., a diaphragm including carbon nanotubes and/or graphene. Also included are a first biasing
20 electrode 1002 and a second biasing electrode 1003, which each or both may include carbon nanotubes and/or graphene. The first biasing electrode 1002 and the second biasing electrode 1003 are coupled, via operable connections 1004, e.g., fixed physical connections, to a frame 1005. The frame 1005 may also have any of the characteristics of housings described herein. Also, the diaphragm 1001 is
25 coupled, via operable connections 1006 to the frame 1005.

[00138] Also, as is shown in FIG. 10, in some versions, biasing electrodes, such as a first biasing electrode 1002 and a second biasing electrode 1003 may be operably, e.g., electrically, connected via operable connections 1007 to one or more other components, such as a step-up transformer 1008 and/or a source of an electric
30 potential, such as a voltage and/or current source, such as an audio signal generation unit 1009. Also, in some versions, a step-up transformer 1008 is operably coupled to the audio signal generation unit 1009.

[00139] Furthermore in some embodiments a diaphragm 1001 is coupled, via operable connection 1010 to a voltage source 1011, such as a power supply, such

as an extra high tension (EHT) power supply. The voltage source 1011 may in turn be coupled, via an operable connection 1012, to another component such as a step-up transformer 1008. Furthermore, in some versions, the devices include a resistor, e.g., a large value resistor, (not shown) is in series between, for example, a power supply and a diaphragm.

[00140] Also, in some versions of the devices, a biasing electrode of a device, e.g., a first biasing electrode, is electrically insulated from another biasing electrode of a device, e.g., a second biasing electrode, by a diaphragm, such as a diaphragm including carbon nanotubes and/or graphene. In such embodiments, for example, the diaphragm may prevent or substantially prevent arcing between the biasing electrodes and/or between a biasing electrode and another electrical component.

[00141] In some versions, the diaphragm is configured to be maintained at a particular direct current (DC) potential, such as a potential of 1-10 kV with respect to the first and/or second biasing electrode. Also, in some versions, the devices or components thereof, such as a signal generation unit, such as an audio signal generation unit, are configured to drive, e.g., apply an electrical potential to, the first biasing electrode in antiphase with the second biasing electrode. Accordingly, some embodiments of the devices are configured to produce a uniform or substantially uniform, electrostatic field proportional to the signal, e.g., audio signal, between the first and second biasing electrodes. Such an electrostatic field causes a force to be exerted on the diaphragm, e.g., the charged diaphragm, and the resulting movement of the diaphragm generates sound.

[00142] In some versions, the devices are headphones and include, for example, one or more, e.g., two, speaker driver devices, such as electrostatic speaker driver devices. Headphone devices may be hand-held, portable devices and may include one or more, housings for housing each speaker driver device. Each housing may include an insertion portion for fitting inside and being retained in a human ear. The housings may also be operably coupled to one another by a connector configured for retaining the headphones on a human head and retaining a speaker driver device housing over each ear. Headphone devices may also include one or more electrical contacts, e.g., insulated electrical contacts, such as electrical contacts including carbon nanotubes and/or graphene, and which may be cords including one or more wires for operably coupling the speaker driver or drivers with a

signal source, such as an audio signal source, such as a media player, such as a portable media player, such as a cellular telephone.

SYSTEMS AND KITS

5 **[00143]** The present disclosure provides systems, such as sound generation systems which may include one or more, such as a plurality, such as two, three, four, five, or ten or more speaker driver devices as described herein. Systems according to the subject embodiments may also include one or more electrical power sources, signal generation units, e.g., audio signal generation units, one or more amplifier,
10 one or more housing, or any combination thereof. Systems as disclosed herein may be or include a public address system, such as a theater or stadium audio system, or an electronic media player, e.g., a computer, a television, and/or a telephone, or one or more components of such devices. The subject systems may also be portable, hand-held systems.

15 **[00144]** In some versions, signal generation units, e.g., audio signal generation units, include for example, a control unit such as a central processing unit, a display for displaying data and/or an interface for receiving an input. An audio signal generation unit may be, for example, a desktop or laptop computer or a mobile electronic device, such as a mobile media player and/or cellular telephone. A signal
20 generation unit may also be configured for delivering a signal, e.g., an audio signal, such as an electric potential, voltage and/or current to a speaker driver device or components thereof, such as a biasing electrode.

[00145] The disclosed systems may also include a wireless signal transmitter and/or a wireless signal receiver. A wireless signal transmitter may be operably
25 coupled to a signal generation unit and may be configured to transmit a signal, such as an audio signal from the signal generation unit to, for example, a wireless receiver operably coupled to one or more speaker driver device. The wireless receiver may in turn be configured to transmit the signal to the one or more speaker driver device or components thereof, e.g., a biasing electrode.

30 **[00146]** Embodiments of the systems also include one or more, e.g., a plurality of, amplifiers, such as current, voltage, transconductance and/or transresistance amplifiers. Such amplifiers may be configured to amplify a signal, such as an audio signal before it is transmitted to one or more speaker driver device or components thereof, e.g., a biasing electrode.

[00147] Embodiments of the disclosed systems include one or more power sources. By “power source”, as used herein, is meant a device that supplies electric power to an electrical load. As such, in some aspects, power sources may include, for example, one or more battery, direct current (DC) power supply, alternating
5 current (AC) power supply, linear regulated power supply, switched-mode power supply, programmable power supply, uninterruptible power supply, high-voltage power supply and/or a voltage multiplier. The amount of power, current and/or voltage capable of being provided by a power supply may, for example, be equivalent to that of a public address system, such as a theater or stadium audio
10 system, or an electronic media player, e.g., a computer, or one or more components thereof, a television, and/or a telephone.

[00148] Embodiments of power sources include power sources configured to turn on to provide electrical power to another component and/or turn off to stop providing electrical power to another component. Such power sources may be
15 configured to be turned on and/or off, for example, by operation of a switch, button, timer or other component operably connected to or included in the power source.

[00149] A power source may, in certain aspects, be operably connected to one or more components of the disclosed systems, e.g., a signal generation unit. As such, embodiments of power sources include electrical connections from a power
20 source to components of the disclosed systems. Such electrical connections may include one or more lengths of electrically conductive material, e.g., contacts and/or wires.

[00150] Embodiments of power sources include a wide variety of shapes and sizes including, for example, all possible combinations of the shapes and sizes of
25 various components described herein. One or more power sources may, in certain aspects, be operably, e.g., adhesively, snapedly, hingedly or otherwise, connected to one or more components of the disclosed systems. In certain aspects, all or portion of the power source may be on the interior and/or the exterior of another component of the disclosed systems, e.g., a housing.

[00151] The disclosed systems may also include one or more housings each
30 having one or more characteristics of the housings described above. The housings of the systems may include one or more opening therein each configured to receive a speaker driver device therein. As such, a single housing may include a plurality of, e.g., two or more, three or more, five or more, or ten or more, speaker driver devices.

Housings may also be operably coupled to a frame of one or more speaker driver devices and may be configured to contain therein, such as entirely contain therein one or more speaker driver devices. A housing may also include one or more openings for a display and/or an interface for receiving an input.

5 **[00152]** One embodiment of a system 1100 according to the subject embodiments is provided in FIG. 11. FIG. 11 provides a schematic illustration of a speaker driver device 1101 including a diaphragm 1102 and a biasing electrode 1103. The speaker driver device also includes a frame 1104 and a housing 1105 as well as a first electrical contact 1106 and a second electrical contact 1107.

10 **[00153]** Operable connections 1108, e.g., electrical connections, operably connect the speaker driver device 1101, a power source 1109, a signal generation unit 1110, e.g., an audio signal generation unit, and/or an optional amplifier 1111. Such components, and/or other components described herein, can be operably connected in any series or order to allow the devices operate effectively. Each of
15 such components, e.g., the power source, and/or the signal generation unit may be manually or automatically controlled. The signal generation unit 1110 also includes a control unit 1112 such as a central processing unit, a display 1113 for displaying data and/or an interface 1114 for receiving an input, such as input data, such as a user selection. Also, in some versions, a power source is included in the signal
20 generation unit and/or a speaker driver device.

[00154] Also provided are kits that at least include one or more speaker driver devices as described above, and which may be used according to the subject methods. The subject kits may include two or more, e.g., a plurality, three, four, five, eight, ten, etc., speaker driver devices or other system components according to any
25 of the embodiments described herein, or any combinations thereof. Kits may also include packaging, e.g., packaging for shipping the systems and/or devices without breaking.

[00155] In some embodiments, the kits include a set of two or more, e.g., four or more, speaker driver devices and/or a housing, e.g., a single housing, therefor.
30 Each device of a set may include a diaphragm including carbon nanotubes and/or graphene. Each device of a set may also include a biasing electrode including carbon nanotubes and/or graphene.

[00156] In certain embodiments, the kits include instructions, such as instructions for using the subject devices and/or systems. The instructions are, in

some aspects, recorded on a suitable recording medium. For example, the instructions may be printed on a substrate, such as paper or plastic, etc. As such, the instructions may be present in the kits as a package insert, in the labeling of the container of the kit or components thereof, e.g., associated with the packaging or subpackaging, etc. In other embodiments, the instructions are present as an electronic storage data file present on a suitable computer readable storage medium, e.g., Portable Flash drive, CD-ROM, diskette, etc. The instructions may take any form, including complete instructions for how to use the systems or devices or as a website address with which instructions posted on the world wide web may be accessed.

METHODS

[00157] The present disclosure provides methods for generating sound with speaker driver devices, such as any of the devices disclosed herein. The methods include applying an electric potential and/or voltage to an electrode, e.g., biasing electrode, in a magnetic field, such as a magnetic field provided by one or magnets of a device. In some versions, a biasing electrode to which an electric potential and/or voltage is applied includes, e.g., includes entirely, carbon nanotubes and/or graphene. Embodiments of the subject methods also include moving a diaphragm of the device or a portion thereof. A diaphragm which is moved may include, e.g., include entirely, carbon nanotubes and/or graphene. The methods also include generating sound when the diaphragm is moved.

[00158] In some versions, applying an electric potential and/or voltage to a biasing electrode includes operably coupling a biasing electrode with a signal source, such as a voltage source, such as an audio signal generation unit. A biasing electrode may be operably coupled with such a signal source by one or more electrical contacts, e.g., wires. As such, in some versions, the methods include applying an electric potential and/or voltage to a biasing electrode via one or more, e.g., a first and second, electrical contacts, each including carbon nanotubes and/or graphene.

[00159] Applying an electrical potential and/or voltage to a biasing electrode may include flowing a current through the biasing electrode or one or more portions thereof including carbon nanotubes and/or graphene. As such, the methods may include flowing a current from a first end of a biasing electrode to a second end.

They may also include flowing the current through a biasing electrode including a coil in a coiled path. Such current may be flowed through the biasing electrode around or across one or more portions of a diaphragm, such as a former. Such current may also be flowed around one or more portions of a pole piece. Furthermore, in some versions, a biasing electrode includes carbon nanotubes, e.g., only carbon nanotubes, and applying a potential and/or voltage to the biasing electrode includes transferring, e.g., flowing, a current, e.g., transferring a current across a diaphragm, such as from a first end of a diaphragm to a second end of a diaphragm, via the carbon nanotubes.

10 **[00160]** Applying an electric potential and/or voltage and/or flowing a current through one or more components may include generating thermal energy, which is also referred to herein as heat, in the biasing electrode and/or the diaphragm. In such embodiments, the methods thereafter include cooling the biasing electrode and/or diaphragm by transmitting, e.g., conducting, the thermal energy to
15 surrounding air, for example, when each component moves. Furthermore, the biasing electrode can be cooled by transmitting, e.g., conducting, thermal energy away from the biasing electrode via, for example, the diaphragm or one or more portions thereof including carbon nanotubes and/or graphene. Also, as used herein, the term “via” means by way of, such as by going through. In addition the biasing
20 electrode and/or diaphragm can be cooled by transmitting, e.g., conducting, thermal energy away from the biasing electrode via, for example, the diaphragm or one or more portions thereof including carbon nanotubes and/or graphene to a frame and/or case of a device. Thermal energy may thereafter be transferred, e.g., via convection, from the frame and/or case to air. In addition, the biasing electrode can
25 be cooled by transmitting, e.g., conducting, thermal energy away from the biasing electrode via, for example, a portion of the diaphragm, such as a former and/or a dome to another portion of the diaphragm, e.g., the cone. The cone may then be configured to transmit the thermal energy to the air. By cooling the components, the structural, thermal and/or electrical integrity of the components and/or operably, e.g.,
30 adhesive, connections between the components, can be maintained or prolonged. For example, the methods include preventing degradation, such as cracking and/or breaking, of a biasing electrode by transferring heat away from the biasing electrode.

[00161] The methods also include providing temperature protection, e.g., adhesive temperature protection, to components. Such methods may include

cooling operable connections, e.g., adhesive connections between components of the devices, such as an adhesive connection between a diaphragm and a biasing electrode, such as a biasing electrode which is a coil. Such methods may also include cooling operable connections, e.g., adhesive connections between portions
5 of components of the devices, such as an adhesive connection between a cone and/or a former and/or a dome of a diaphragm. Operable connections, e.g., adhesive connections, may be cooled by transmitting heat away from the connection via a diaphragm, e.g., a diaphragm including carbon nanotubes and/or graphene. By cooling the operable connections, the structural, thermal and/or electrical integrity of
10 the connections can be maintained or prolonged. For example, the methods include preventing degradation, such as cracking and/or breaking, of an adhesive connection by transferring heat away from the connection.

[00162] Furthermore, as noted above, embodiments of carbon nanotubes and materials including carbon nanotubes may have a high thermal conductivity in one
15 direction while also having a low thermal conductivity in a perpendicular direction. As such, components, such as diaphragms including such materials, may provide temperature protection to components and/or operable connections by insulating the components or connections from heat in a first direction while simultaneously conveying heat away from the components or connections in a second direction
20 perpendicular to the first direction.

[00163] In some instances, applying an electric potential and/or voltage includes transmitting, e.g., wirelessly transmitting, a signal, e.g., an audio signal, from an audio signal generation unit to a biasing electrode. In some versions, an audio signal generation unit includes, for example, a controller, a display for
25 displaying data and/or an interface for receiving an input. An audio signal generation unit may be, for example, a desktop or laptop computer or a mobile device, such as a mobile media player and/or cellular telephone. In such embodiments, applying an electric potential and/or voltage includes entering one or more input, e.g., a tone or song selection, into the audio signal generation unit.

[00164] Furthermore, applying an electric potential and/or voltage includes applying to the biasing electrode a bias to move in a magnetic field, such as a magnetic field generated by one or more magnets of the disclosed devices. Such a magnetic field may have a magnetic field strength large enough so that the biasing electrode will be biased to move in the magnetic field. Since biasing electrodes of

the subject devices are operably, e.g., fixedly, coupled to diaphragms, applying an electric potential and/or voltage to a biasing electrode may include applying to the diaphragm a bias to move, e.g., move one or more times to generate sound. In some versions of the methods, a diaphragm and/or biasing electrode are moved in one or more directions, e.g., opposite directions, which are each perpendicular to a magnetic field, such as a magnetic field generated by a magnet of a device.

[00165] Various embodiments of the methods also include moving, such as moving in a first direction and a second direction opposite the first direction, such as by vibrating, a diaphragm of the device or a portion thereof. Moving the diaphragm may include moving one or more portions thereof including, e.g., including entirely, carbon nanotubes and/or graphene.

[00166] Versions of the embodiments of the methods include exerting a bias, e.g., a bias to move, and/or one or more force on the diaphragm with the biasing electrode. For example, as noted above, when a biasing electrode which is operably coupled with a diaphragm has a potential and/or voltage applied to it in a magnetic field, the biasing electrode is biased to move. When the biasing electrode moves, it exerts one or more forces on the diaphragm to which it is operably, e.g., fixedly, coupled to also move. Such forces may be in a first direction and/or a second direction opposite the first direction and may cause the diaphragm to vibrate to, for example, generate sound.

[00167] In some variations of the methods, a portion of a diaphragm furthest from a frame, e.g., a diaphragm center, moves a greater distance than portions of the diaphragm closer to the frame. In other words, moving a diaphragm may include displacing, such as by flexing, the diaphragm or a portion thereof, e.g., a center portion, a distance to a first, e.g., arched, configuration in a first direction, then moving the diaphragm in a second direction opposite the first direction to its original, e.g., flat, configuration. Thereafter, the methods may include displacing, such as by flexing, the diaphragm or a portion thereof, e.g., a center portion, a distance to a second, e.g., arched, configuration in the second direction, then moving the diaphragm in the first direction to its original, e.g., flat, configuration. Such a process may be repeated a plurality of times to generate sound, such as a pattern of sound including for example, one or more tones. The methods may also include varying, e.g., increasing and/or decreasing, the distance which the diaphragm is moved in the first or second direction.

[00168] In some versions, moving a diaphragm of a device, or a portion thereof, e.g., a center portion furthest from all portions of a frame, may include moving the diaphragm or portion thereof in a first and/or second direction which are each opposite one another and parallel to a central axis defined by a former. Moving a
5 diaphragm or a portion thereof, may include moving the diaphragm or portion thereof in a first and/or second direction which are each opposite one another and perpendicular or substantially perpendicular to one or more planes defined by a surface of the diaphragm and/or frame.

[00169] As noted above, embodiments of diaphragms include a former, e.g., a
10 cylindrical former, defining a central axis of symmetry therethrough. In such versions, the biasing electrode may be shaped as a coil extending around the former. Accordingly, in various embodiments, moving the diaphragm of a device includes moving the coil, e.g., moving the coil in one or more direction parallel with the central axis, such as a first direction and a second direction opposite the first direction.

[00170] In various embodiments, the devices include one or more opening, e.g., passage, in a pole piece which may be a cooling opening. The subject methods may include generating an air flow in the opening and thereby, for example, conducting thermal energy away from and cooling the coil and/or diaphragm. Such an air flow may be bidirectional and may be generated by pressure exerted on air in
20 an interior of the device by the diaphragm when the diaphragm moves, e.g., vibrates to generate sound. Generating such an air flow may also include drawing air past a biasing electrode, e.g., a biasing electrode shaped as a coil.

[00171] As noted herein, versions of the subject embodiments include a housing, e.g., a planar housing, having a first wall, e.g., a first interior wall, including
25 a first magnet, or a plurality of first magnets, and a second wall, e.g., a second interior wall, opposite the first wall and including a second magnet, or a plurality of second magnets. As such, the methods may include moving, such as moving in a first direction and a second direction opposite the first direction, such as by vibrating, a diaphragm and/or a biasing electrode between the first magnet, or plurality of first
30 magnets, and the second magnet, or plurality of second magnets. The diaphragm may be moved toward and/or away from the first magnet and/or toward and/or away from the second magnet. The methods also may include vibrating the diaphragm between the first wall and the second wall.

[00172] In some versions of the methods, a device includes a frame operably connected to a diaphragm and defining an opening. A diaphragm and/or a biasing electrode may be contained within the opening. In such embodiments, the methods may include moving, e.g., vibrating, the diaphragm and/or the biasing electrode within the opening.

[00173] The methods also include generating sound. Generating sound includes moving, e.g., vibrating, one or more portions of a device, such as a diaphragm and/or biasing electrode, so that energy is transferred from the portion of the device, to the surrounding environment, e.g., air, and is thereafter perceivable to a human as sound, e.g., sound which is detectable by a human ear.

[00174] In some instances, the methods may include making, e.g., manufacturing, one or more components of the devices or portions thereof, such as for example, one or more nanotube sheets. More specifically, as noted above, in some versions, diaphragms include a sheet of randomly dispersed, e.g., oriented, nanotubes held together, for example, by van der Waals forces. The methods may include making such a sheet by suspending the nanotubes in a solvent to create a liquid nanotube/solvent mixture. The nanotube/solvent mixture can then be dispersed on a flat surface. Thereafter, the solvent can be evaporated to leave the sheet of randomly dispersed nanotubes.

[00175] Also, in some versions, the diaphragms include woven nanotube sheets composed of fine nanotube carbon threads which are woven together. As such, the methods may include growing nanotubes on substrates and/or extruding nanotube threads from the nanotube grown on the substrates.

[00176] Furthermore, in some versions, a biasing electrode may be an electrical trace. As such, the methods may include generating an electrical trace on a surface, e.g., a surface of a diaphragm. Such biasing electrodes, e.g., traces, may include, for example, graphene and/or carbon nanotube threads, such as woven carbon nanotube threads or randomly dispersed nanotubes from a solvent dispersion.

[00177] In addition, carbon materials including carbon nanotubes and/or graphene have a high temperature resilience and as such, maintain their structural, electrical and/or thermal properties even at high temperatures. Accordingly, in some versions, the methods include utilizing the components of the devices, such as diaphragms and/or biasing electrodes to generate sound at significantly higher

temperatures than would be possible and/or safe with components not including such materials, such as components only including copper and/or aluminum and/or glass fiber and/or polymer film, such as polyimide. For example, the methods may include moving a diaphragm, and/or a biasing electrode, at a temperature, e.g., a temperature inside a housing of a device, of 300 °C or more, such as 400 °C or more, such as 500 °C, such as 600 °C or more, such as 700 °C or more. The methods may also include moving a diaphragm, such as moving a diaphragm with a biasing electrode, at a temperature, e.g., a temperature inside a housing of a device, in a range of, for example, 300 °C to 750 °C, such as from 350 °C to 600 °C, such as from 400 °C to 500 °C, each range inclusive.

[00178] Embodiments of the subject methods include generating sounds with devices including air motion transformer devices. In some versions, the methods include moving, e.g., vibrating, the diaphragm, such as a diaphragm including carbon nanotubes and/or graphene, e.g., moving the diaphragm to push air, in a first, e.g., an upward, or substantially upward, direction and/or a second, e.g., downward, or substantially downward, direction along the z-axis, as designated for example in FIG. 6, and thereby generating sound. The methods also may include moving the diaphragm, e.g., moving the diaphragm to push air, in a first, direction and/or a second direction opposite the first and along the x-axis, as designated for example in FIG. 6, and thereby generating sound. In some embodiments, air is pushed by the diaphragm out of a device or one or more portions thereof, e.g., a frame and/or a case.

[00179] Embodiments of the methods also include moving a first portion and a second portion of a diaphragm and/or a biasing electrode, such as a biasing electrode including carbon nanotubes and/or graphene, toward and/or away from one another. For example, as noted above, one or more arch may separate, e.g., separate along a surface, a first portion of a surface of a diaphragm and a second portion of a surface of a diaphragm opposite and/or facing the first portion. Such opposite portions of a diaphragm surface may be directly across from one another and/or parallel to one another, e.g., each having a surface defining a plane, wherein the planes are parallel to one another. Such opposite portions of a diaphragm surface may also be moved toward and/or away from one another to, for example, generate sound. The opposite portions of a diaphragm surface may be moved by, for example, by applying an electrical potential and/or a voltage and/or a current to a

biasing electrode operably coupled to one portion or each portion. In other words, in some instances, the methods include moving different portions of a surface of a diaphragm toward and/or away from one another to generate sound.

[00180] Furthermore, in some versions, the methods include moving, e.g., flexing, one or more portions of an arch of a diaphragm so that the radius of curvature of the arch increases and/or decreases, and the diaphragm thereby moves, e.g., vibrates to produce sound. Embodiments of the methods also include moving a first biasing electrode and a second biasing electrode toward and/or away from one another while the diaphragm moves to generate sound.

[00181] In some embodiments, the methods include applying an electrical potential and/or a voltage to one or more biasing electrodes of a device in a magnetic field. An electrical potential and/or a voltage applied to each biasing electrode of a device at a particular time may be the same or may be different. The methods also include, in some instances, flowing a current through one or more biasing electrodes, e.g., a plurality of biasing electrodes. Such a current may be flowed in a first direction or a second direction opposite the first direction, wherein each of the first and second direction are in a direction along the y-axis, as designated for example in FIG. 6. A current applied to different biasing electrodes of a device may be in the same direction or opposite directions at a given time. A current applied to a biasing electrode may also be flowed from a first electrical contact, e.g., a first electrical contact at a first end of a device, to a second electrical contact, e.g., a second electrical contact at a second end of a device or the first end of the device, via a biasing electrode.

[00182] The methods also include flowing a current through a biasing electrode, e.g., a single biasing electrode of a device, of a device in an arcing manner along and/or across one or more, e.g., every, arch of the diaphragm. Flowing such a current through the biasing electrode in a magnetic field, such as a magnetic field generated by one or more magnets of the device, in some versions, includes inducing the biasing electrode to exert a force on the diaphragm which may in turn, cause the diaphragm to move to generate sound. In some versions, the methods also include flowing a current through one or more biasing electrode to move the diaphragm in an expanding and/or contracting accordion-like motion.

[00183] The subject methods may also include generating sounds with devices including electrostatic speaker devices, e.g., electrostatic tweeter devices. In some

versions, the methods include moving, e.g., vibrating, the diaphragm, such as a diaphragm including carbon nanotubes and/or graphene, between two biasing electrodes, e.g., moving the diaphragm to push air, in a first direction and/or a second direction opposite the first direction along the x-axis, as designated for example in FIG. 9, and thereby generating sound. In some versions, the first and/or second biasing electrodes are fixed, meaning that they are fixed, e.g., spatially fixed, or substantially fixed in a position and as such, do not move, e.g., vibrate, with the diaphragm, to generate sound.

[00184] In some versions, the methods include moving the diaphragm or a portion thereof, e.g., a center portion, toward a first biasing electrode while moving the portion away from a second biasing electrode. The methods also may thereafter include moving the diaphragm or a portion thereof, e.g., a center portion, away from a first biasing electrode while moving the portion toward a second biasing electrode.

[00185] Where desired, the methods include applying an electric potential and/or voltage, such as an audio signal, simultaneously to one or more, e.g., a first and second, biasing electrodes. Such a potential may be applied to the electrodes from a signal source, a transformer, e.g., a step-up transformer and/or a power source. The methods also may include generating an electrostatic field between biasing electrodes of a device, such as first and second biasing electrodes.

[00186] The methods also may include exerting a force, e.g., an electrostatic force, on a diaphragm from one or more, e.g., first and second, biasing electrodes each including, for example, carbon nanotubes and/or graphene. For example, a first biasing electrode may exert a force on the diaphragm while the second biasing electrode exerts an opposite but equal force on the diaphragm. As a result of force being applied thereto, the diaphragm may move, e.g., vibrate, between the electrodes to generate sound.

[00187] Where appropriate, the methods also may include applying an electric potential and/or voltage to, for example, to build up charge on, a diaphragm, such as a diaphragm including carbon nanotubes and/or graphene. Such a signal may be applied to the electrodes from a power and/or voltage source.

[00188] The methods also may include maintaining the diaphragm at a particular direct current (DC) potential, such as a potential of 1-10 kV, such as 1-5 kV, with respect to the first and/or second biasing electrode. The methods also include applying an electrical potential to, so as to drive, the first biasing electrode in

antiphase with the second biasing electrode. Accordingly, the methods include producing a uniform, or substantially uniform, electrostatic field proportional to a signal, e.g., audio signal, between the first and second biasing electrodes. Such an electrostatic field causes a force to be exerted on the diaphragm, e.g., the charged
5 diaphragm, and the resulting movement of the diaphragm generates sound.

[00189] The embodiments of the methods include maintaining one or more, e.g., first and second, biasing electrodes in a fixed position while a diaphragm is flexed and thereby vibrated between them. The methods also may include not touching the diaphragm and the biasing electrodes while the diaphragm moves to
10 generate sound. Also, in some aspects, the methods include pushing and/or pulling air through one or more, e.g., a plurality of, openings in one or more biasing electrodes, e.g., biasing electrodes shaped as screens and/or grids, with a diaphragm.

15 UTILITY

[00190] The subject devices and methods may be used to generate sound and may be applied in a wide variety of settings. For example, the disclosed subject matter may be used in an automobile audio system, a public address system, such as a theater or stadium audio system, an electronic media player, e.g., a computer, a
20 television, and/or a telephone, or one or more components of such devices.

[00191] As described herein, the devices having one or more components including carbon nanotubes and/or graphene may operate in a way that is more efficient and/or safer than speaker driver devices not including such materials. For example, carbon nanotubes and/or graphene in components may make the
25 components more resistant to degradation than components not including such materials. More specifically, and as noted herein, operation of speaker driver devices, to for example, generate sound, may generate thermal energy. Such thermal energy may in turn cause degradation of the devices or components thereof over time by causing the components or connections between the components to
30 crack, break, burn, melt, and/or permanently deform. For example, if temperatures of a component, e.g., a diaphragm and/or an electrode, rises too high, glues used to bond the electrode to the diaphragm can weaken and the electrode can break loose, melt, and/or go open circuit. Such degradation may negatively affect the performance and/or safety of such devices. For example, a deformed speaker driver

device may be unable to produce sound or unable to produce sound without using a large amount of electrical energy. Also, for example, in some circumstances, one or more components exposed to thermal energy could short circuit and/or catch on fire and thereby put a user's health in danger.

5 **[00192]** However, because carbon nanotubes and/or graphene have high thermal resilience and conductivity, components including such materials can be more resistant to degradation by heat. Such components also have a high thermal conductivity and can therefore be more effective at cooling, e.g., cooling other components and/or connections between components, such as a connection
10 between a diaphragm and a biasing electrode, than other components, such as components including, e.g., including only, glass fiber, polyimide, and/or a metal or alloy, such as copper and/or aluminum. For example, a diaphragm including carbon nanotubes and/or graphene may be more effective at cooling an electrode operably coupled thereto, such as a biasing electrode including carbon nanotubes and/or
15 graphene, than a diaphragm not including such materials. Accordingly, speaker driver devices with one or more components including carbon nanotubes and/or graphene can be more resistant to degradation from exposure to thermal energy or thermal energy changes and can be less likely to crack, break, burn, melt, and/or permanently deform from heat exposure than components not including such
20 materials. As such, speaker driver devices with one or more components including carbon nanotubes and/or graphene can be longer-lasting, e.g., longer-lasting under the same conditions, than devices without components including such materials. Such speaker devices can also be less likely to short circuit and/or catch on fire and can therefore be safer than devices without components including such materials.

25 **[00193]** Furthermore, and as noted herein, speaker device components may move to produce sound and are therefore exposed to kinetic energy. Kinetic energy may have any of the same effects of degradation on components of speaker driver devices as thermal energy.

30 **[00194]** However, because carbon nanotubes and/or graphene have a high strength and are therefore highly resistant to deformation, e.g., plastic deformation, components including such materials can be more resistant to degradation by exposure to kinetic energy than components not including such materials, such as components including, e.g., including only, glass fiber, polyimide, and/or a metal or alloy, such as copper and/or aluminum. Also, carbon nanotubes and/or graphene

are flexible so that they can temporarily vibrate, bend and/or stretch when exposed to an audio signal but are not permanently deformed or broken. Accordingly, speaker driver devices with one or more components including carbon nanotubes and/or graphene can be less likely to crack, break, burn, melt, and/or permanently deform from continued exposure to kinetic energy than components not including such materials.

[00195] As such, speaker driver devices with one or more components including carbon nanotubes and/or graphene can be longer-lasting, e.g., longer-lasting under the same conditions, than devices without components including such materials. For example, speaker driver devices with one or more components including carbon nanotubes and/or graphene can maintain their shape and therefore vibrate or push air consistently and/or in direct or substantially direct proportion to an input signal, e.g., an input audio signal, more effectively than a device not having components. Speaker driver devices with one or more components including carbon nanotubes and/or graphene can also be less likely to short circuit or catch on fire and can therefore be safer than devices without components including such materials.

[00196] In addition, speaker driver devices with a plurality of components, e.g., a diaphragm and a biasing electrode, composed of carbon nanotubes and/or graphene can be longer-lasting, e.g., longer-lasting under the same conditions, and safer than devices only having single components, e.g., diaphragms, composed of such materials. In other words, operably coupling, such as by fixedly coupling, such as by adhesively and/or mechanically coupling a first component including carbon nanotubes and/or graphene with a second component including carbon nanotubes and/or graphene, in a speaker driver device may make the device longer-lasting and safer than devices not including such operably coupled first and second components. Such an operable connection between carbon-containing components may also result in other benefits which are discussed below including having an ability to conduct a greater amount of electricity without being subject to degradation, being lighter, and having smaller overall dimensions, as well as being more efficient by using less energy and therefore having less impact on the surrounding environment.

[00197] Due to their high strength and high electrical and/or thermal conductivity, components, e.g., diaphragms and/or biasing electrodes, of the devices including carbon nanotubes and/or graphene having specific dimensions may be

able to conduct a greater amount of electricity without being subject to degradation than components having the same dimensions but not including carbon nanotubes and/or graphene. Accordingly, devices having components, e.g., diaphragms and/or biasing electrodes, including carbon nanotubes and/or graphene, may be more able
5 to receive a higher amount electrical power without degrading and thus produce higher sound levels than devices having components not including such materials. Furthermore, speaker driver devices with a plurality of components, e.g., a diaphragm and a biasing electrode, composed of carbon nanotubes and/or graphene may be able to conduct a greater amount of electricity without being subject to
10 degradation than devices only having single components, e.g., diaphragms, composed of such materials.

[00198] Additionally, for example, in some versions of the devices, one or more components, e.g., diaphragms and/or biasing electrodes, of the devices including carbon nanotubes and/or graphene, such as non-electrically conductive components
15 or substantially non-electrically conductive components, e.g., diaphragms, may effectively insulate other components, e.g., biasing electrodes, and thereby make the devices safer and/or more able to handle higher electrical power. For example, a diaphragm, e.g., a substantially non-electrically conductive diaphragm, may prevent or substantially prevent arcing between biasing electrodes and/or between a biasing
20 electrode and another electrical component and/or between a first portion of a biasing electrode and a second portion of a biasing electrode.

[00199] Carbon nanotubes and/or graphene may also be lighter than other materials used in speaker driver devices, e.g., metals such as aluminum and/or copper. Because carbon nanotubes and/or graphene have a comparatively light
25 weight and, as noted above, have a high strength and are therefore highly resistant to deformation, e.g., plastic deformation, components including such materials can be lighter and/or smaller than components of speaker driver devices not including such materials. For example, by including carbon nanotubes and/or graphene in a device component, such as a diaphragm or a biasing electrode, the component can
30 be made thinner than it could if it were composed of, e.g., entirely of, another material such as copper, aluminum and/or polymer film, such as polyimide, while still retaining its ability to perform effectively to generate sound as described herein.

[00200] Since speaker driver device components including carbon nanotubes and/or graphene can be lighter and/or smaller than components not including such

materials, devices including such materials may have smaller overall, e.g., external, dimensions and thus be easier and more convenient to use, e.g., carry, for users than devices not including such materials. Also, devices including a plurality of components composed of such materials may be even lighter and/or have even smaller overall, e.g., external, dimensions than devices including only single components composed of such materials.

[00201] Furthermore, because speaker driver device components including carbon nanotubes and/or graphene can be lighter and/or smaller than components not including such materials, speaker driver devices including such components may use less energy, e.g., less electrical energy, to operate and therefore be more efficient than devices not including such components. In addition, speaker driver device components including carbon nanotubes and/or graphene which are lighter and/or smaller than components not including such materials, speaker driver devices including such components may be longer-lasting than devices not including such components because there will be less degradation from kinetic energy in such devices.

[00202] By using less energy to operate, the speaker driver devices having components including carbon nanotubes and/or graphene may have less impact on the surrounding environment, e.g., a smaller carbon footprint, than devices which do not. Using less energy may also allow speaker driver devices having components including carbon nanotubes and/or graphene may also allow such devices to operate for longer periods of time using a fixed amount of energy than devices not including such components using the same amount of energy.

[00203] Speaker driver devices with one or more components including carbon nanotubes and/or graphene may also be more effective at damping and therefore may be more effective at converting a signal, e.g., an audio signal, into a desired sound than components not including such materials. More specifically, and as described above, components including such materials, e.g., diaphragms, are highly resistant to storing energy, e.g., kinetic energy, when a stimulus, such as a stimulus to move, e.g., an electrical potential and/or a force from a biasing electrode, is taken away. Such components absorb and/or effectively disperse the kinetic energy in a very short time period. As such, the components, e.g., diaphragms, are substantially resistant to continued movement which may impede the conversion of a signal into a desired sound, and which occurs when a stimulus is removed.

[00204] Furthermore, materials including carbon nanotubes and/or graphene are being produced in greater volume and/or by using cheaper and/or more efficient methods, such as methods that have less impact on the surrounding environment. Producing speaker driver devices with materials including carbon nanotubes and/or graphene leverages such developments on behalf of consumers and makes more affordable devices, which as described above, are safer and/or more efficient than alternatives, available to consumers.

EXEMPLARY NON-LIMITING EMBODIMENTS

[00205] Embodiments of the present subject matter described above may be beneficial alone or in combination, with one or more other embodiments or characteristics. Without limiting the foregoing description, non-limiting embodiments of the disclosure numbered 1-23 are provided below. As will be apparent to those of skill in the art upon reading this disclosure, each of the individually numbered embodiments may be used or combined with any of the preceding or following individually numbered embodiments or characteristics. This is intended to provide support for all such combinations of embodiments and is not limited to combinations of embodiments explicitly provided below.

1. A speaker driver device including:
a diaphragm including carbon nanotubes, graphene or both carbon nanotubes and graphene; and
a biasing electrode including carbon nanotubes, graphene or both carbon nanotubes and graphene, wherein the biasing electrode is operably connected to the diaphragm.

2. The device according to 1, wherein the biasing electrode includes carbon nanotubes.

3. The device according to 1 or 2, further including an electrical contact including graphene and configured to operably connect the biasing electrode with a voltage source.

4. The device according to any one of 1-3, wherein the diaphragm and the biasing electrode are planar.

5. The device according to any one of 1-4, wherein the diaphragm has a thickness of 20 microns or less.

6. The device according to any one of 1-3 or 5, wherein the diaphragm includes a cone and the biasing electrode includes a coil.

7. The device according to any one of 1-6, wherein the diaphragm includes carbon nanotubes and is substantially non-electrically conductive.

8. The device according to any one of 1-7, further including a frame operably connected to and extending around the diaphragm.

9. A speaker driver device including:
a diaphragm; and
a biasing electrode including carbon nanotubes,
wherein the biasing electrode is operably connected to the diaphragm.

10. The device according to 9, wherein the diaphragm includes a polyimide film.

11. The device according to 9 or 10, further including an electrical contact including carbon nanotubes or graphene and configured to operably connect the biasing electrode with a voltage source.

12. The device according to any one of 9-11, wherein the diaphragm defines a plurality of arches, and wherein each of the arches separates portions of a diaphragm surface which are opposite from one another.

13. A method of generating sound with a speaker driver device, the method including:

applying a voltage to a biasing electrode of the device in a magnetic field, wherein the biasing electrode includes carbon nanotubes, graphene or both carbon nanotubes and graphene;

5 moving a diaphragm of the device via application of the voltage, wherein the diaphragm includes carbon nanotubes, graphene or both carbon nanotubes and graphene, and is operably connected to the biasing electrode, and wherein moving the diaphragm generates sound.

10 14. The method according to 13, wherein the biasing electrode includes a coil and applying a voltage to the biasing electrode includes flowing a current through the coil.

15 15. The method according to any one of 12-14, wherein the voltage is applied to the biasing electrode via an electrical contact including carbon nanotubes or graphene.

20 16. The method according to any one of 12-15, wherein the diaphragm includes a former defining a central axis therethrough, wherein the biasing electrode includes a coil extending around the former, and wherein moving the diaphragm includes moving the coil in a direction parallel with the central axis.

25 17. The method according to 16, wherein the former includes a passage and wherein moving the diaphragm includes generating an air flow in the passage thereby cooling the coil.

30 18. The method according to any one of 12-15, wherein the device includes a housing having a first wall including a first magnet and a second wall opposite the first wall and including a second magnet, and moving the diaphragm includes vibrating the diaphragm between the first magnet and the second magnet.

19. The method according to any one of 12-18, wherein the biasing electrode includes carbon nanotubes and applying a voltage to the biasing electrode includes transferring a current across the diaphragm via the carbon nanotubes of the biasing electrode.

20. The method according to any one of 12-15, 18 or 19, wherein the device includes a frame operably connected to the diaphragm and defining an opening, and wherein moving the diaphragm includes moving the biasing electrode
5 within the opening.

21. A speaker driver device including:
a fixed first biasing electrode;
a fixed second biasing electrode;
10 a diaphragm between the fixed first biasing electrode and the fixed second biasing electrode, wherein the diaphragm includes carbon nanotubes, graphene or both carbon nanotubes and graphene.

22. The device according to 21, wherein the first biasing electrode includes
15 carbon nanotubes, graphene or both carbon nanotubes and graphene, and the second biasing electrode includes carbon nanotubes, graphene or both carbon nanotubes and graphene.

23. A speaker driver device comprising:
20 a diaphragm; and
a biasing electrode comprising carbon nanotubes or graphene and encapsulated within the diaphragm.

24. The device according to 9, wherein the diaphragm includes a polyimide
25 film.

25. The device according to any one of 1-6, 8-12 or 22-24, wherein the diaphragm includes carbon nanotubes.

26. The device according to any one of 1-12, or 22-24, wherein the diaphragm includes graphene.

27. The device according to any one of 1, 3-12, 23 or 24, wherein the biasing electrode includes carbon nanotubes.

28. The device according to any one of 1-12, 23 or 24, wherein the biasing electrode includes graphene.

5 29. The method according to any one of 13-20, wherein the diaphragm includes carbon nanotubes.

30. The method according to any one of 13-20, wherein the diaphragm includes graphene.

10

31. The method according to any one of 13-20, wherein the biasing electrode includes carbon nanotubes.

15 32. The method according to any one of 13-20, wherein the biasing electrode includes graphene.

[00206] Although the foregoing embodiments of the invention have been described in some detail by way of illustration and example for purposes of clarity of understanding, it is readily apparent to those of ordinary skill in the art in light of the teachings of this subject matter that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present embodiments of the invention will be limited only by the appended claims.

[00207] Accordingly, the preceding merely illustrates the principles of the embodiments of the invention. It will be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the embodiments of the invention and are included within its spirit and scope. Furthermore, all examples and conditional language recited herein are principally intended to aid the reader in understanding the principles of the embodiments of the invention and the concepts contributed by the inventors to furthering the art, and are to be construed as being without limitation

to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both
5 currently known equivalents and equivalents developed in the future, e.g., any elements developed that perform the same function, regardless of structure. The scope of the presently disclosed subject matter, therefore, is not intended to be limited to the exemplary embodiments shown and described herein. Rather, the scope and spirit of presently disclosed subject matter is embodied by the appended
10 claims.

CLAIMS

WHAT IS CLAIMED IS:

1. A speaker driver device comprising:
a diaphragm comprising carbon nanotubes, graphene or both carbon nanotubes and graphene; and
a biasing electrode comprising carbon nanotubes, graphene or both carbon nanotubes and graphene, wherein the biasing electrode is operably connected to the diaphragm.
2. The device according to Claim 1, wherein the biasing electrode comprises carbon nanotubes.
3. The device according to Claim 1 or Claim 2, further comprising an electrical contact comprising graphene and configured to operably connect the biasing electrode with a voltage source.
4. The device according to any one of Claims 1-3, wherein the diaphragm and the biasing electrode are planar.
5. The device according to any one of Claims 1-4, wherein the diaphragm has a thickness of 20 microns or less.
6. The device according to any one of Claims 1-3 or 5, wherein the diaphragm comprises a cone and the biasing electrode comprises a coil.
7. The device according to any one of Claims 1-6, wherein the diaphragm comprises carbon nanotubes and is substantially non-electrically conductive.
8. The device according to any one of Claims 1-7, further comprising a frame operably connected to and extending around the diaphragm.

9. A speaker driver device comprising:
a diaphragm; and
a biasing electrode comprising carbon nanotubes,
wherein the biasing electrode is operably connected to the diaphragm.
10. The device according to Claim 9, wherein the diaphragm comprises a polyimide film.
11. The device according to Claim 9 or Claim 10, further comprising an electrical contact comprising carbon nanotubes or graphene and configured to operably connect the biasing electrode with a voltage source.
12. The device according to any one of Claims 9-11, wherein the diaphragm defines a plurality of arches, and wherein each of the arches separates portions of a diaphragm surface which are opposite from one another.
13. A method of generating sound with a speaker driver device, the method comprising:
applying a voltage to a biasing electrode of the device in a magnetic field, wherein the biasing electrode comprises carbon nanotubes, graphene or both carbon nanotubes and graphene;
moving a diaphragm of the device via application of the voltage, wherein the diaphragm comprises carbon nanotubes, graphene or both carbon nanotubes and graphene, and is operably connected to the biasing electrode, and wherein moving the diaphragm generates sound.
14. The method according to Claim 13, wherein the biasing electrode comprises a coil and applying a voltage to the biasing electrode comprises flowing a current through the coil.
15. The method according to any one of Claims 12-14, wherein the voltage is applied to the biasing electrode via an electrical contact comprising carbon nanotubes or graphene.

16. The method according to any one of Claims 12-15, wherein the diaphragm comprises a former defining a central axis therethrough, wherein the biasing electrode comprises a coil extending around the former, and wherein moving the diaphragm comprises moving the coil in a direction parallel with the central axis.

17. The method according to Claim 16, wherein the former comprises a passage and wherein moving the diaphragm comprises generating an air flow in the passage thereby cooling the coil.

18. The method according to any one of Claims 12-15, wherein the device comprises a housing having a first wall comprising a first magnet and a second wall opposite the first wall and comprising a second magnet, and moving the diaphragm comprises vibrating the diaphragm between the first magnet and the second magnet.

19. The method according to any one of Claims 12-18, wherein the biasing electrode comprises carbon nanotubes and applying a voltage to the biasing electrode comprises transferring a current across the diaphragm via the carbon nanotubes of the biasing electrode.

20. The method according to any one of Claims 12-15, 18 or 19, wherein the device comprises a frame operably connected to the diaphragm and defining an opening, and wherein moving the diaphragm comprises moving the biasing electrode within the opening.

21. A speaker driver device comprising:
a fixed first biasing electrode;
a fixed second biasing electrode;
a diaphragm between the fixed first biasing electrode and the fixed second biasing electrode, wherein the diaphragm comprises carbon nanotubes, graphene or both carbon nanotubes and graphene.

22. The device according to Claim 21, wherein the first biasing electrode comprises carbon nanotubes, graphene or both carbon nanotubes and graphene,

and the second biasing electrode comprises carbon nanotubes, graphene or both carbon nanotubes and graphene.

Figure 1

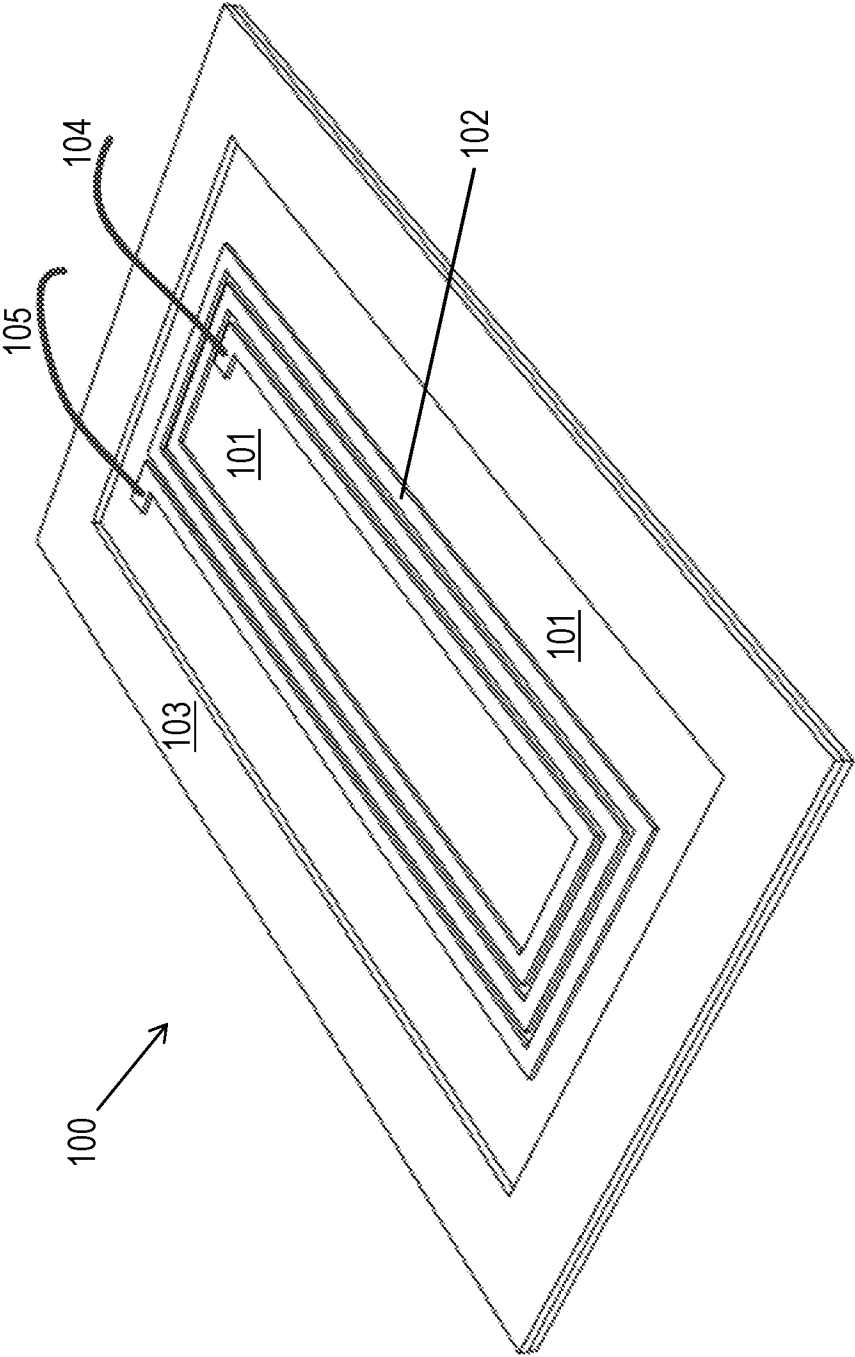


Figure 2

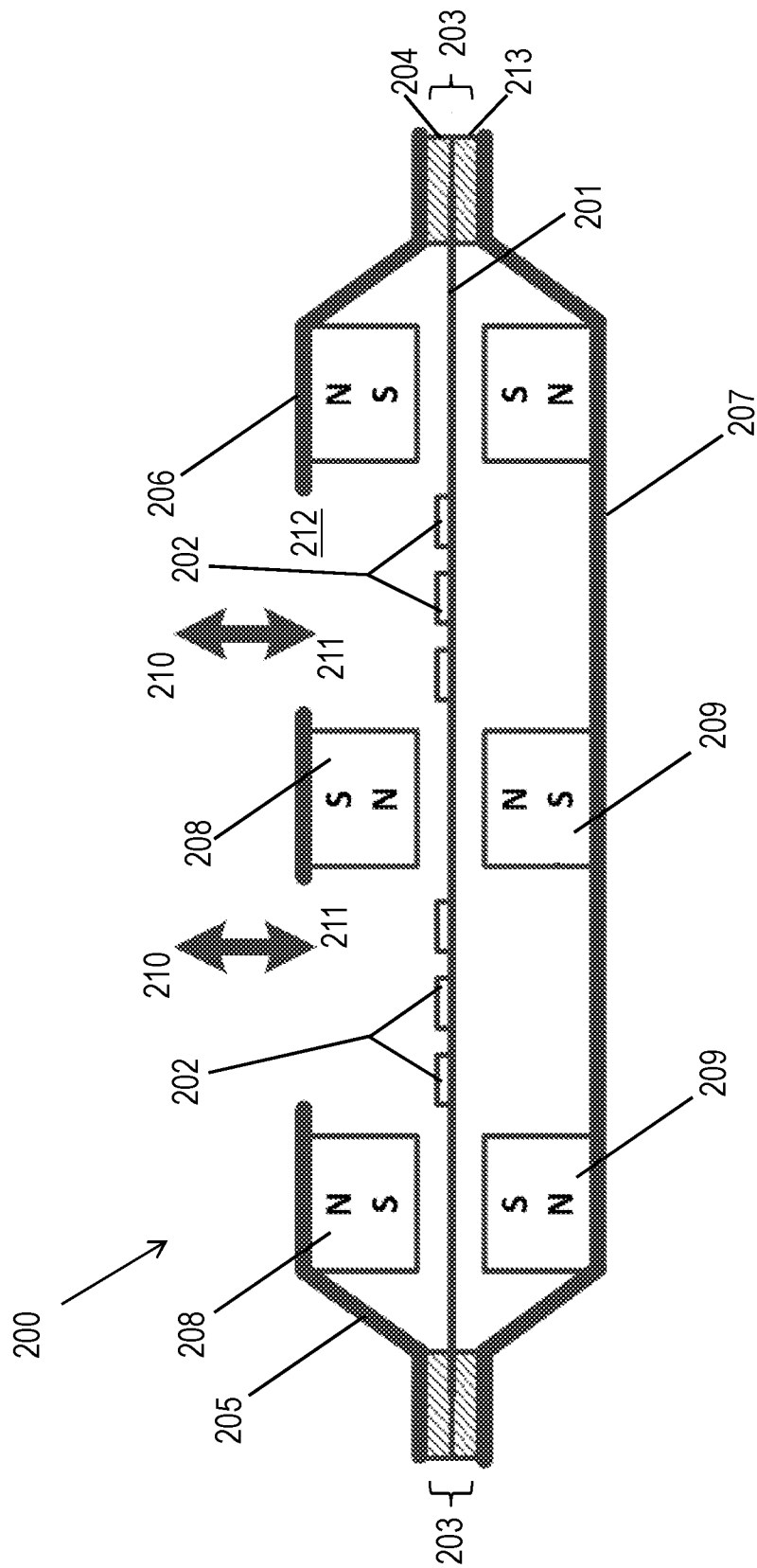


Figure 3

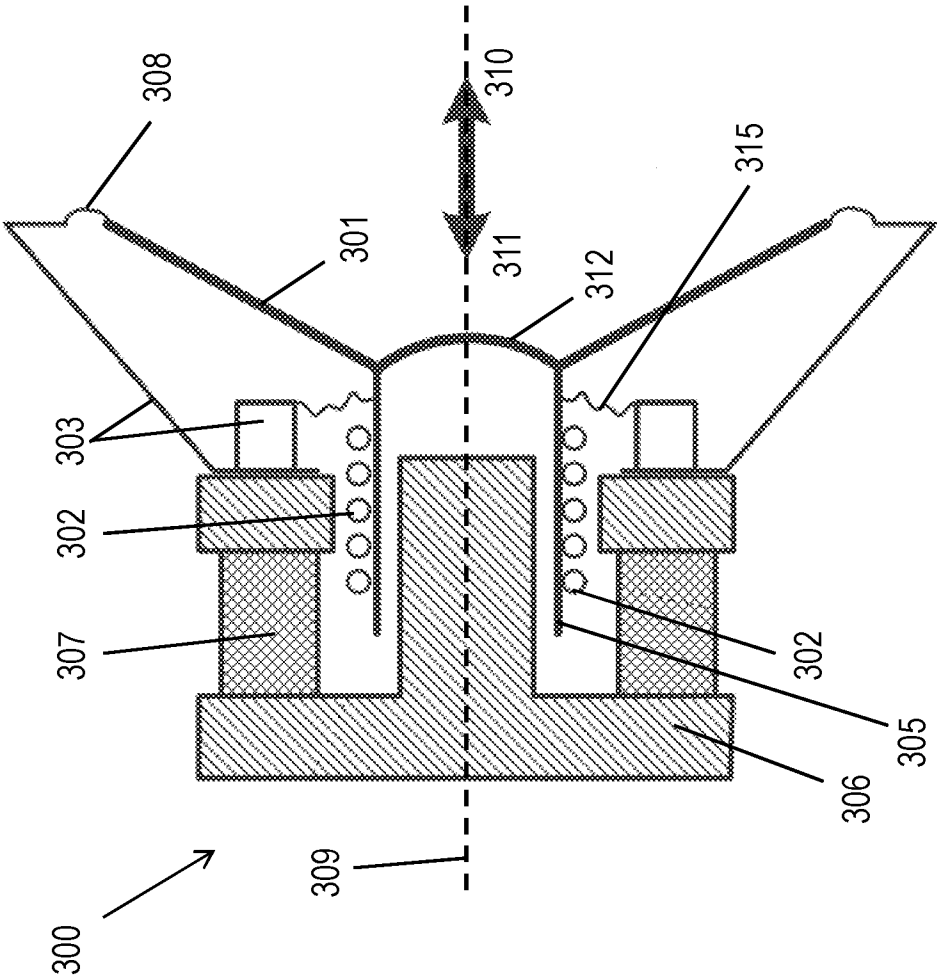


Figure 4

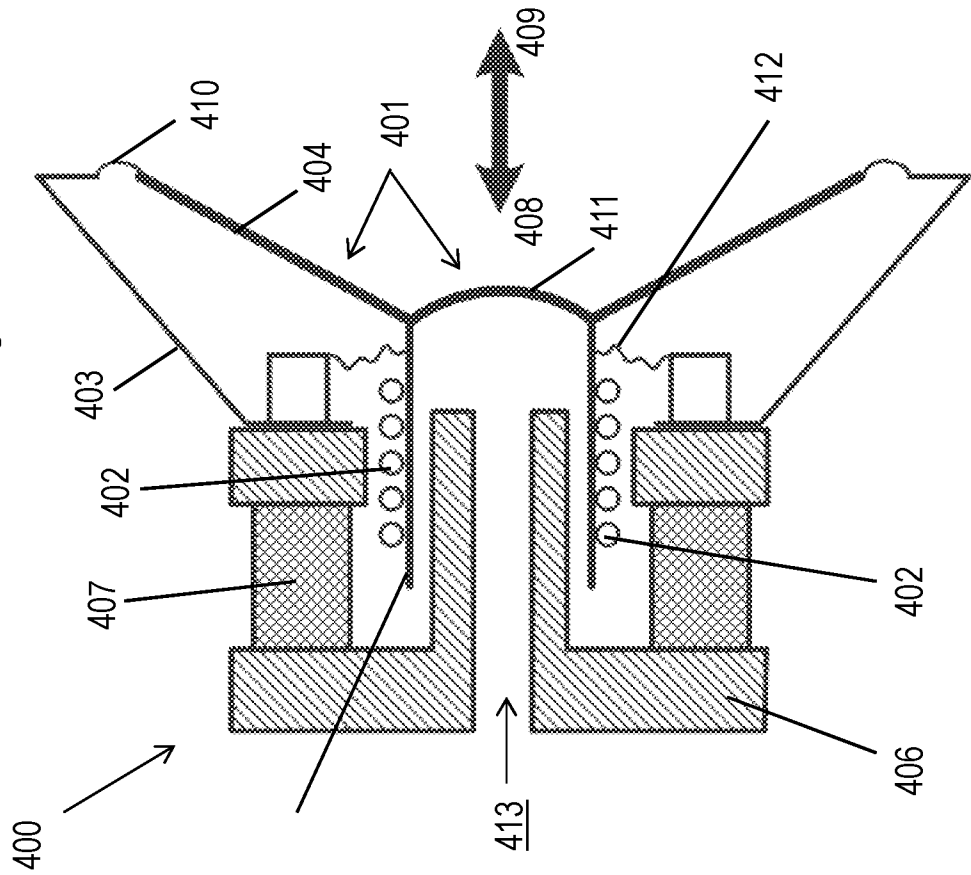


Figure 5

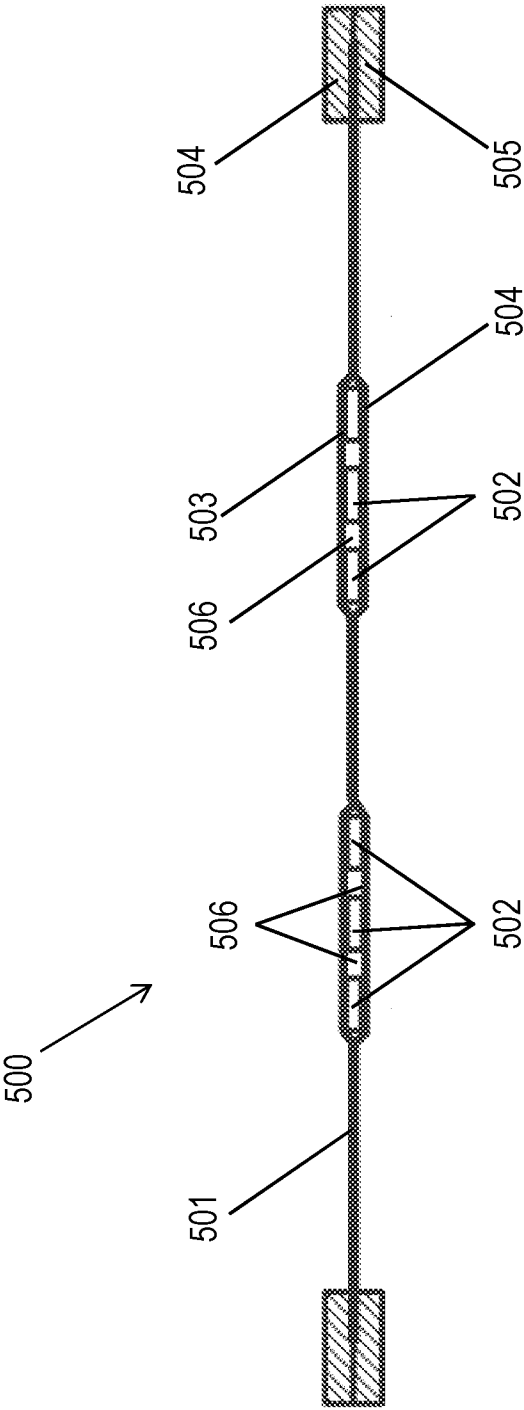


Figure 7

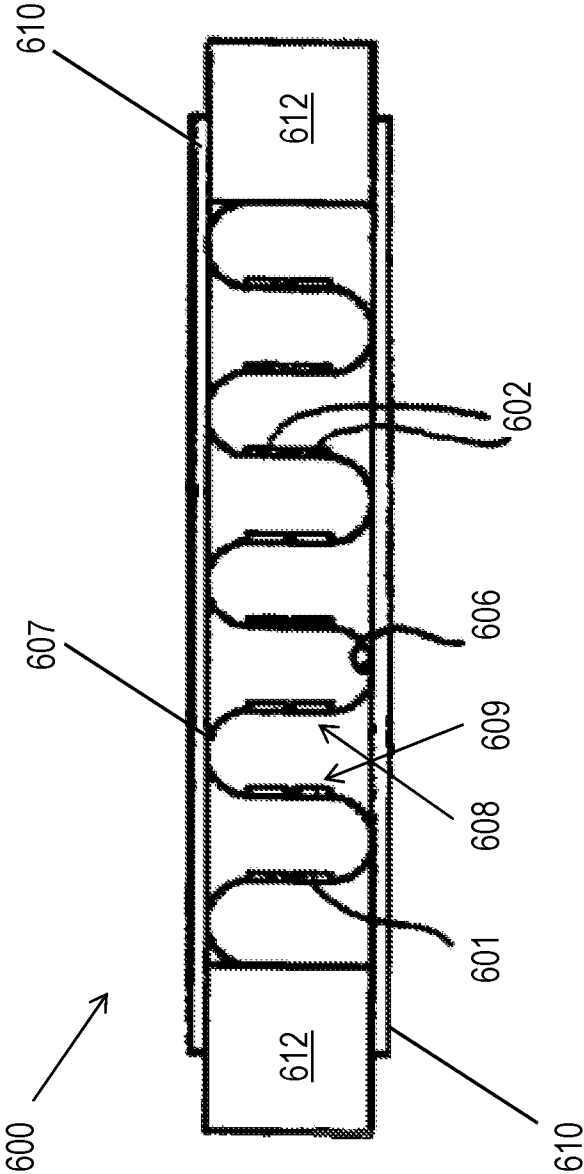
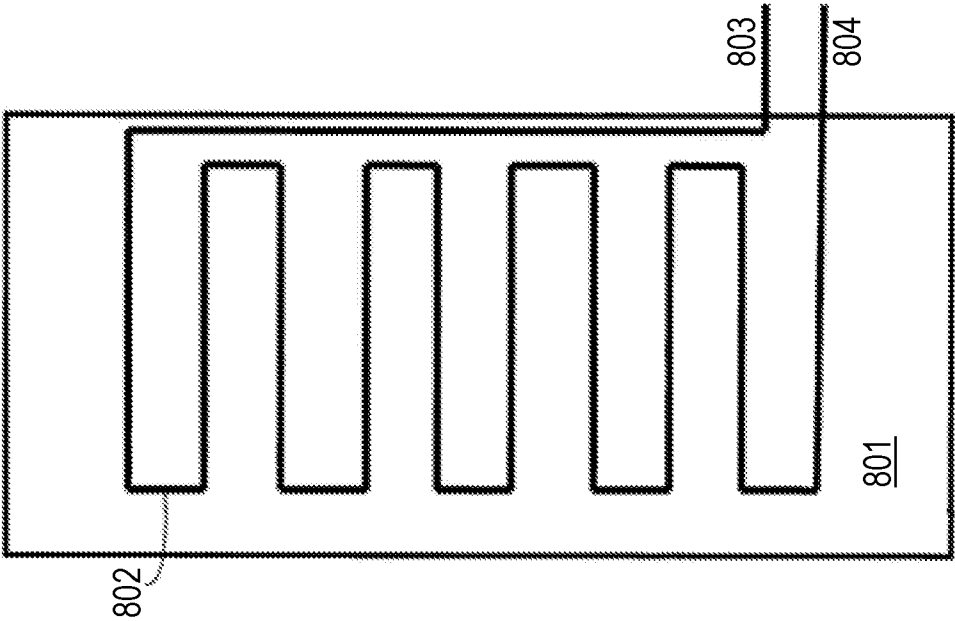


Figure 8



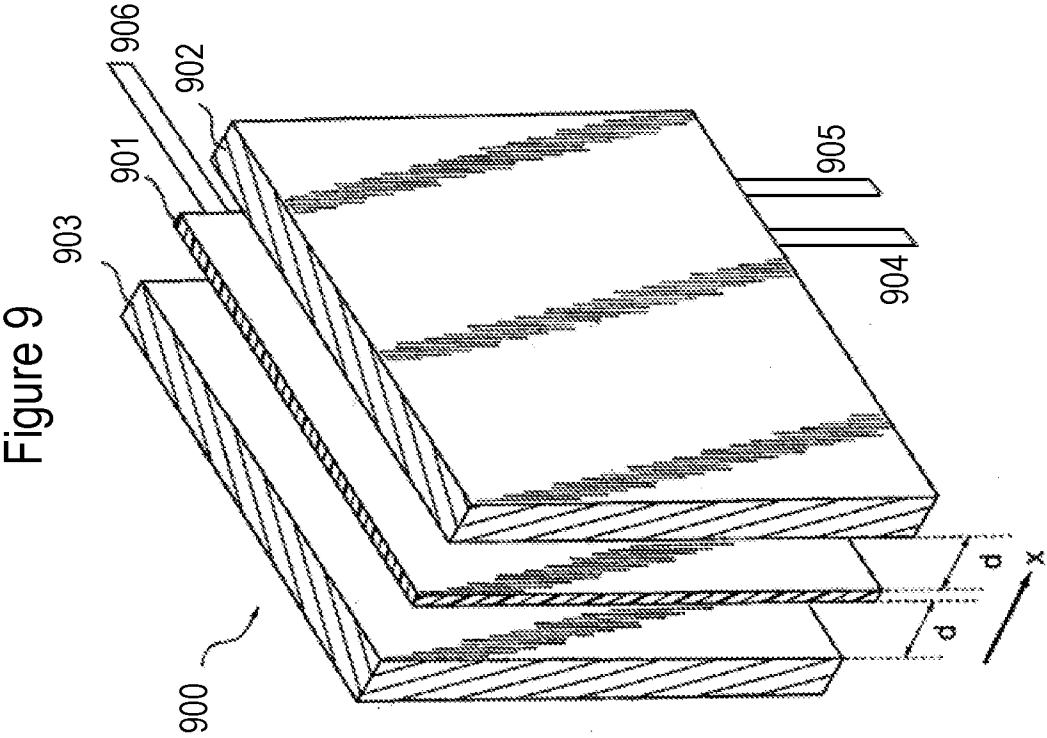


Figure 10

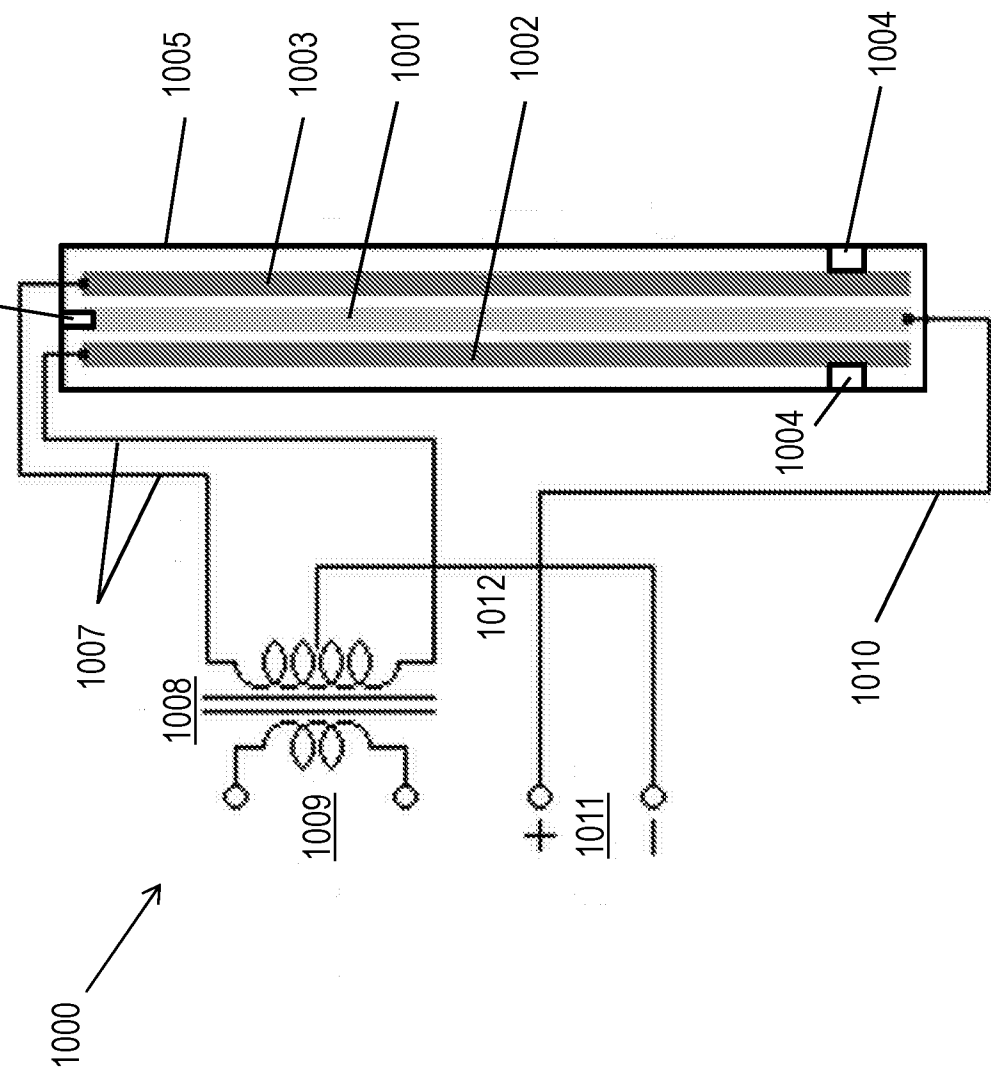


Figure 11

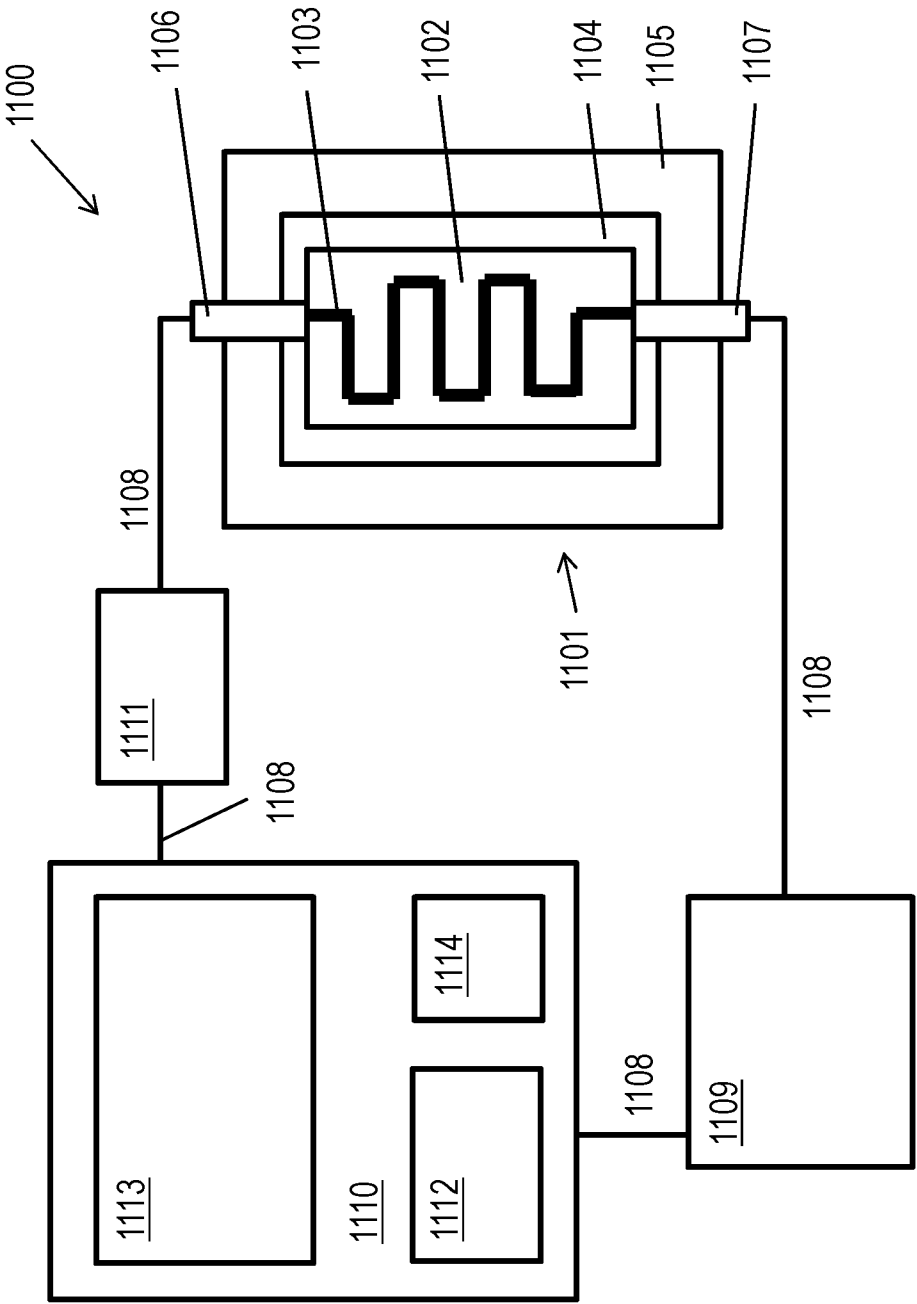
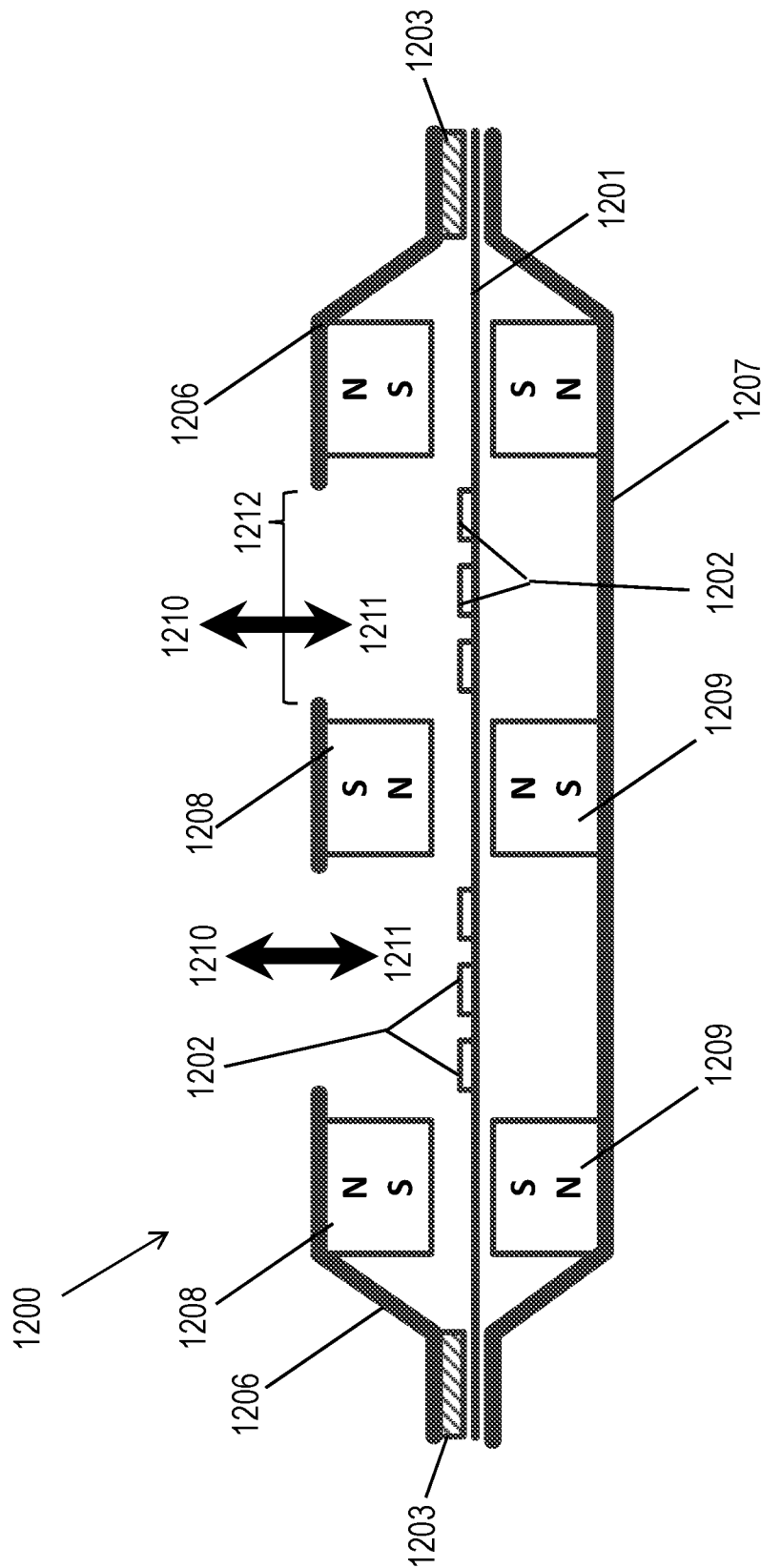


Figure 12



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/043284

A. CLASSIFICATION OF SUBJECT MATTER INV. H04R7/02 H04R9/06 H04R19/02 ADD. H04R7/14 H04R9/04		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) H04R		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/317866 A1 (WANG JIA-PING [CN] ET AL) 29 December 2011 (2011-12-29) paragraphs [0031] - [0037], [0049] - [0052], [0059] - [0061], [0068] - [0071]; figures 1,2,9,16 -----	1-8,10, 12-20
X	US 2011/064256 A1 (LIU LIANG [CN] ET AL) 17 March 2011 (2011-03-17) paragraphs [0015] - [0024]; figures 1-3 -----	9,11
Y	DE 10 2013 010654 A1 (WEISS TOBIAS [DE]) 31 December 2014 (2014-12-31) the whole document ----- -/--	1-8,10, 12-20 1-3,7-9, 11, 13-16, 19,20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 7 October 2016		Date of mailing of the international search report 17/10/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Fobel, Oliver

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/043284

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2014/100012 A1 (UNIV CALIFORNIA [US]) 26 June 2014 (2014-06-26) paragraphs [0008], [0009], [0012], [0029], [0032], [0041]; figure 1 -----	21,22
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Information on patent family members

International application No

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