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(54) **TRANSDUCER ASSEMBLY AND ULTRASONIC SENSOR WITH ABSORBING ELEMENT**

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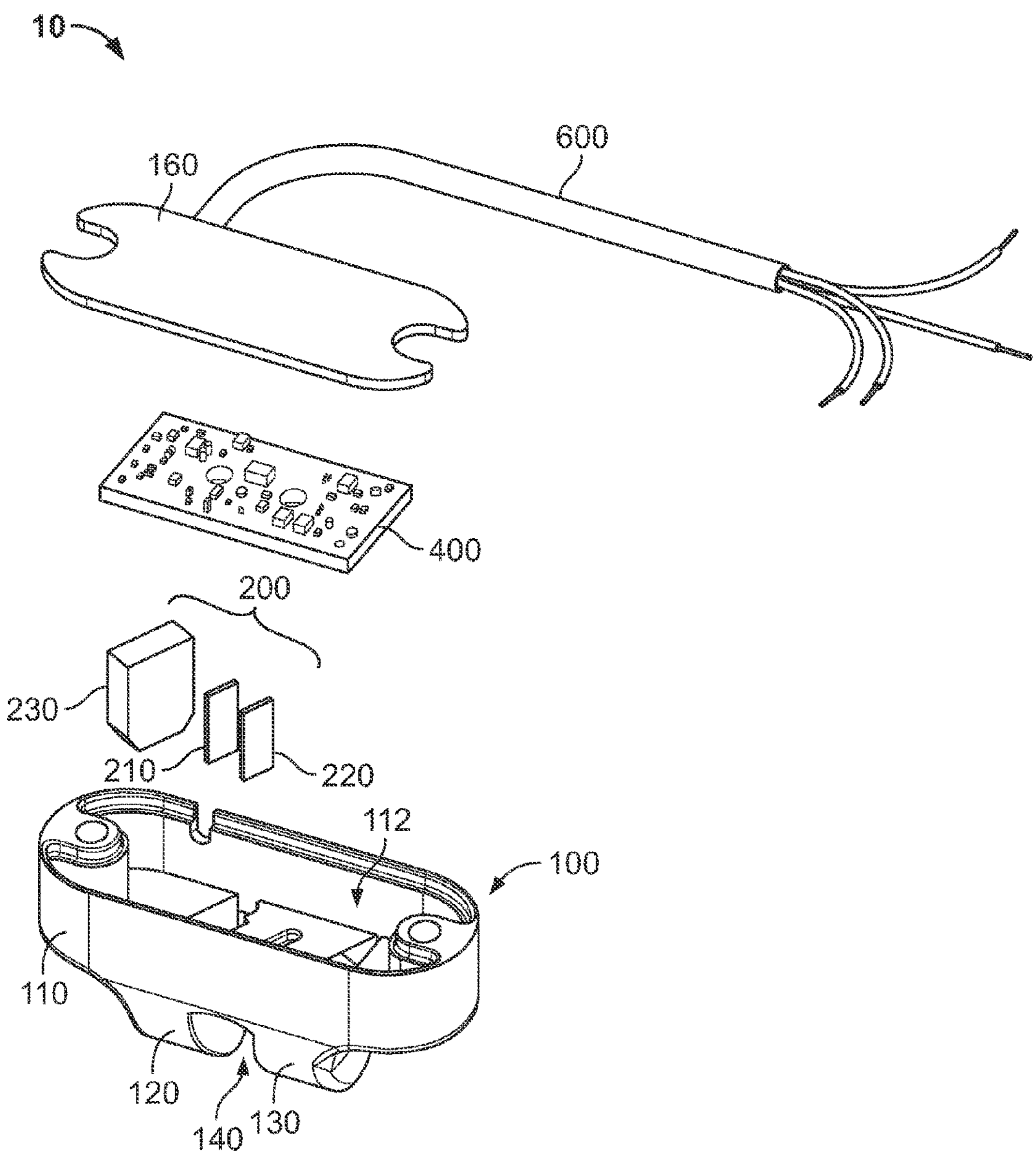
CPC ***G01S 7/521*** (2013.01); ***B06B 1/0644*** (2013.01); ***G10K 11/004*** (2013.01)

(57) **ABSTRACT**

A transducer assembly includes a transducer emitting or receiving an ultrasonic wave and a backing adjacent to the transducer. The backing is an absorbing element that provides acoustic damping for the transducer. The backing is formed of a base material with a bio-based additive dispersed within the base material.



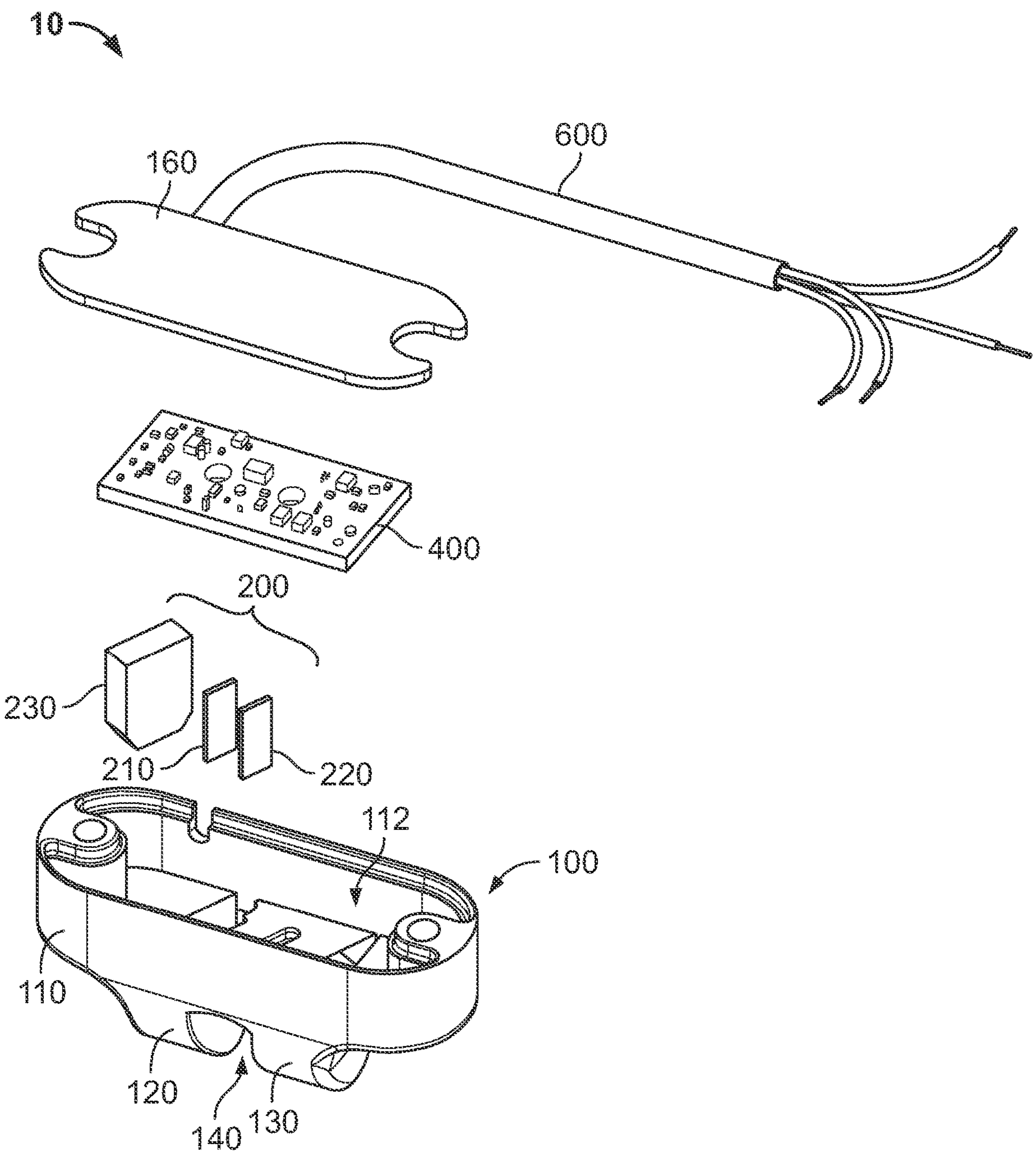


Fig. 1

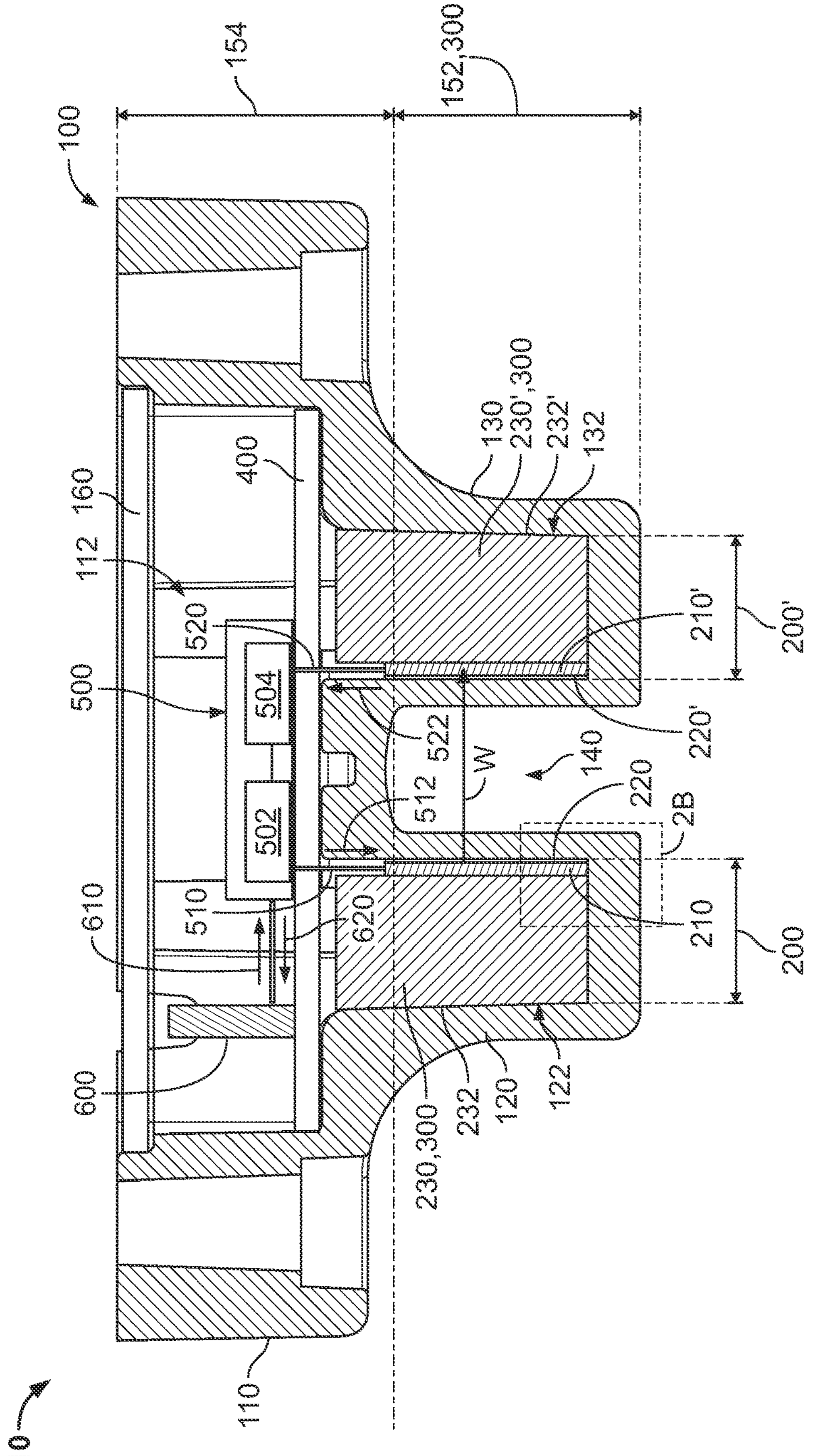

10
100
110
112
120
122
130
132
140
154
152,300
160
200
200'
210
210'
220
220'
230,300
230',300
232
232'
2B
400
500
502
504
510
512
520
522
600
610
620
W
P

Fig. 2A

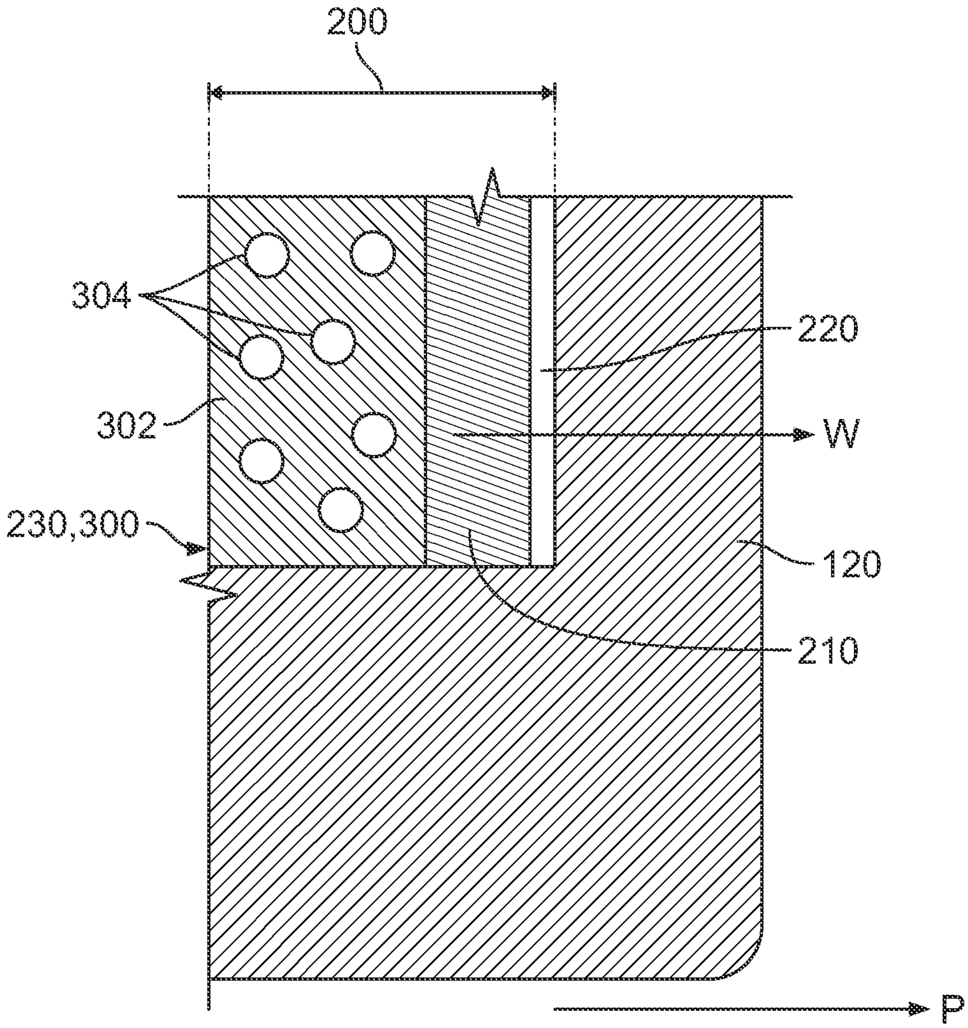


Fig. 2B

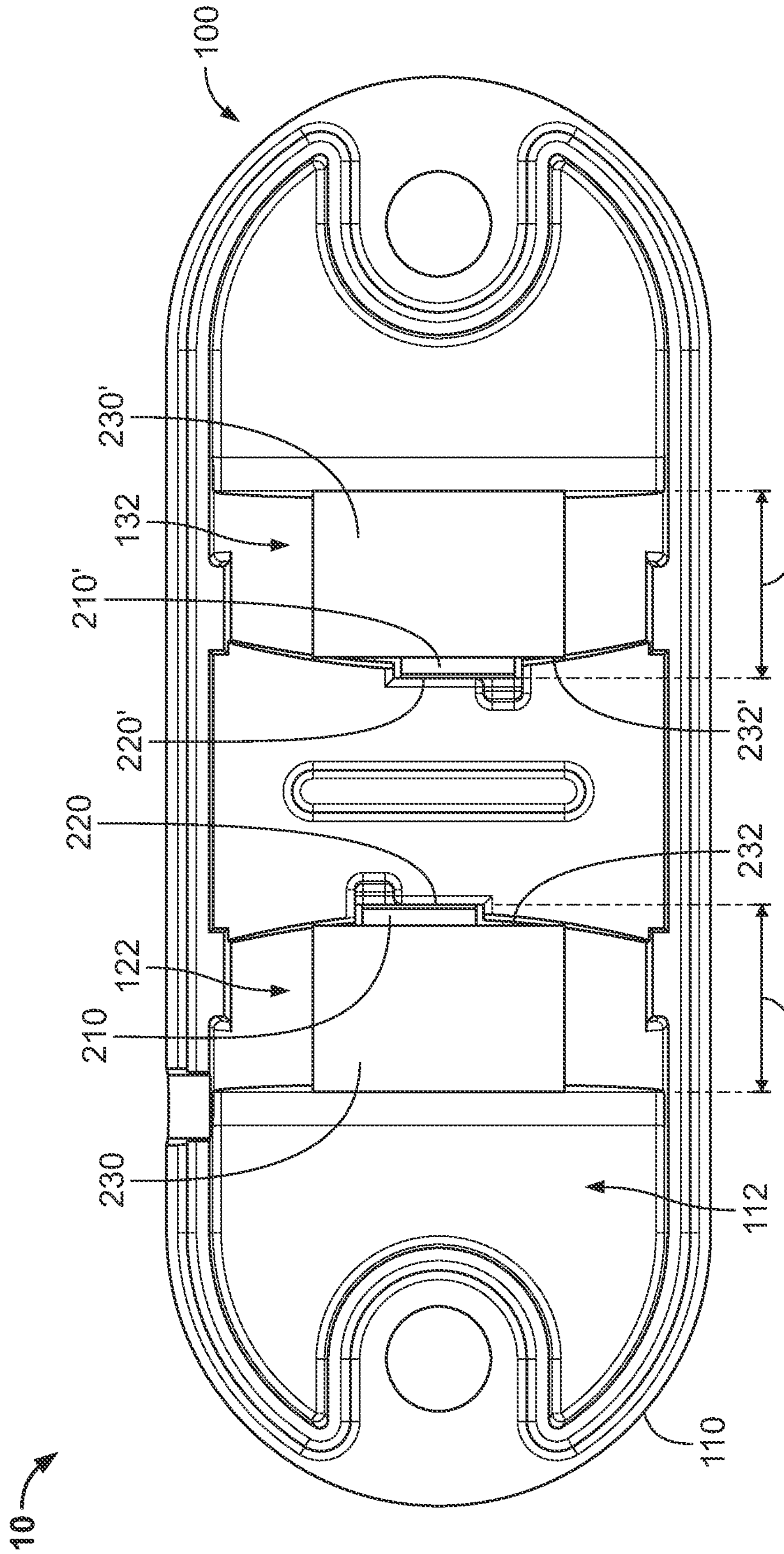


Fig. 3

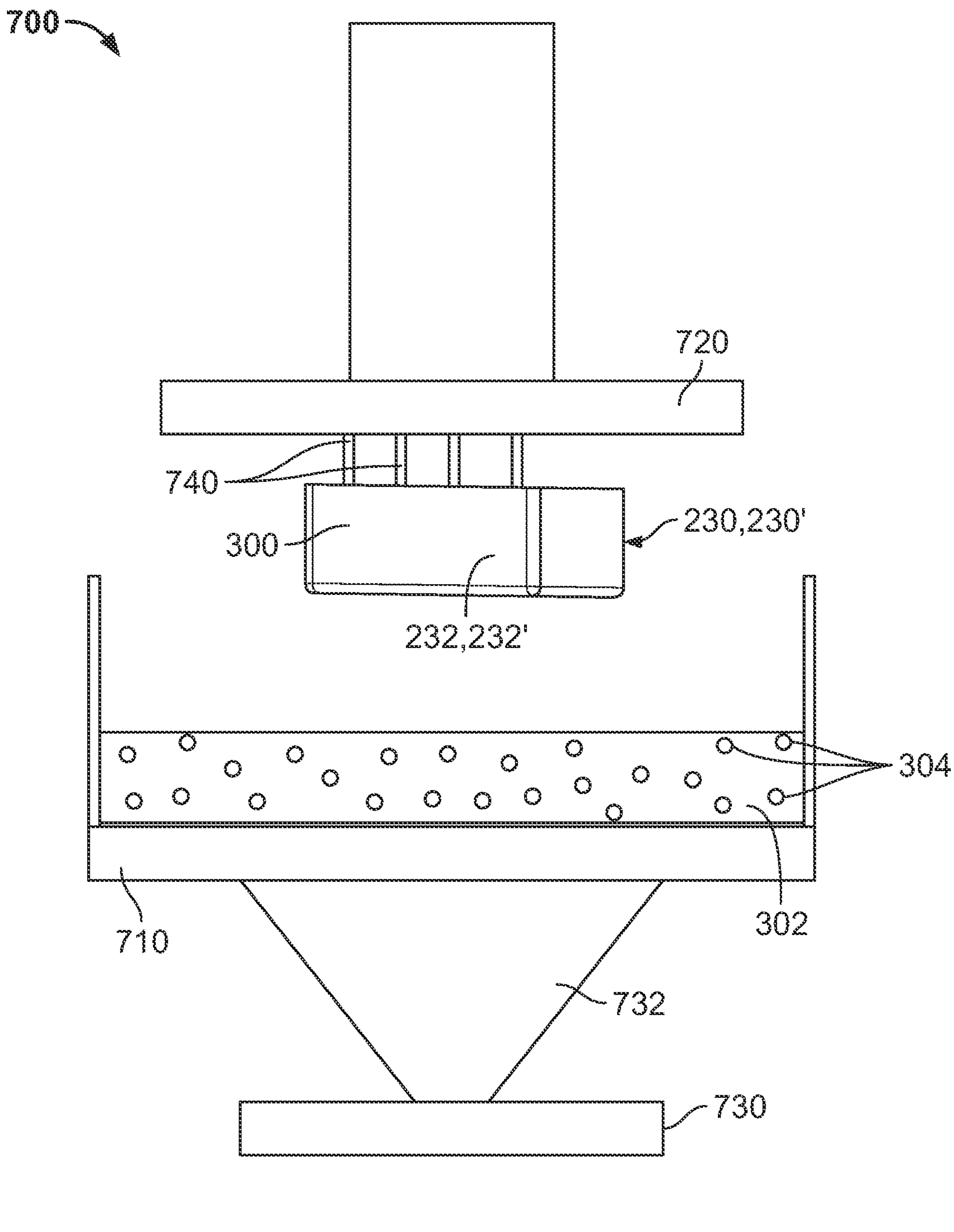


Fig. 4

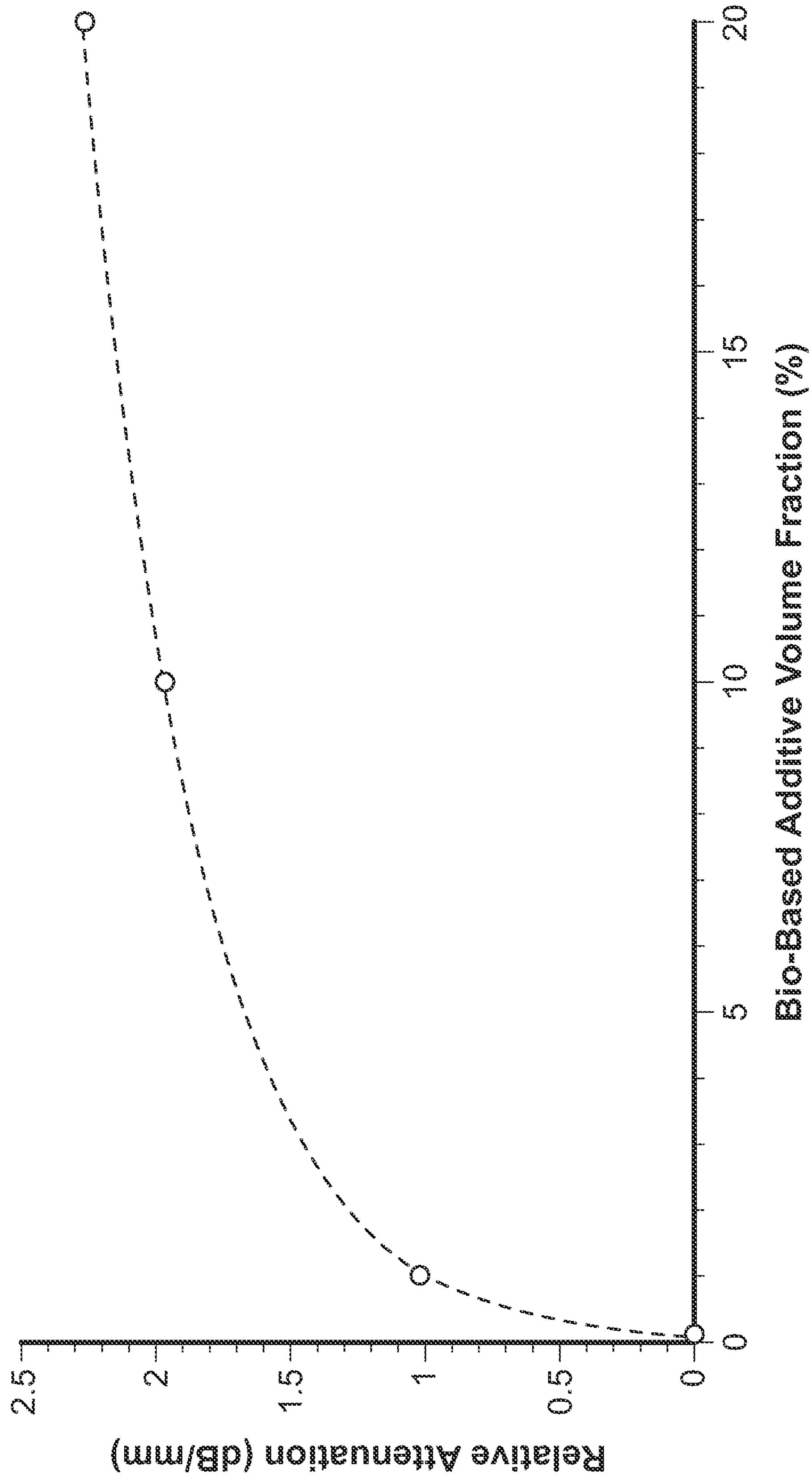

Relative Attenuation (dB/mm)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
Bio-Based Additive Volume Fraction (%)

Fig. 5

TRANSDUCER ASSEMBLY AND ULTRASONIC SENSOR WITH ABSORBING ELEMENT

FIELD OF THE INVENTION

[0001] The present invention relates to an ultrasonic sensor and, more particularly, to an absorbing element of the ultrasonic sensor.

BACKGROUND

[0002] An ultrasonic sensor includes a housing having an emitter and a receiver disposed in the housing. The emitter is controlled to emit an ultrasonic wave through the housing that is received by the receiver and output as a voltage signal. When external elements, such as a tube having a fluid, are positioned between the emitter and the receiver, the ultrasonic sensor can be used to detect qualities of the external element by analyzing the voltage signal that depends on the ultrasonic wave received by the receiver.

[0003] Acoustic absorbing materials can be used to improve the performance of the ultrasonic sensor by damping portions of the ultrasonic wave. The acoustic absorbing material is commonly an epoxy that is mixed with a tungsten powder. The epoxy and tungsten mixture is wet potted into the housing around the emitter and receiver and cured in the housing to provide the acoustic absorption. This assembly process, however, is difficult and time consuming. Further, the tungsten can settle within the epoxy, which can increase electrical conductivity at surfaces of the epoxy and cause unwanted signal attenuation.

SUMMARY

[0004] A transducer assembly includes a transducer emitting or receiving an ultrasonic wave and a backing adjacent to the transducer. The backing is an absorbing element that provides acoustic damping for the transducer. The backing is formed of a base material with a bio-based additive dispersed within the base material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The invention will now be described by way of example with reference to the accompanying Figures, of which:

[0006] FIG. **1** is an exploded perspective view of an ultrasonic sensor according to an embodiment;

[0007] FIG. **2**A is a schematic sectional side view of the ultrasonic sensor of FIG. **1**;

[0008] FIG. **2**B is a detail view of a portion **2**B of FIG. **2**A;

[0009] FIG. **3** is a top view of the ultrasonic sensor of FIG. **1**;

[0010] FIG. **4** is a schematic perspective view of a printer printing a backing according to an embodiment; and

[0011] FIG. **5** is a graph of relative attenuation versus the volume fraction of a bio-based additive in an absorbing element according to an embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENT(S)

[0012] Exemplary embodiments of the present disclosure will be described hereinafter in detail with reference to the attached drawings, wherein like reference numerals refer to like elements. The present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein; rather, these embodiments are provided so that the present disclosure will convey the concept of the disclosure to those skilled in the art. In addition, in the following detailed description, for purposes of explanation, numerous specific details are set forth to provide a thorough understanding of the disclosed embodiments. However, it is apparent that one or more embodiments may also be implemented without these specific details. Throughout the drawings, only one of a plurality of identical elements may be labeled in a figure for clarity of the drawings, but the detailed description of the element herein applies equally to each of the identically appearing elements in the figure.

[0013] An ultrasonic sensor **10** according to an embodiment, as shown in FIGS. **1** and **2**A, includes a housing **100** and a pair of transducer assemblies **200**, **200'** positioned in the housing **100**. Only a first transducer assembly **200** is visible in FIG. **1**; a second transducer assembly **200'** is positioned within the housing **100** in the view of FIG. **1**.

[0014] The housing **100**, as shown in FIGS. **1** and **2**A, has a body **110**, a first protrusion **120** extending from the body **110**, and a second protrusion **130** extending from the body **110**. The housing **100** has a channel **140** defined between the first protrusion **120** and the second protrusion **130**. The channel **140** is positioned between the first protrusion **120** and the second protrusion **130** along a propagating direction P shown in FIG. **2**A and described in greater detail below.

[0015] The body **110** defines a housing receiving space **112** at an interior of the housing **100**. As shown in FIG. **2**A, the first protrusion **120** defines a first receiving portion **122** within the first protrusion **120** that is connected to the housing receiving space **112**. The second protrusion **130** defines a second receiving portion **132** within the second protrusion **130** that is connected to the housing receiving space **112**.

[0016] The housing **100**, including the body **110** and the protrusions **120**, **130**, may be monolithically formed in a single piece from a housing material. In an embodiment, and as described in greater detail below, the housing **100** may be formed by additive manufacturing, for example by vat polymerization with the housing material as a photopolymer resin that is curable by light irradiation. In other embodiments, the housing **100** may be formed of any material used in ultrasonic applications and by any process that is capable of forming the components of the housing **100** described herein.

[0017] In the embodiment shown in FIGS. **1** and **2**A, the housing **100** has a cover **160**. The cover **160** may be formed of a same material as the body **110** and the protrusions **120**, **130**, but is formed separately from the body **110** and the protrusions **120**, **130**.

[0018] The transducer assemblies **200**, **200'** each have a transducer **210**, **210'**, a securing element **220**, **220'** attached to the transducer **210**, **210'**, and a backing **230**, **230'** disposed on a side of the transducer **210**, **210'** opposite the securing element **220**, **220'** in the propagating direction P, as shown in FIGS. **1**, **2**A, and **2**B. The components of the first transducer assembly **200** and the second transducer assembly **200'** are identical and, throughout the description, the same description applies to the same reference numbers used for both transducer assemblies **200**, **200'**. The components of the second transducer assembly **200'** have reference numbers with added apostrophes only for clarity in differentiating between the two transducer assemblies **200**, **200'**.

[0019] The transducer **210**, **210'** of each of the transducer assemblies **200**, **200'**, in the shown embodiment, is a piezoelectric crystal. In the shown embodiment, the transducer assembly **200** is an emitter, and the transducer **210** is capable of being electrically excited at its resonant frequency with an input voltage to emit an ultrasonic wave W. The transducer **210** can be any type of transducer that is capable of producing the ultrasonic wave W as described herein. The transducer assembly **200'** is a receiver in the shown embodiment, and the transducer **210'** is capable of receiving the ultrasonic wave W from the transducer **210** and producing an output voltage based on the received ultrasonic wave W. In other embodiments, the transducer assembly **200** is the receiver and the transducer assembly **200'** is the emitter.

[0020] The securing element **220**, **220'** of each of the transducer assemblies **200**, **200'**, shown in FIGS. 2A and 2B, may be any type of element or material that is capable of securing the transducers **210**, **210'** to the housing material of the housing **100**. In various exemplary embodiments, the securing element **220**, **220'** may be an adhesive, such as epoxy, acrylic, or polyurethane, and secures by adhesive attachment. In other embodiments, the securing element **220**, **220'** may be a conformal material or a viscous gel that secures by friction generated through compression.

[0021] The backing **230**, **230'** of each of the transducer assemblies **200**, **200**, shown in FIGS. **1**, 2A, and 2B, is an absorbing element **300** that provides acoustic damping for the transducer **210**, **210'**. In the embodiment of FIGS. **1**, 2A, and 2B, the backing **230**, **230'** acting as the absorbing element **300** is formed of a base material **302** with a bio-based additive **304** dispersed within the base material **302**, as shown schematically in FIG. **2**B.

[0022] The base material **302** is a polymer, such as a polyacrylate. In the embodiment described below in which the backing **230**, **230'** of each of the transducer assemblies **200**, **200** is formed by additive manufacturing, the base material **302** is a photopolymer resin that is curable by light irradiation.

[0023] The bio-based additive **304** is a biological or naturally occurring element that, when dispersed in the base material **302** and formed into the backing **230**, **230'**, enhances the acoustic damping for the transducer **210**, **210'** as described in greater detail below. In an embodiment, the bio-based additive **304** is cellulose. In other embodiments, the bio-based additive **304** may be wood flour, rice hulls, ground shells, or any other biological elements that can provide the damping function described herein. The bio-based additive **304**, in an embodiment, is at least 10% of the backing **230**, **230'** by volume and is less than or equal to 30% of the backing **230**, **230'** by volume.

[0024] The formation of the backing **230**, **230'** by additive manufacturing using a printer **700** is shown schematically in FIG. **4**. The printer **700** produces products by additive manufacturing, and in the shown embodiment is a vat photopolymerization printer. The printer **700** includes a vat **710** that contains the base material **302** in a liquid state mixed with the bio-based additive **304**. A plate **720** is movable into and out of the liquid contained in the vat **710**, and a light source **730** can selectively expose light **732** on various areas of the base material **302** and bio-based additive **304** mixture contained in the vat **710**. In this embodiment, the base material **302** is a photopolymer resin that is curable from the liquid state to a cured state by the light **732** irradiated by the light source **730**. The printer **700** may operate by stereolithography (SLA), digital light processing (DLP), continuous digital light processing (CDLP), or any other type of three-dimensional printing process that creates a product by sequentially curing a plurality of layers of a liquid material. In an embodiment, the base material **302** may require secondary curing of additional light irradiation and/or heat.

[0025] The printer **700** moves the plate **720** into and out of the vat **710** to progressively cure a series of layers of the base material **302** mixed with the bio-based additive **304**. The layers are attached to the plate **720** by a plurality of supports **740**. The layers are cured on top of one another until the backing **230**, **230'** serving as the absorbing element **300** is fully formed monolithically as schematically shown in FIG. **4**. The printer **700** shown in FIG. **4** is merely one exemplary embodiment of the printer **700**; the printer **700** may be of any type capable of forming the absorbing element **300** as described herein.

[0026] The assembly of the transducer assemblies **200**, **200'** in the housing **100** will now be described in greater detail primarily with reference to FIGS. **1-3**.

[0027] The transducer assemblies **200**, **200'** are each positioned in one of the receiving portions **122**, **132** of the housing **100**, as shown in FIGS. 2A, 2B, and **3**. The first transducer assembly **200** is positioned in the first receiving portion **122** of the first protrusion **120** and the second transducer assembly **200'** is positioned in the second receiving portion **132** of the second protrusion **130**.

[0028] As shown in FIGS. 2A and 2B, the securing element **220** is positioned between the transducer **210** of the first transducer assembly **200** and the first protrusion **120**, and the securing element **220'** is positioned between the transducer **210'** of the second transducer assembly **200'** and the second protrusion **130**. The securing element **220**, **220'** secures the transducer **210**, **210'** to the respective protrusion **120**, **130** of the housing **100**. In an embodiment in which the securing element **220**, **220'** is an adhesive, the securing element **220**, **220'** attaches the transducer **210**, **210'** to the housing **100**. In an embodiment in which the securing element **220**, **220'** is a compressive element, the securing element **220**, **220'** is compressed between the transducer **210**, **210'** and the housing **100** and secures the transducer **210**, **210'** by friction.

[0029] As shown in FIG. 2A, the securing element **220** secures the transducer **210** of the first transducer assembly **200** in the first receiving portion **122** of the first protrusion **120** and facing along the propagating direction P toward the channel **140**. The securing element **220'** secures the transducer **210'** of the second transducer assembly **200'** in the second receiving portion **132** of the second protrusion **130** and facing opposite to the propagating direction P, facing the channel **140** and the transducer **210** of the first transducer assembly **200**.

[0030] The backing **230**, **230'** formed as the absorbing element **300** is inserted into the receiving portion **122**, **132** of each of the protrusions **120**, **130** adjacent to one of the transducers **210**, **210'**, as shown in FIGS. 2A, 2B, and **3**. Printing the backing **230**, **230'** by additive manufacturing allows for precise control of an outer shape **232**, **232'** and dimensions of the backing **230**, **230'**. As shown schematically in FIGS. 2A and **3**, the size and outer shape **232**, **232'** of the backing **230**, **230'** can be adapted to fit precisely in the receiving portions **122**, **132**; the backing **230**, **230'** is printed with the outer shape **232**, **232'** that corresponds to a space between the transducer **210**, **210'** and the housing **100**, and is adaptable to the particular shape of and size of the receiving portions **122**, **132** of the housing **100**. The backing **230**, **230'** is dimensioned to have the transducer assembly **200**, **200'** fill the respective receiving portion **122**, **132**. The transducer **210**, **210'** of each of the transducer assemblies **200**, **200'** is positioned between the backing **230**, **230'** and the securing element **220**, **220'**. The backing **230**, **230'** abuts the transducer **210**, **210'** and forms an interference fit between the transducer **210**, **210'** and the housing **100**.

[0031] An assembly of a remainder of the ultrasonic sensor **10** shown in FIGS. **1** and 2A and the operation of the ultrasonic sensor **10** will now be described in greater detail.

[0032] The ultrasonic sensor **10** includes a printed circuit board (PCB) **400** that has a controller **500** and is connected to a connection line **600**, as shown schematically in FIGS. **1** and 2A. The controller **500** includes a processor **502** and a memory **504** connected to the processor **510**. The memory **504** is a non-transitory computer readable medium capable of storing program instructions thereon that are executable by the processor **502**. The processor **502** executes programs stored on the memory **504** to perform the functions of the controller **500** described herein.

[0033] As shown in FIG. **2**A, the PCB **400** with the controller **500** is positioned in the housing receiving space **112** of the body **110**. The cover **160** is positioned to enclose the housing receiving space **112** with a space for the connection line **600** to extend from the PCB **400** to an area external of the housing **100**. In the shown embodiment, the controller **500** receives power from a supply voltage **610** transmitted along the connection line **600**.

[0034] The controller **500**, as shown in FIG. **2**A, has an emitter connection line **510** connecting the controller **500** to the transducer **210** of the transducer assembly **200** that serves as the emitter, along which the controller **500**, by execution of the processor **502**, can transmit an input signal **512** to the transducer **210**. The controller **500** has a receiver connection line **520** connecting the controller **500** to the transducer **210'** of the transducer assembly **200'** that serves as the receiver, along which the controller **500**, by execution of the processor **502**, can receive an output signal **522** from the transducer **210'**.

[0035] During operation of the ultrasonic sensor **10**, the controller **500** outputs the input signal **512** to the transducer **210** along the emitter connection line **510**. The transducer **210** produces the ultrasonic wave W in accordance with the input signal **512**, which is emitted out from the transducer **210** in the propagation direction P toward the channel **140**. The ultrasonic wave W is received by the transducer **210'** after it passes through the channel **140**, and the transducer **210'** outputs the output signal **522** depending on the ultrasonic wave W along the receiver connection line **520** back to the controller **500**.

[0036] The ultrasonic wave W received at the transducer **210'** is impacted by refraction through elements positioned in the channel **140**. The controller **500** analyzes the output signal **522** to determine changes in the elements positioned in the channel **140**, which can be used for various detection applications. For example, if a fluid conduit is positioned in the channel **140**, the controller **500** can analyze the output signal **522** to determine a presence or an absence of a bubble in fluid that is transmitted along the fluid conduit. The controller **500** can output the results of the analysis of the output signal **522** via a signal voltage **620** transmitted along the connection line **600**.

[0037] The positioning of the backing **230**, **230'** acting as the absorbing element **300** adjacent to each of the transducers **210**, **210'** provides acoustic damping for the transducers **210**, **210'**, which improves the performance of the ultrasonic sensor **10** by increasing the bandwidth and decreasing ringing associated with the ultrasonic wave W. As shown in FIG. **5**, using different quantities of the bio-based additive **304** in the absorbing element **300** provides varying ultrasonic attenuation that improves the performance of the ultrasonic sensor **10**. The bio-based additive **304** included as at least 10% of the backing **230**, **230'** by volume provides at least approximately 2 dB/mm of relative attenuation for the ultrasonic wave W.

[0038] In another embodiment, additional and/or alternative parts of the ultrasonic sensor **10** may be formed of the absorbing element **300** having the base material **302** with the bio-based additive **304** dispersed within the base material **302**.

[0039] As shown in FIG. **2**A, in an embodiment, the housing **100** has a first section **152** and a second section **154** formed monolithically with the first section **152**. The first section **152** extends along the first protrusion **120** and the second protrusion **130**, and the second section **154** forms the body **110** of the housing **100**. In this embodiment, the first section **152** of the housing **100** is formed as the absorbing element **300**; the housing material is the base material **302** and the bio-based additive **304** is dispersed within the base material **302** of the housing **100** in the first section **152**. In this embodiment, the second section **154** of the housing **100** does not have the bio-based additive **304** and is not formed as the absorbing element **300**.

[0040] The housing **100** in the embodiment with the first section **152** and the second section **154** may be formed by additive manufacturing, using the printer **700** as described above with respect to FIG. **4**. In this embodiment, the second section **154** is printed first with only the base material **302** in the vat **710**, then the base material **302** is mixed with the bio-based additive **304** prior to printing the remaining layers of the first section **152** on the second section **154**.

[0041] The first section **152** of the housing **100** formed as the absorbing element **300** provides attenuation and acoustic damping benefits as described above with respect to the backing **230**, **230'**. As shown in FIG. **2**A, the first section **152** of the housing **100** can be formed as the absorbing element **300** with the bio-based additive **304** and the backing **230**, **230'** of the transducer assemblies **200**, **200'** can also be formed as the absorbing element **300** with the bio-based additive **304** in the same embodiment. In another embodiment, the housing **100** is formed of only one material and does not have the first section **152** formed as the absorbing element **300**; in this embodiment, the backing **230**, **230'** is the only absorbing element **300**. In a further embodiment, the first section **152** of the housing **100** is the only absorbing element **300**; in this embodiment, the backing **230**, **230'** is formed as another type of acoustic damping material, such as foam, an epoxy filled with a tungsten powder, or any other type of acoustic damping material that provides damping for ultrasonic applications.

[0042] In the embodiments of the ultrasonic sensor **10** described above, the absorbing element **300**, formed as the backing **230**, **230'** and/or the first section **152** of the housing

100, provides acoustic damping that improves the emission and reception of the ultrasonic wave W by the transducers **210**, **210'**, which improves the accuracy and reliability of the ultrasonic sensor **10**. Forming the absorbing element **300** by additive manufacturing allows for easier positioning of the transducers **210**, **210'** adjacent to the absorbing element **300**. The backing **230**, **230'** formed as the absorbing element **300** by additive manufacturing further allows for precise fitting of the backing **230**, **230'** into spaces of the housing **100** that may require complex shapes.

What is claimed is:

1. A transducer assembly, comprising:

a transducer emitting or receiving an ultrasonic wave; and

a backing adjacent to the transducer, the backing is an absorbing element that provides acoustic damping for the transducer, the backing is formed of a base material with a bio-based additive dispersed within the base material.

2. The transducer assembly of claim **1**, wherein the backing abuts the transducer.

3. The transducer assembly of claim **1**, wherein the bio-based additive is cellulose.

4. The transducer assembly of claim **1**, wherein the bio-based additive is at least 10% of the backing by volume.

5. The transducer assembly of claim **4**, wherein the bio-based additive is less than or equal to 30% of the backing by volume.

6. The transducer assembly of claim **1**, further comprising a securing element, the transducer is positioned between the backing and the securing element.

7. The transducer assembly of claim **1**, wherein the transducer is a piezoelectric crystal.

8. An ultrasonic sensor, comprising:

a housing; and

a transducer assembly positioned in the housing, the transducer assembly includes a transducer and a backing adjacent to the transducer, the backing and/or a portion of the housing is an absorbing element that provides acoustic damping for the transducer, the absorbing element is formed of a base material with a bio-based additive dispersed within the base material.

9. The ultrasonic sensor of claim **8**, wherein the transducer assembly includes a securing element positioned between the transducer and the housing, the securing element secures the transducer to the housing.

10. The ultrasonic sensor of claim **8**, wherein the housing has a body, a first protrusion extending from the body, a second protrusion extending from the body, and a channel positioned between the first protrusion and the second protrusion.

11. The ultrasonic sensor of claim **10**, wherein the transducer assembly is one of a pair of transducer assemblies, one of the transducer assemblies is positioned in a first receiving portion of the first protrusion and the other of the transducer assemblies is positioned in a second receiving portion of the second protrusion.

12. The ultrasonic sensor of claim **10**, wherein the housing has a first section and a second section formed monolithically with the first section, the first section is the only portion of the housing formed as the absorbing element.

13. The ultrasonic sensor of claim **12**, wherein the first section extends along the first protrusion and the second protrusion.

14. A process for manufacturing an ultrasonic sensor, comprising:

printing an absorbing element by additive manufacturing; and

positioning the absorbing element adjacent to a transducer that emits an ultrasonic wave, the absorbing element provides acoustic damping for the transducer.

15. The process of claim **14**, wherein the absorbing element is printed of a base material with a bio-based additive dispersed within the base material.

16. The process of claim **15**, wherein the base material is a photopolymer resin that is curable by light irradiation.

17. The process of claim **14**, wherein the absorbing element is a portion of a housing, the positioning step includes inserting the transducer into the housing.

18. The process of claim **14**, wherein the absorbing element is a backing that is inserted into a housing adjacent to the transducer.

19. The process of claim **18**, wherein the backing is interference fit between the transducer and the housing.

20. The process of claim **18**, wherein the backing is printed with an outer shape corresponding to a space between the transducer and the housing.

* * * * *