(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 068 803 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
05.10.2022 Bulletin 2022/40

(21) Application number: **20892453.0**

(22) Date of filing: **13.11.2020**

(51) International Patent Classification (IPC):
H04R 7/02 *(2006.01)* ***H04R 31/00*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
H04R 7/02; H04R 31/00

(86) International application number:
PCT/JP2020/042412

(87) International publication number:
WO 2021/106628 (03.06.2021 Gazette 2021/22)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **26.11.2019 JP 2019213495**

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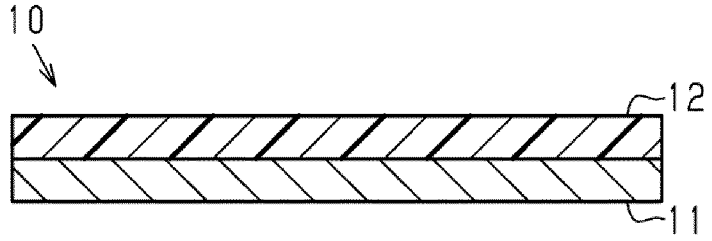
(54) **ACOUSTIC VIBRATION PLATE AND METHOD FOR MANUFACTURING ACOUSTIC VIBRATION PLATE**

(57) An acoustic vibration plate 10 is provided with a metal foil 11 and a thermoplastic resin film 12 laminated on the metal foil 11. The ratio of a linear coefficient of expansion CTEZ in the thickness direction to a linear coefficient of expansion CTEX of the thermoplastic resin film 12, or CTEZ/CTEX, is 3.0 to 10.0 inclusive. The total of the basis weights of the metal foil 11 and the thermoplastic resin film 12 is 45 g/m^2 to 150 g/m^2 inclusive.

Fig. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to an acoustic diaphragm and a method for manufacturing an acoustic diaphragm.

BACKGROUND ART

[0002] A known acoustic diaphragm for use with an audio device such as a speaker or a sonar sensor includes a laminate in which a metal foil and a thermoplastic resin are laminated.
[0003] Patent Literature 1 discloses an acoustic diaphragm that is obtained by laminating and thermocompression-bonding an aluminum foil and a cast unoriented thermoplastic resin film. Examples of the cast unoriented thermoplastic resin film used in Patent Literature 1 include a polyurethane-based thermoplastic resin film, a polyamide-based thermoplastic resin film, and a polyester-based thermoplastic resin film.

CITATION LIST

Patent Literature

[0004] Patent Literature 1: Japanese Patent No. 3911935

SUMMARY OF INVENTION

Technical Problem

[0005] The acoustic diaphragm of Patent Literature 1 is manufactured through a lamination process in which an aluminum foil and a cast unoriented thermoplastic resin film placed one upon the other are heated to a temperature near the melting temperature of the cast unoriented thermoplastic resin film, and the cast unoriented thermoplastic resin film is pressure-bonded to the aluminum foil. The aluminum foil and the cast unoriented thermoplastic resin film of the acoustic diaphragm have different coefficients of thermal expansion. Thus, the acoustic diaphragm obtained through the lamination process will warp greatly. Warping of the acoustic diaphragm adversely affects workability when shaping the acoustic diaphragm into the form of a speaker or the like.
[0006] Accordingly, one objective of the present invention is to provide an acoustic diaphragm that resists warping.

Solution to Problem

[0007] An acoustic diaphragm that solves the above problem includes a metal foil and a thermoplastic resin film laminated on the metal foil. The thermoplastic resin film has a ratio of a coefficient of linear thermal expansion in a thickness-wise direction to a smaller one of a coefficient of linear thermal expansion in an MD-direction and a coefficient of linear thermal expansion in a TD-direction that is between 3.0 and 10.0. A total weight per unit area of the metal foil and the thermoplastic resin film is between 45 g/m^2 and 150 g/m^2.
[0008] In some embodiments, the metal foil may have a specific gravity of between 1.7 and 5.0.
[0009] In some embodiments, a difference between a coefficient of linear thermal expansion of the metal foil and the smaller one of the coefficient of linear thermal expansion in the MD-direction and the coefficient of linear thermal expansion in the TD-direction of the thermoplastic resin film may be between 0 ppm/K and 15 ppm/K.
[0010] In some embodiments, the coefficient of linear thermal expansion of the metal foil may be between 5.0 ppm/K and 35 ppm/K.
[0011] In some embodiments, the smaller one of the coefficient of linear thermal expansion in the MD-direction and the coefficient of linear thermal expansion in the TD-direction may be between 10 ppm/K and 50 ppm/K.
[0012] In some embodiments, the thermoplastic resin film may include at least one polyimide film adjoining the metal foil.
[0013] A method for manufacturing an acoustic diaphragm that solves the above problem includes a lamination process that thermocompression-bonds the metal foil and the thermoplastic resin film. Advantageous Effects of Invention
[0014] The acoustic diaphragm in accordance with the present invention resists warping.

BRIEF DESCRIPTION OF DRAWINGS

[0015]

Fig. 1 is a cross-sectional view of an acoustic diaphragm according to an embodiment.
Fig. 2 is a cross-sectional view of an acoustic diaphragm in a modified example.
Fig. 3 is a cross-sectional view of an acoustic diaphragm in another modified example.

DESCRIPTION OF EMBODIMENT

[0016] An embodiment of the present invention will now be described.

[0017] As shown in Fig. 1, an acoustic diaphragm 10 is a laminate of a sheet-like metal foil 11 and a thermoplastic resin film 12 that is disposed on one side of the sheet-like metal foil 11. The acoustic diaphragm 10 is used in an audio device as a transducer for acoustic oscillation. The acoustic diaphragm 10 is used in an audio device such as a speaker, a sonar sensor, and a microphone.

Metal Foil

[0018] Examples of the metal forming the metal foil 11 include aluminum, titanium, magnesium, copper, and an alloy combining two or more of the above metals. In these metals, a metal having a specific gravity of between 1.7 and 5.0 is preferred, and a metal having a specific gravity of between 2.4 and 4.9 is further preferred. This improves the sound quality when the acoustic diaphragm 10 is applied to a speaker.

[0019] Preferably, the metal foil 11 has a coefficient of linear thermal expansion CTEM of, for example, between 5.0 ppm/K and 35 ppm/K, more preferably between 7.0 ppm/K and 30 ppm/K, and further preferably between 8.0 ppm/K and 28 ppm/K. When the coefficient of linear thermal expansion CTEM of the metal foil 11 is set within the above-described ranges, the difference is decreased between the coefficient of linear thermal expansion CTEM of the metal foil 11 and the coefficient of linear thermal expansion of the thermoplastic resin film 12. This effectively limits warping in the acoustic diaphragm 10 caused by the difference in coefficient of linear thermal expansion.

[0020] Preferably, the metal foil 11 has a thickness of, for example, between 10 μm and 50 μm, and more preferably between 14 μm and 35 μm.

[0021] Preferably, the weight per unit area of the metal foil 11 is, for example, between 27 g/m^2 and 130 g/m^2, and more preferably between 37 g/m^2 and 90 g/m^2.

Thermoplastic Resin Film

[0022] Specific examples of the thermoplastic resin film 12 include a polyimide film such as a multilayer aromatic polyimide film or a single-layer polyimide film, a polyetherimide film, a polyester film (including liquid crystal film), a polyamide film (including aramid film), a vinyl ester film, a thermoplastic fluorine resin film, a polyetherketone film (including polyetheretherketone film), a polyphenylsulfone film, and the like. A multilayer aromatic polyimide film includes a layer of polyimide that has a thermocompression bonding property disposed on both sides of an aromatic polyimide film that does not have a pressure-bonding property. For example, a commercially available product such as UPILEX VT™ manufactured by UBE INDUSTRIES, LTD. can be used. Japanese Laid-Open Patent Publication No. 2001-270033 discloses examples of such multilayer aromatic polyimide film. Among them, a polyimide film is particularly preferably used as the thermoplastic resin film 12.

[0023] The thermoplastic resin film 12 may include another component such as an additive.

[0024] The thermoplastic resin film 12 may be a resin having voids such as a foamed body.

[0025] The thermoplastic resin film 12 may have a structure combined with a non-thermoplastic resin film as long as the thermoplastic resin film 12 is adherable to the metal foil 11 without impairing the audio characteristics and the effects of the invention. For example, the thermoplastic resin film 12 may have a multilayer structure in which the thermoplastic resin film 12 is adhered to one side or both sides of the non-thermoplastic resin film. Alternatively, the thermoplastic resin film 12 may have a sea-island structure in which the thermoplastic resin film 12 forms a sea component and the non-thermoplastic resin film forms an island component.

[0026] The thermoplastic resin film 12 has a ratio CTEZ/CTEX of between 3.0 and 10.0. The ratio CTEZ/CTEX is a ratio of a coefficient of linear thermal expansion CTEZ in a thickness-wise direction to a coefficient of linear thermal expansion CTEX of the smaller one of the coefficient of linear thermal expansion in an MD-direction and the coefficient of linear thermal expansion in a TD-direction. Further, it is preferred that the ratio CTEZ/CTEX be between 4.0 and 9.5, and more preferably between 5.0 and 9.0.

[0027] When the ratio CTEZ/CTEX is 3.0 or greater, molecules in the thermoplastic resin film 12 are oriented in a planar direction at a specific level or greater. This limits warping of the acoustic diaphragm 10. Also, when the ratio CTEZ/CTEX is 10.0 or less, the thermoplastic resin film 12 will be stretchable in the planar direction without lowering resistance against shearing in the planar direction. This improves the workability of the acoustic diaphragm 10. For example, the acoustic diaphragm 10 can easily be drawn into a predetermined shape such as the shape of a dome.

[0028] Preferably, the coefficient of linear thermal expansion CTEX of the thermoplastic resin film 12 is, for example, between 10 ppm/K and 50 ppm/K, more preferably between 12 ppm/K and 43 ppm/K, and further preferably between 14 ppm/K and 35 ppm/K. When the coefficient of linear thermal expansion CTEX is set within the above-described ranges, the thermoplastic resin film 12 is stretchable in the planar direction so that the workability of the acoustic diaphragm 10 is improved.
[0029] Preferably, the thermoplastic resin film 12 has a thickness of, for example, between 12 μm and 90 μm, and more preferably between 16 μm and 75 μm.
[0030] Preferably, the thermoplastic resin film 12 has a weight per unit area of, for example, between 18 g/m^2 and 120 g/m^2, and more preferably between 22 /m^2 and 100 g/m^2.

Acoustic Diaphragm

[0031] Preferably, in the acoustic diaphragm 10, the difference CTEX-M (absolute difference) between the coefficient of linear thermal expansion CTEX of the thermoplastic resin film 12 and the coefficient of linear thermal expansion CTEM of the metal foil 11 is between 0 ppm/K and 15 ppm/K, and more preferably between 0 ppm/K and 12 ppm/K. When the difference CTEX-M is set within the above-described ranges, warping of the acoustic diaphragm 10 is effectively limited.
[0032] Preferably, the acoustic diaphragm 10 has a thickness of, for example, between 22 μm and 100 μm, and more preferably between 25 μm and 85 μm.
[0033] Preferably, the weight per unit area of the acoustic diaphragm 10, that is, the total weight per unit area of the metal foil 11 and the thermoplastic resin film 12, is between 45 g/m^2 and 150 g/m^2, and preferably between 45 g/m^2 and 130 g/m^2. When the weight per unit area of the acoustic diaphragm 10 is set within the above-described ranges, warping of the acoustic diaphragm 10 is limited. Also, when the weight per unit area of the acoustic diaphragm 10 is 150 g/m^2 or less, the sound pressure will not be reduced by the weight. When the weight per unit area of the acoustic diaphragm 10 is 45 g/m^2 or greater, the acoustic diaphragm 10 becomes more rigid so that the acoustic diaphragm 10 can easily obtain a self-supporting property even when used in an audio device such as a large speaker.
[0034] Preferably, the acoustic diaphragm 10 has a resin ratio, or the volume percent of the thermoplastic resin film 12 to the total volume of the metal foil 11 and the thermoplastic resin film 12, that is 60% or less, and more preferably 40% or less. When the thermoplastic resin film 12 is set within the above-described ranges of the resin ratio, warping of the acoustic diaphragm 10 is effectively limited. Also, when the acoustic diaphragm 10 is applied to a speaker, the acoustic diaphragm 10 can achieve both the reduction of warping and the improvement of the sound quality at a high level. The lower limit of the resin ratio of the thermoplastic resin film 12 is, for example, 10%.
[0035] Preferably, the adhesion strength between the metal foil 11 and the thermoplastic resin film 12 in the acoustic diaphragm 10 is, for example, 0.4 N/mm or greater. This avoids delamination of the acoustic diaphragm 10 when shaped into a predetermined form.
[0036] Preferably, internal loss tanδ of the acoustic diaphragm 10 is between 0.02 and 0.08. This improves the sound quality in high-frequency and low-frequency ranges when the acoustic diaphragm 10 is applied to a speaker.
[0037] The acoustic diaphragm 10 is shaped into a predetermined form such as a flat plate shape or a dome-like shape depending on the intended use and used in an audio device.
[0038] The acoustic diaphragm 10 is manufactured through, for example, a lamination process in which the metal foil 11 and the thermoplastic resin film 12 are placed one upon the other and thermocompression-bonded. The method used for the thermocompression-bonding in the lamination process is not limited and may be, for example, a known method using a roller-type lamination apparatus, a double belt press machine, or the like.
[0039] The present embodiment has the following advantages.

(1) The acoustic diaphragm 10 includes the metal foil 11 and the thermoplastic resin film 12 laminated on the metal foil 11. The ratio CTEZ/CTEX, which is a ratio of the coefficient of linear thermal expansion CTEZ in the thickness-wise direction to the coefficient of linear thermal expansion CTEX of the thermoplastic resin film 12 is between 3.0 and 10.0. The total weight per unit area of the metal foil 11 and the thermoplastic resin film 12 is between 45 g/m^2 and 150 g/m^2.
This structure minimizes warping in the acoustic diaphragm 10 so that the workability of the acoustic diaphragm 10 is improved.
(2) The specific gravity of the metal foil 11 is between 1.7 and 5.0.
This structure improves the sound quality when the acoustic diaphragm 10 is used in a speaker.
(3) The difference CTEX-M between the coefficient of linear thermal expansion CTEX of the thermoplastic resin film 12 and the coefficient of linear thermal expansion CTEM of the metal foil 11 is between 0 ppm/K and 15 ppm/K.
This structure significantly limits warping in the acoustic diaphragm 10.
(4) The coefficient of linear thermal expansion CTEM of the metal foil 11 is between 5.0 ppm/K and 35 ppm/K.
With this structure, the difference CTEX-M between the coefficient of linear thermal expansion CTEX of the ther-

moplastic resin film 12 and the coefficient of linear thermal expansion CTEM of the metal foil 11 is easily set within the above-described range.

(5) The coefficient of linear thermal expansion CTEX of the thermoplastic resin film 12 is between 10 ppm/K and 50 ppm/K.

With this structure, the acoustic diaphragm 10 is stretchable in the planar direction so that the workability of the acoustic diaphragm 10 is improved.

(6) The resin ratio of the acoustic diaphragm 10 is 40% or less.

This structure significantly limits warping in the acoustic diaphragm 10 and further improves the sound quality when the acoustic diaphragm 10 is applied to a speaker.

(7) The thermoplastic resin film 12 is a polyimide film.

This structure significantly limits warping in the acoustic diaphragm 10.

(8) The method for manufacturing the acoustic diaphragm 10 includes the lamination process in which the metal foil 11 and the thermoplastic resin film 12 are thermocompression-bonded.

[0040] This method allows for manufacture of the acoustic diaphragm 10 that resists warping.

[0041] The present embodiment may be modified as follows. The present embodiment and the following modifications can be combined as long as the combined modifications remain technically consistent with each other.

[0042] The number of layers of the metal foil 11 forming the acoustic diaphragm 10 is not limited to one. Alternatively, the acoustic diaphragm 10 may include two or more layers of the metal foil 11.

[0043] Fig. 2 shows an example in which the acoustic diaphragm 10 includes a first metal foil 11a, the thermoplastic resin film 12, and a second metal foil 11b that are laminated in order from one side in a lamination direction. That is, the thermoplastic resin film 12 is located between the first metal foil 11a and the second metal foil 11b. In this case, warping in the acoustic diaphragm 10 is significantly limited.

[0044] When the acoustic diaphragm 10 includes two or more metal foils 11, the acoustic diaphragm 10 may have a part where the metal foils 11 are successively laminated without an intervening layer in the lamination direction. The metal foils 11 may all be the same or different.

[0045] The number of layers of the thermoplastic resin film 12 forming the acoustic diaphragm 10 is not limited to one. Alternatively, the acoustic diaphragm 10 may include two or more layers of the thermoplastic resin film 12.

[0046] Fig. 3 shows an example in which the acoustic diaphragm 10 includes a first thermoplastic resin film 12a, the metal foil 11, and a second thermoplastic resin film 12b that are laminated in order from one side in a lamination direction. That is, the first thermoplastic resin film 12a and the second thermoplastic resin film 12b are laminated on the two sides of the metal foil 11, respectively. In this case, warping in the acoustic diaphragm 10 is significantly limited.

[0047] When the acoustic diaphragm 10 includes two or more thermoplastic resin films 12, the acoustic diaphragm 10 may include a part where the thermoplastic resin films 12 are successively laminated without an intervening layer in the lamination direction. The thermoplastic resin films 12 may all be the same or different.

[0048] When two or more thermoplastic resin films 12 are included, it is preferred that at least one thermoplastic resin film 12 that is in contact with the metal foil 11 be a polyimide film. In this case, the above-mentioned advantage (7) is obtained.

[0049] The acoustic diaphragm 10 may include another layer, such as a protection layer, other than the metal foil 11 and the thermoplastic resin film 12.

[0050] Technical concepts that can be understood from the above embodiment and the modified examples will be described hereafter.

(a) The acoustic diaphragm in which the thermoplastic resin film accounts for 40% or less in volume percent of a total volume of the metal foil and the thermoplastic resin film.

(b) The acoustic diaphragm in which the thermoplastic resin film includes a first thermoplastic resin film and a second thermoplastic resin film respectively laminated on two sides of the metal foil.

(c) The acoustic diaphragm in which the metal foil includes a first metal foil and a second metal foil, and the thermoplastic resin film is laminated between the first metal foil and the second metal foil.

Examples

[0051] The present embodiment will now be described in detail with reference to examples and comparative examples.

[0052] Hereinafter, the difference CTEX-M between the coefficient of linear thermal expansion CTEX of the thermoplastic resin film and the coefficient of linear thermal expansion CTEM of the metal foil in the acoustic diaphragm will be referred to as "CTE-difference".

Test 1

Example 1

[0053] An acoustic diaphragm of Example 1 was obtained by laminating and thermocompression-bonding an aluminum foil AL (type: 1N30) having a thickness of 20 μm and a polyimide film PI (UPILEX VT manufactured by UBE INDUSTRIES, LTD.) having a thickness of 25 μm with a double belt press machine. Table 1 shows the specific gravity and the coefficient of linear thermal expansion CTEM of the metal foil and the coefficients of linear thermal expansion CTEX, CTEZ and the weight per unit area of the thermoplastic resin film, which were used in the acoustic diaphragm of Example 1. Table 2 shows CTE-difference, weight per unit area, and resin ratio of the acoustic diaphragm of Example 1.

[0054] The coefficient of linear thermal expansion CTEX and the coefficient of linear thermal expansion CTEZ of the thermoplastic resin film and the coefficient of linear thermal expansion CTEM of the metal foil were measured as described below.

Measurement of Coefficient of Linear Thermal Expansion CTEX

[0055] Samples were cut out from the thermoplastic resin film and preprocessed by heating at 300°C for thirty minutes. The heat-processed samples were set in a thermal mechanical analysis (TMA) apparatus (TMA-Q400 manufactured by TA Instruments), and the temperature was increased at a rate of 10°C /min to measure the thermal expansion amount from 50°C to 200°C and calculate the coefficient of linear thermal expansion. The samples were collected from two locations on the thermoplastic resin film in MD-direction and TD-direction, and the smaller measurement value of the two samples was defined as the coefficient of linear thermal expansion CTEX.

Measurement of Coefficient of Linear Thermal Expansion CTEZ

[0056] A sample was cut out from the thermoplastic resin film and set on a thermal dilatometer that uses laser interferometry (laser thermal dilatometer L1X-1 manufactured by ULVAC-RIKO). Preprocessing of the samples was performed by increasing the temperature to 300°C, holding the temperature for five minutes, and then lowering the temperature to room temperature. Subsequently, the temperature was increased at a rate of 2°C /min to measure the thermal expansion amount from 50°C to 200°C and calculate the coefficient of linear thermal expansion CTEZ.

Measurement of Coefficient of Linear Thermal Expansion CTEM

[0057] Samples were cut out from the metal foil and preprocessed by heating at 300°C for thirty minutes. The heat-treated samples were set on a thermal mechanical analysis (TMA) apparatus (TMA-Q400 manufactured by TA Instruments), and the temperature was increased at a rate of 10°C /min to measure the thermal expansion amount from 50°C to 200°C and calculate the coefficient of linear thermal expansion. The samples were collected from two locations on the metal foil in MD-direction and TD-direction, and the smaller measurement value of the two samples was defined as the coefficient of linear thermal expansion CTEM.

Example 2

[0058] An aluminum foil AL (5052) having a thickness of 20 μm was used as the metal foil. Otherwise, the conditions were the same as Example 1.

Example 3

[0059] A titanium foil having a thickness of 20 μm was used as the metal foil. A polyimide foil PI having a thickness of 12.5 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Comparative Example 1

[0060] An aluminum foil AL (1N30) having a thickness of 30 μm was used as an acoustic diaphragm of Comparative Example 1.

Comparative Example 2

[0061] An aluminum foil AL (5052) having a thickness of 30 μm was used as an acoustic diaphragm of Comparative

Example 2.

Comparative Example 3

[0062] A titanium foil having a thickness of 20 μm was used as an acoustic diaphragm of Comparative Example 3.

Comparative Example 4

[0063] A titanium foil having a thickness of 25 μm was used as an acoustic diaphragm of Comparative Example 4.

Comparative Example 5

[0064] A magnesium alloy foil (AZ31B) having a thickness of 44 μm was used as an acoustic diaphragm of Comparative Example 5.

Comparative Example 6

[0065] A thermoplastic resin film was formed by stacking a first polyimide film PI (UPILEX VT manufactured by UBE INDUSTRIES, LTD.) having a thickness of 25 μm and a second polyimide film PI (UPILEX VT manufactured by UBE INDUSTRIES, LTD.) having a thickness of 50 μm, in this order, and thermocompression-bonding them using a double belt press machine. The thermoplastic resin film thus obtained was used as an acoustic diaphragm of Comparative Example 6. In Table 1, the numerical values in the columns headed "Thermoplastic Resin Film" were obtained from the thermoplastic resin films after the thermocompression-bonding. The ratio CTEZ/CTEX for the coefficient of linear thermal expansion CTEZ of the first polyimide film PI was 5.3, and the ratio CTEZ/CTEX for the coefficient of linear thermal expansion CTEZ of the second polyimide film PI was 6.1.

Comparative Example 7

[0066] A thermoplastic resin film was formed by stacking an aluminum foil AL (1N30) having a thickness of 20 μm, a first polyimide film PI having a thickness of 25 μm, and a second polyimide film PI having a thickness of 50 μm, in this order, and thermocompression-bonding them using a double belt press machine. The thermoplastic resin film thus obtained was used as an acoustic diaphragm of Comparative Example 7.

Comparative Example 8

[0067] An aluminum foil AL (1N30) having a thickness of 6 μm was used as the metal foil, and a polyimide film PI having a thickness of 12.5 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Comparative Example 9

[0068] A polyethylene terephthalate film PET having a thickness of 25 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Warping Evaluation

[0069] Warping in the acoustic diaphragm of each example and comparative example was evaluated.

[0070] A sample having a size of 10 cm in length ×10 cm in width was cut out from the acoustic diaphragm of each example and comparative example and left to rest under the environment of 23°C and 65%RH for at least twenty-four hours to allow the sample to warp. Then, the warped sample was set on a level bench top such that the inwardly curved surface faces the upward direction. The raised height of the sample was measured at the most raised part of the sample from the bench top to evaluate warping in the acoustic diaphragm using the following indices. The results are shown in Table 2.

A: The raised height is less than 2 mm.
B: The raised height is greater than or equal to 2 mm and less than 5 mm.
C: The raised heighted is greater than or equal to 5 mm and less than 10 mm.
D: The raised height is greater than or equal to 10 mm or the sample is curled into a tubular shape.

Workability Evaluation

[0071] Workability of the acoustic diaphragm of each example and comparative example was evaluated.

[0072] The acoustic diaphragm of examples and comparative examples each underwent ten operations in which the sheet-like acoustic diaphragm was processed with a die to be dome-shaped. The number of processing defects that occurred during the ten operations was counted to evaluate the workability of the acoustic diaphragm using the following indices. The results are shown in Table 2.

A: The acoustic diaphragm was easy to set on the die, and there was no defect.
B: The acoustic diaphragm as was difficult to set on the die, but there was no defect.
C: There was one or more defects.
D: The acoustic diaphragm was not able to be processed.

Sound Quality Evaluation

[0073] Speakers were produced by attaching a voice coil to the back surface of the acoustic diaphragm of each example and comparative example, which was dome-shaped and had a diameter of 34 mm. Five panelists listened to the sounds output from the produced speakers and evaluated the sound quality of the acoustic diaphragm using the following indices. The results are shown in Table 2. The sound quality evaluation was omitted for the acoustic diaphragm that could not be processed.

A: Five panelists determined that the sound quality is desirable.
B: Four panelists determined that the sound quality is desirable.
C: Three panelists determined that the sound quality is desirable.
D: Two or less panelists determined that the sound quality is desirable.

[0074] Further, a dynamic viscoelasticity measurement apparatus was used to measure the internal loss tanδ of the acoustic diaphragm of each example and comparative example at 25°C and 100Hz. The results are shown in Table 2.

Adhesiveness Evaluation

[0075] Adhesiveness in the acoustic diaphragm of each of the examples and comparative examples 7 to 9 was evaluated.

[0076] Strips of sample having the size of 1 cm in width $\times$ 20 cm in length were prepared for MD-direction and TD-direction from the acoustic diaphragm of each of the examples and Comparative Examples 7 to 9. Then, the adhesiveness was evaluated using the 90°-delamination method as described in JIS C 6471. Evaluation was conducted three times in MD-direction and TD-direction, and the smallest value of the results was defined as the adhesiveness in the diaphragm.

Long-Term Reliability Evaluation

[0077] Long-term reliability was evaluated with the acoustic diaphragm of each of the examples and Comparative Examples 7 to 9.

[0078] A heat-cycle test was conducted on the acoustic diaphragm of each of the examples and Comparative Examples 7 to 9 under a condition of the temperature cycle described below. Subsequently, the adhesiveness was evaluated using the same method as the above adhesiveness evaluation.

[0079] In the heat cycle test condition, the temperature was held at -50°C for ten minutes and then the temperature was increased to 150°C in two hours. Then, the temperature was held at 150°C for ten minutes and then decreased to -50°C in two hours. This cycle was repeated 3000 times.

Table 1

	Composition	Metal Foil			Thermoplastic Resin Film			
		Specific Gravity	CTEM (ppm/K)	Weight Per Unit Area (g/m^2)	CTEX (ppm/K)	CTEZ (ppm/K)	CTEZ/X	Weight Per Unit Area (g/m^2)
Example 1	AL(1N30)/PI = 20/25	2.7	27	54	19	101	5.3	36
Example 2	AL(5052)/PI = 20/25	2.7	27	54	19	101	5.3	36
Example 3	Ti/PI = 20/12.5	4.5	8.4	90	22	121	5.5	18
Comparative Ex. 1	AL(1N30) = 30	2.7	27	81	-			
Comparative Ex. 2	AL(5052) = 30	2.7	27	81	-			
Comparative Ex. 3	Ti = 20	4.5	8.4	90	-			
Comparative Ex. 4	Ti = 25	4.5	8.4	113	-			
Comparative Ex. 5	Mg(AZ31B)= 44	1.8	26	79	-			
Comparative Ex. 6	PI = 75	-			19	110	5.8	99.4
Comparative Ex. 7	AL(1N30)/PI = 20/75	2.7	27	54	18	104	5.8	107
Comparative Ex. 8	AL(1N30)/PI = 6/12.5	2.7	27	16	22	121	5.5	18
Comparative Ex. 9	AL(1N30) /PET = 20/25	2.7	27	54	60	120	2	34

Table 2

	Acoustic Diaphragm			Evaluation					
	CTE-Difference	Weight Per Unit Area (g/m^2)	Resin Rate (%)	Warping	Workability	Sound Quality	$\tan\delta$	Adhesiveness (N/mm)	Long-Term Reliability Post Heat Cycle Adhesiveness (N/mm)
Example 1	8	90	56	B	A	B	0.048	0.80	0.72
Example 2	8	90	56	C	A	C	0.032	1.02	0.85
Example 3	13.6	109	38	B	A	C	0.034	0.55	0.35
Comparative Ex. 1	-	81	0	A	A	D	0.040	-	-
Comparative Ex. 2	-	81	0	A	A	D	0.038	-	-
Comparative Ex. 3	-	90	0	A	A	D	0.036	-	-
Comparative Ex. 4	-	113	0	A	A	D	0.038	-	-
Comparative Ex. 5	-	79	0	A	A	D	0.030	-	-
Comparative Ex. 6	-	99.4	100	A	A	D	0.060	-	-
Comparative Ex. 7	9	161	79	D	B	D	0.050	0.80	0.62
Comparative Ex. 8	5	34	68	D	D	-	-	0.41	0.35
Comparative Ex. 9	33	88	56	D	D	-	-	0.20	0.05

[0080] As shown in Tables 1 and 2, warping did not occur in the acoustic diaphragm of Comparative Examples 1 to 6, which were formed of only one of a metal foil and a thermoplastic resin film. Warping occurred greatly in the acoustic diaphragm of Comparative Examples 7 to 9, which were formed by laminating a metal foil and a thermoplastic resin film. Further, the acoustic diaphragm of Comparative Examples 7 to 9 had a poor workability or could not be processed.

[0081] In the acoustic diaphragm of Examples 1 to 3, in which the ratio CTEZ/CTEX of the coefficient of linear thermal expansion CTEZ of the thermoplastic resin film was between 3.0 and 10.0 and the total weight per unit area was between 45 g/m^2 and 150 g/m^2, significant warping did not occur even though the acoustic diaphragm was formed by laminating the metal foil and the thermoplastic resin film. Further, the acoustic diaphragm of Examples 1 to 3 were easy to process and did not yield any defects.

[0082] The evaluation results of the sound quality, adhesiveness, and long-term reliability indicate that the acoustic diaphragm of Examples 1 to 3 are applicable as an acoustic diaphragm for a speaker. Although the details are not described, frequency characteristics measured for the acoustic diaphragm of Examples 1 to 3 indicated that a desirable sound pressure reproduction performance was obtained throughout all frequencies.

Test 2

[0083] As shown in Table 3, the acoustic diaphragms of Examples 4 to 8 were produced each having different thickness and different arrangement of the metal foil and the thermoplastic resin film. Then, various evaluations were conducted in the same manner as Test 1. The results are shown in Table 4.

Example 4

[0084] A polyimide foil PI having a thickness of 12.5 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Example 5

[0085] An aluminum foil AL (1N30) having a thickness of 12 μm was used as the metal foil, and a polyimide film PI having a thickness of 12.5 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Example 6

[0086] A polyimide foil PI having a thickness of 50 μm was used as the thermoplastic resin film. Otherwise, the conditions were the same as Example 1.

Example 7

[0087] An acoustic diaphragm of Example 7 was obtained by laminating and thermocompression-bonding a polyimide film PI having a thickness of 12.5 μm on both sides of an aluminum foil AL (1N30) having a thickness of 20 μm with a double belt press machine.

Example 8

[0088] An acoustic diaphragm of Example 8 was obtained by laminating and thermocompression-bonding an aluminum foil AL (1N30) having a thickness of 12 μm on both sides of a polyimide film PI having a thickness of 25 μm with a double belt press machine.

Table 3

	Composition	Metal Foil			Thermoplastic Resin Film			
		Specific Gravity	CTEM (ppm/K)	Weight Per Unit Area (g/m^2)	CTEX (ppm/K)	CTEZ (ppm/K)	CTEZ/X	Weight Per Unit Area (g/m^2)
Example 4	AL/PI = 20/12.5	2.7	27	54	22	121	5.5	18

(continued)

	Composition	Metal Foil			Thermoplastic Resin Film			
		Specific Gravity	CTEM (ppm/K)	Weight Per Unit Area (g/m^2)	CTEX (ppm/K)	CTEZ (ppm/K)	CTEZ/X	Weight Per Unit Area (g/m^2)
Example 5	AL/PI = 12/12.5	2.7	27	32	22	121	5.5	18
Example 1	AL/PI = 20/25	2.7	27	54	19	101	5.3	36
Example 6	AL/PI = 20/50	2.7	27	54	18	110	6.1	72
Example 7	PI/AL/PI = 12.5/20/12.5	2.7	27	54	22	121	5.5	36
Example 8	AL/PI/AL = 12/25/12	2.7	27	64.8	19	101	5.3	36

Table 4

	Acoustic Diaphragm			Evaluation					
	CTE-Difference	Weight Per Unit Area (g/m^2)	Resin Rate (%)	Warping	Workability	Sound Quality	$\tan\delta$	Adhesiveness (N/mm)	Long-Term Reliability Post Heat Cycle Adhesiveness (N/mm)
Example 4	5	72	38	B	A	A	0.048	0.48	0.32
Example 5	5	50	51	B	A	B	0.045	0.45	0.32
Example 1	8	90	56	B	A	B	0.048	0.80	0.72
Example 6	9	125	71	C	A	C	0.060	0.65	0.45
Example 7	5	90	56	A	A	B	0.060	0.45	0.30
Example 8	8	100	51	A	A	B	0.067	0.75	0.68

[0089] As shown in Tables 3 and 4, the results of Examples 1 and 4 to 6 indicate that when the resin rate is smaller, warping is limited and the sound quality is improved. In particular, when the resin rate is 60% or less, warping is limited and the sound quality is improved highly effectively. When the resin rate is 40% or less, the sound quality is further improved.

[0090] The results of Examples 7 to 8 indicate that when the acoustic diaphragm has a laminated structure in which the metal foil is sandwiched between the thermoplastic resin films or a laminated structure in which the thermoplastic resin film is sandwiched between metal foils, warping is significantly limited.

Industrial Applicability

[0091] The present invention is easily processed into a dome-shaped speaker using a die and is thus suitably utilized as a diaphragm for an active speaker or as a support for a voice coil. Also, the audio characteristics of the present invention are satisfactory. Accordingly, the present invention can be desirably utilized as a diaphragm for a flat surface speaker, a headphone, an earphone, and the like.

REFERENCE SIGNS LIST

[0092] 10) acoustic diaphragm, 11) metal foil, 11a) first metal foil, 11b) second metal foil, 12) thermoplastic resin film, 12a) first thermoplastic resin film, 12b) second thermoplastic resin film.

Claims

1. An acoustic diaphragm comprising:

a metal foil; and
a thermoplastic resin film laminated on the metal foil,
wherein the thermoplastic resin film has a ratio of a coefficient of linear thermal expansion in a thickness-wise direction to a smaller one of a coefficient of linear thermal expansion in an MD-direction and a coefficient of linear thermal expansion in a TD-direction that is between 3.0 and 10.0, and
a total weight per unit area of the metal foil and the thermoplastic resin film is between 45 g/m^2 and 150 g/m^2.

2. The acoustic diaphragm according to claim 1, wherein the metal foil has a specific gravity of between 1.7 and 5.0.

3. The acoustic diaphragm according to claim 1 or 2, wherein a difference between a coefficient of linear thermal expansion of the metal foil and the smaller one of the coefficient of linear thermal expansion in the MD-direction and the coefficient of linear thermal expansion in the TD-direction of the thermoplastic resin film is between 0 ppm/K and 15 ppm/K.

4. The acoustic diaphragm according to claim 3, wherein the coefficient of linear thermal expansion of the metal foil is between 5.0 ppm/K and 35 ppm/K.

5. The acoustic diaphragm according to any one of claims 1 to 4, wherein the smaller one of the coefficient of linear thermal expansion in the MD-direction and the coefficient of linear thermal expansion in the TD-direction is between 10 ppm/K and 50 ppm/K.

6. The acoustic diaphragm according to any one of claims 1 to 5, wherein the thermoplastic resin film includes at least one polyimide film adjoining the metal foil.

7. A method for manufacturing the acoustic diaphragm according to any one of claims 1 to 6, the method being **characterized by**:
a lamination process that thermocompression-bonds the metal foil and the thermoplastic resin film.

Fig. 1

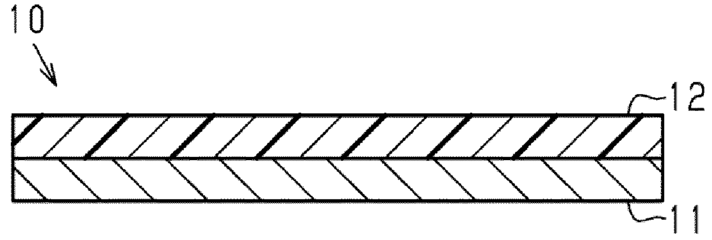


Fig. 2

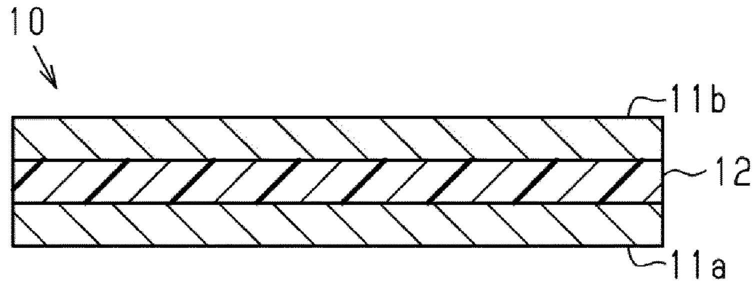
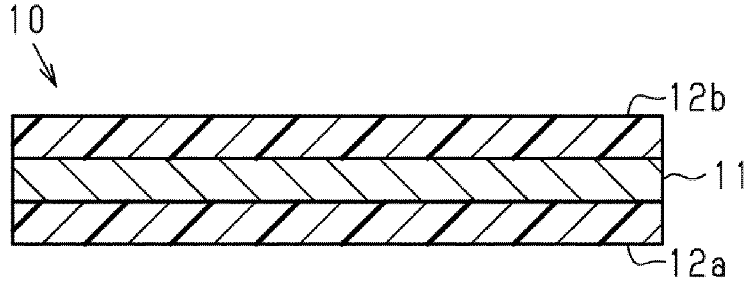


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2020/042412

A. CLASSIFICATION OF SUBJECT MATTER

H04R 7/02(2006.01)i; H04R 31/00(2006.01)i
FI: H04R7/02 D; H04R7/02 B; H04R31/00 A

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)
H04R7/02; H04R31/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 095185/1972 (Laid-open No. 053731/1974) (NIHON GAKKI SEIZO KABUSHIKI KAISHA) 13 May 1974 (1974-05-13) entire text, all drawings	1-7
A	JP 2001-313993 A (FUJITSU TEN LIMITED) 09 November 2001 (2001-11-09) entire text, all drawings	1-7
A	JP 2010-11436 A (ONKYO CORPORATION) 14 January 2010 (2010-01-14) entire text, all drawings	1-7

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"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	Date of mailing of the international search report
02 February 2021 (02.02.2021)	16 February 2021 (16.02.2021)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/042412

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
JP 49-053731 U1	13 May 1974	(Family: none)	
JP 2001-313993 A	09 Nov. 2001	(Family: none)	
JP 2010-11436 A	14 Jan. 2010	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 3911935 B **[0004]**
- JP 2001270033 A **[0022]**