



(51) International Patent Classification:

*B32B 3/12* (2006.01) *G10K 11/16* (2006.01)  
*B32B 3/26* (2006.01) *G10K 11/168* (2006.01)  
*E04B 1/84* (2006.01) *G10K 11/172* (2006.01)  
*E04B 1/86* (2006.01) *B60R 13/08* (2006.01)

(21) International Application Number:

PCT/US2017/046399

(22) International Filing Date:

11 August 2017 (11.08.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/377,285 19 August 2016 (19.08.2016) US

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(54) Title: SOUND-ABSORBING PANELS COMPRISING A CORE CONSISTING OF CONNECTED CELLS, WHEREIN SOME OF THE CELL WALLS HAVE OPENINGS

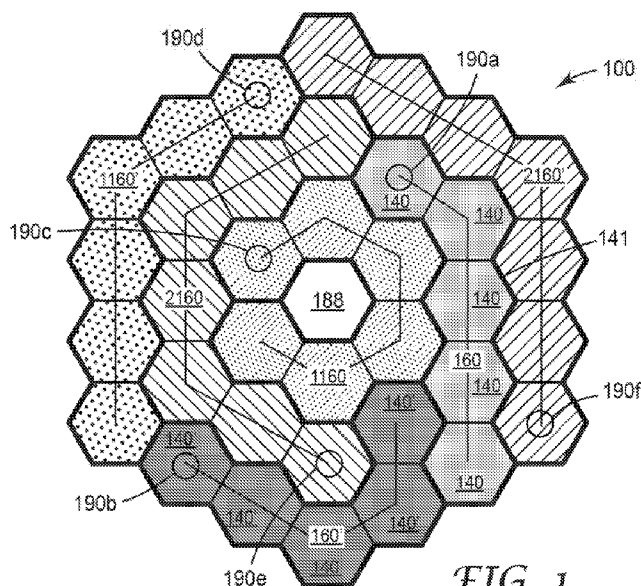


FIG. 1

(57) Abstract: Panels comprising first and second layers and a core disposed there between, wherein the core has a plurality of walls providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall. Exemplary embodiments of panels described herein can be formed articles such as panels, walls, or other parts with curved surfaces. In one exemplary method, panels are shaped via thermoforming. In another exemplary method, panels are shaped via insert molding to provide the article. In another exemplary method, panels are shaped via compression molding to provide the article. The panels are useful for absorbing sound in a designed frequency range.



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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, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, 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))*

**SOUND-ABSORBING PANELS COMPRISING A CORE CONSISTING OF CONNECTED  
CELLS, WHEREIN SOME OF THE CELL WALLS HAVE OPENINGS**

Background

[0001] Sound-absorbing panels are sometimes used to reduce noise in, for example, automobiles and other modes of transportation. There exists a need for thin panels that can absorb acoustical frequencies below 1400 Hz. Fibrous absorption is very effective above 2000 Hz, but very thick (over 50 mm) layers are required for absorption below 1400 Hz. Helmholtz resonator designs can effectively absorb low frequency sound, but the need for a cavity of sufficient volume often leads to a thickness in excess of 40 mm. Panels of less than 20 mm thickness, particularly less than 10 mm thickness, that can absorb frequencies below 1400 Hz, are particularly desirable for use in industrial, office and home settings. Lightweight panels that may be shaped into finished articles with curved surfaces would be especially useful in transportation. Panels made of recyclable thermoplastic materials would offer a further sustainability advantage.

Summary

[0002] In one aspect, the present disclosure describes a panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings (i.e., none) between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even at least 80; in some embodiments, in a range from 50 to 80) percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0003] In another aspect, the present disclosure describes a panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, 80, 85, 90, 95, or even at least 100) percent of the openings in a cell wall emanate from either the first or second layer, and

wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0004] In an additional aspect, the present disclosure describes an article comprising a panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the panel is a flat panel or a shaped panel.

[0005] In a further aspect, the present disclosure describes a panel comprising first, second, and third layers, each of the first, second, and third layers having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells and a plurality of walls extending from the second surface of the second layer to the first surface of the third layer, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0006] In another aspect, the present disclosure describes a laminated article comprising first and second panels, each of the first and second panels comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein

the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of either the first layer or the second layer of the second panel.

5 [0007] In an additional aspect, the present disclosure describes a method of absorbing at least one acoustical frequency below 1400 Hz by disposing an article adjacent to an item that emits at least one acoustical frequency below 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz), wherein the article comprises at least one panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the  
10 second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and  
15 wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0008] In a further aspect, the present disclosure describes a method of making an article, the method comprising: placing a panel in an injection mold; closing the injection mold; and injection  
20 molding plastic onto the panel in the injection mold to provide the article.

[0009] In another aspect, the present disclosure describes a method of making an article, the method comprising: pre-heating a panel; placing the panel proximate to a thermoforming mold; and applying vacuum or pressure to shape the panel to provide the article.

[0010] In an additional aspect, the present disclosure describes a method of making an article,  
25 the method comprising: pre-heating a panel; placing the panel between matched halves of a mold; and applying pressure to close the mold and shape the panel to provide the article.

[0011] In a further aspect, the present disclosure describes a method of making a laminated article comprising first and second panels, the method comprising welding the first and second panels together, wherein each of the first and second panels comprise first and second layers each  
30 having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein

each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the first layer of the second panel.

[0012] In another aspect, the present disclosure describes a method of making an article, the method comprising: obtaining first and second panels, wherein each panel comprises a layer having first and second opposed major surfaces and a core disposed on the layer, wherein the core has a plurality of walls extending from the second surface of the layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the layer has at least a first opening extending between the first and second major surfaces of the layer into at least one cell in the series; heating the first and second panels; contacting the first and second panels such that the core of the first panel is aligned with the core of the second panel; and holding the first panel and the second panel in contact to form a bond between the core of the first panel and the core of the second panel as the first and second panels cool to form the article, wherein the core of the first panel and the core of the second panel together form a core disposed between the layer of the first panel and the layer of the second panel.

[0013] In an additional aspect, the present disclosure describes a method of making a panel, the method comprising: generating a panel by an additive manufacturing method; wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0014] In a further aspect, the present disclosure describes a method of manufacturing an article, the method comprising: modeling an acoustical performance and a structural performance of a plurality of walls forming interconnected channels within the core of a panel; and producing the article comprising a plurality of the walls having the acoustical performance, the structural performance, or both, by an additive manufacturing method.

[0015] In another aspect, the present disclosure describes a method of making an article, the method comprising: a. placing at least a portion of a panel in an injection molding die; and b. overmolding at least one mold structure on a surface of the panel in the injection molding die, thereby forming a material-to-material connection between the surface of the panel and the mold structure, wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

[0016] Exemplary embodiments of panels described herein can be formed into articles such as panels, walls, or other parts with curved surfaces. In one exemplary method, panels are shaped via thermoforming. In another exemplary method, panels are shaped via insert molding to provide the article. In another exemplary method, panels are shaped via compression molding to provide the article.

#### Brief Description of the Drawings

[0017] FIG. 1 is a top view of an exemplary panel described herein.

[0018] FIG. 1A is a cross-sectional view of the exemplary panel described herein shown in FIG. 1.

[0019] FIG. 1B is a perspective view of a cell from FIG. 1.

[0020] FIG. 2 is a top view of another exemplary panel described herein.

[0021] FIG. 2A is a cross-sectional view of the exemplary panel described herein shown in FIG. 2.

[0022] FIG. 2B is a perspective view of a cell from FIG. 2.

[0023] FIG. 3 is a top view of an exemplary repeating array of hexagonal cells.

5 [0024] FIG. 4 is a top view of an exemplary spiral repeating array of hexagonal cells.

[0025] FIG. 5 is a top view of an exemplary semi-spiral repeating array of hexagonal cells.

[0026] FIG. 6 is a top view of an exemplary repeating rectangular array of regular cells.

[0027] FIG. 7 is a top view of an exemplary repeating array of triangular cells.

[0028] FIG. 8 is a top view of an exemplary repeating array of regular pentagonal cells.

10 [0029] FIG 9 is a top view of an exemplary repeating array of regular triangular and hexagonal cells.

[0030] FIG. 10 is a top view of an exemplary repeating array of regular octagonal and rectangular cells.

15 [0031] FIG. 11 is a top view of an exemplary repeating array of regular rectangular and triangular cells.

[0032] FIG. 12 is a top view of an exemplary repeating array of cells with multiple shapes, including curved walls.

[0033] FIG. 13 is a top view of an exemplary irregular pattern of cells.

20 [0034] FIG. 14 is a top view of 3-D printed samples showing 5, 6, and 7 connected cells and hole locations in one of the skin layers.

[0035] FIG. 15 is a plot of acoustical absorption coefficient vs. frequency for Example 1.

[0036] FIG. 16 is a plot of acoustical absorption coefficient vs. frequency for Example 2.

[0037] FIG. 17 is a plot of acoustical absorption coefficient vs. frequency for Example 3.

[0038] FIG. 18 is a plot of acoustical absorption coefficient vs. frequency for Example 4.

25 [0039] FIG. 19 is a top view of the linear array of connected hexagons for Examples 5 and 6.

[0040] FIG. 20 is a cross-sectional view of FIG. 19.

[0041] FIG. 21 is a schematic showing the ineffective area along the edge of Examples 5 and 6.



[0042] FIG. 22 is a plot of Acoustical Absorption Coefficient vs. Frequency for Examples 5 and 6.

[0043] FIG. 23 is a plot of Acoustical Absorption Coefficient vs. Frequency for Examples 7, 8, and 9.

5 [0044] FIG. 24 is a schematic perspective view of an exemplary underbody shield described herein.

[0045] FIG. 25A is a schematic top view of an exemplary engine cover described herein.

[0046] FIG. 25B is a schematic cross-sectional view of the exemplary engine cover of FIG. 25A.

[0047] FIG. 25C is a schematic top view of another exemplary engine cover described herein.

10 [0048] FIG. 25D is a schematic cross-sectional view of the exemplary engine cover of FIG. 25C.

[0049] FIG. 26 is a plot of acoustical absorption coefficient vs. frequency for Example 10.

[0050] FIG. 27 is a schematic perspective view of an exemplary wheel well liner described herein.

[0051] FIG. 28A is a partial schematic perspective view of an automobile including a roof area.

15 [0052] FIG. 28B is a partial cross-sectional view of an exemplary headliner described herein.

[0053] FIG. 29 is a schematic perspective view of an exemplary floor mat described herein.

[0054] FIG. 30A is a cross-sectional view of another exemplary floor mat described herein.

[0055] FIG. 30B is a cross-sectional view of a further exemplary floor mat described herein.

[0056] FIG. 31 is a cross-sectional view of an exemplary laminated article described herein.

20 [0057] FIG. 32 is a cross-sectional view of another exemplary laminated article described herein.

[0058] FIG. 33 is a cross-sectional view of a further exemplary laminated article described herein.

[0059] FIG. 34 is a plot of acoustical absorption vs. frequency for Example 11.

[0060] FIG. 35 is a plot of acoustical absorption vs. frequency for Example 12

25 [0061] FIG. 36A is a schematic perspective view of an automotive hood.

[0062] FIG. 36B is a schematic perspective view of an exemplary hood liner described herein on the underside of an automotive hood.

Detailed Description

[0063] Referring to FIGS. 1, 1A, and 1B, panel 100 has first and second layers 110, 130 each having first and second opposed major surfaces, 111, 112, 131, 132 and core 120 disposed there between. Second layer 130 is free of any openings between first and second major surfaces 131, 132 of second layer 130. Core 120 has plurality of walls 141 extending from second surface 112 of first layer 110 to first surface 131 of second layer 130 providing first series 160, 160' of connected cells 140, 140'. Also shown are second and third series of cells 1160, 1160', and 2160, 2160'. Some of cell walls 141a, 141b, 141c have openings 150 providing fluid communication between first series 160 of five cells 140. Each cell wall 141 has a plurality of sides 171, 172. Each side 171, 172 of cell wall 141 has area A. Opening 150 in cell wall 141a has area A' that is at least 50 percent of area A. First layer 110 has at least first opening 190a, 190b extending between the first and second major surfaces 111, 112 of first layer 110 into at least one cell in series 160, 160'. Note that openings 190a, 190b, 190c, etc., displayed as circles, but can be any of a variety of shapes including squares, triangles, rectangles, hexagons, or other polygons. Multiple openings could also be used, including openings having at least two holes, or openings which include a woven or non-woven permeable material. In some embodiments, at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, 80, 85, 90, 95, or even at least 100) percent of openings 150 in a cell wall 141 emanate from either first layer 110 or second layer 130. Referring to FIGS. 1A and 1B, opening 150 can have contours having curved and straight portions, and any straight portions can be either perpendicular to or tilted at another angle to layers 110 and 130. Optionally the center cell 188 could have an opening in the first layer 110.

[0064] Referring to FIGS. 2, 2A, and 2B, panel 200 has first and second layers 210, 230 each having first and second opposed major surfaces 211, 212, 231, 232 and core 220 disposed there between. Second layer 230 is free of any openings between first and second major surfaces 231, 232 of second layer 230. Core 220 has plurality of walls 241 extending from second surface 212 of first layer 210 to first surface 231 of second layer 230 providing first series 260, 260' of connected cells 240, 240'. Also shown are second and third series of cells 1260, 1260' and 2260, 2260'. Some of cell walls 241a, 241b, 241c have openings 250 providing fluid communication between first series 260 of five cells 240. At least 50 percent of openings 250 in cell walls 241 emanate from either first or second layer 210, 230. In some embodiments of panels 200, each cell wall has a plurality of sides, wherein each side of a cell wall has an area (A), and wherein the opening in a cell wall has an area (A') that is at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even at least 80; in some embodiments, in a range from 50 to 80) percent of the area of a side of that cell wall. Optionally the center cell 288 can have an opening in the first layer 210.

[0065] In some embodiments of panels described herein, the series of cells has a first cell in the series and a last cell in the series, and wherein first opening extends into either the first or last cell in the series. In some embodiments of panels described herein, the series of cells includes a middle cell in the series.

5 [0066] In some embodiments of panels described herein, the series of cells has a first cell in a series, a last cell in the series, and at least one cell between the first and last cells, and wherein first opening extends into one of the cells between the first and last cells. In some embodiments, one of the cells between the first and last cells is a middle cell.

10 [0067] In some embodiments of panels described herein, the series of cells is in a regular pattern. For example, FIG. 3 shows a group of regular repeating hexagonal arrays 360, 360', 360'', 360''', 360''', 360''''' of connected cells 340 and openings 390a, 390b, 390c, 390d, 390e, 390f. Cell 380 could be added to the 360', 360'', or 360''''' series of connected cells or stand alone.

15 [0068] FIG. 4 shows a group of spiral repeating hexagonal array 460, 460', 460'', 460''', 460''', 460''''' of connected cells 440 and openings 490a, 490b, 490c, 490d, 490e, 490f. Cell 480 could be added to the 460, 460', 460'', or 460''''' series of connected cells or stand alone.

[0069] FIG. 5 shows a group of semi-spiral repeating hexagonal array 560, 560', 560'', 560''', 560''', 560''''' of connected cells 540 and openings 590a, 590b, 590c, 590d, 590e, 590f. Cell 580 could be added to the 560, 560', or 560''' series of connected cells or stand alone.

20 [0070] FIG. 6 shows an exemplary group of rectangular arrays 660, 660', 660'', 660''', 660''', 660''''' of connected cells 640 and openings 690a, 690b, 690c, 690d, 690e, 690f.

[0071] FIG. 7 shows an exemplary group of triangular arrays 760, 760', 760'', 760''' of connected cells 740 and openings 790a, 790b, 790c, 790d, 790e.

[0072] FIG. 8 shows an exemplary group of pentagonal arrays 860, 860', 860'', 860''' of connected cells 840 and openings 890a, 890b, 890c, 890d, 890e.

25 [0073] FIG. 9 shows an exemplary group of connected triangles and hexagons 906, 960', 960'', 960''', 960''', 960''''' of connected cells 940 and openings 990a, 990b, 990c, 990d, 990e, 990f.

[0074] FIG. 10 shows an exemplary group of connected octagons and squares 1060, 1060', 1060'', 1060''' of connected cells 1040 and openings 1090a, 1090b, 1090c, 1090d.

30 [0075] FIG. 11 shows an exemplary group of squares and triangles 1160, 1160', 1160'', 1160''', 1160''', 1160''''' of connected cells 1140 and openings 1190a, 1190b, 1190c, 1190d, 1190e.

[0076] FIG. 12 shows an exemplary array of mixed shapes 1260, 1260', 1260'', 1260''', 1260''''', 1260'''''' of connected cells 1240 and openings 1290a, 1290b, 1290c, 1290d, 1290e, 1290f, 1290g.

[0077] FIG. 13 shows an exemplary array of random shapes 1360, 1360', 1360'', 1360''', 1360''''', 1360'''''' of connected cells 1340 and openings 1390a, 1390b, 1390c, 1390d, 1390e, 1390f.

[0078] In some embodiments of panels described herein, at least one of the first or second layer is free of openings.

[0079] In some embodiments of panels described herein, each cell has at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, or even at least 10) walls.

[0080] In some embodiments of panels described herein, each cell has a largest distance between two opposed walls of at least 3 mm (in some embodiments, at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, or even at least 30 mm; in some embodiments, in a range from 3 mm to 30 mm, 7 mm to 30 mm, 15 mm to 30 mm, or even 20 mm to 30 mm). In some embodiments of panels described herein, each cell has a largest distance between two opposed vertices of at least 5 mm (in some embodiments, at least 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, or even at least 40 mm; in some embodiments, in a range from 15 mm to 40 mm, 20 mm to 40 mm, or even 30 mm to 40 mm).

[0081] In some embodiments of panels described herein, each cell has a distance from the second surface of the first layer to the first surface of the second layer of at least 2 mm (in some embodiments, at least 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 15 mm, 7 mm to 15 mm, or even 10 mm to 15 mm).

[0082] In some embodiments of panels described herein, each cell has a volume of at least 0.04 cm<sup>3</sup> (in some embodiments, at least 0.1 cm<sup>3</sup>, 0.5 cm<sup>3</sup>, 1 cm<sup>3</sup>, 2 cm<sup>3</sup>, 3 cm<sup>3</sup>, 4 cm<sup>3</sup>, 5 cm<sup>3</sup>, 10 cm<sup>3</sup>, 15 cm<sup>3</sup>, 20 cm<sup>3</sup>, 25 cm<sup>3</sup>, or even at least 30 cm<sup>3</sup>; in some embodiments, in a range from 0.04 cm<sup>3</sup> to 30 cm<sup>3</sup>, 0.1 cm<sup>3</sup> to 30 cm<sup>3</sup>, 0.5 cm<sup>3</sup> to 30 cm<sup>3</sup>, 2 cm<sup>3</sup> to 30 cm<sup>3</sup>, or even 15 cm<sup>3</sup> to 30 cm<sup>3</sup>).

[0083] In some embodiments of panels described herein, a series of cells has a cumulative volume of at least 0.5 cm<sup>3</sup> (in some embodiments, at least 1 cm<sup>3</sup>, 1.5 cm<sup>3</sup>, 2 cm<sup>3</sup>, 3 cm<sup>3</sup>, 4 cm<sup>3</sup>, 5 cm<sup>3</sup>, 10 cm<sup>3</sup>, 25 cm<sup>3</sup>, 50 cm<sup>3</sup>, 75 cm<sup>3</sup>, 100 cm<sup>3</sup>, 150 cm<sup>3</sup>, or even at least 200 cm<sup>3</sup>; in some embodiments, in a range from 1.5 cm<sup>3</sup> to 200 cm<sup>3</sup>, 10 cm<sup>3</sup> to 120 cm<sup>3</sup>, or even 50 cm<sup>3</sup> to 200 cm<sup>3</sup>).

[0084] In some embodiments of panels described herein, a series of cells has a cumulative length of at least 20 mm (in some embodiments, at least 30 mm, 40 mm, 50 mm, 75 mm, 100 mm, 150

mm, or even at least 200 mm; in some embodiments, in a range from 30 mm to 200 mm, 50 mm to 200 mm, or even 100 mm to 200 mm).

[0085] In some embodiments, a series of cells of panels described herein has a cumulative length of at least 20 mm (in some embodiments, at least 25 mm, 30 mm, 40 mm, or even at least 50 mm).

5 [0086] In some embodiments of panels described herein, the first layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix). In some embodiments of panels described herein, the second layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix). In some embodiments of panels described herein, the core  
10 comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

[0087] Exemplary polymeric materials include polyethylenes, polypropylenes, polyolefins, polyvinylchlorides, polyurethanes, polyesters, polyamides, polystyrene, copolymers thereof, and combinations thereof (including blends). The polymeric materials may be thermosetting by, for  
15 example, heat or ultraviolet (UV) radiation, or thermoplastic.

[0088] Exemplary metallic materials include aluminum, steel, nickel, copper, brass, bronze, and alloys thereof.

[0089] Exemplary ceramic (including glass, glass-ceramic, and crystalline ceramic) materials include oxides, nitrides, and carbides.

20 [0090] Exemplary fiber containing materials include fibers such as cellulose, carbon, thermoplastic fibers (polyamide, polyester, and aramid, polyolefin), steel, and glass, as may be applicable to the particular type of material.

[0091] In some embodiments, materials for panels described herein may be in the form of multilayers.

25 [0092] Optionally materials for panels described herein may also include fillers, colorants, plasticizers, dyes, etc., as may be applicable to the particular type of material.

[0093] In some embodiments, panels described herein have a single composition. Such embodiments are desirable to enhance recyclability.

[0094] In some embodiments of panels described herein, the first layer has a thickness of at least  
30 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm). In some embodiments of panels

described herein, the second layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm). In some embodiments, panels described herein have a thickness of at least 4 mm (in some embodiments, at least 7 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm).

[0095] In some embodiments of panels described herein, the cell walls have a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.2 mm, or even at least 0.5 mm; in some embodiments, in a range from 0.01 mm to 0.2 mm, 0.05 mm to 0.5 mm, or even 0.1 mm to 0.5 mm).

[0096] In some embodiments of panels described herein, the first series of cells comprises at least 4 (in some embodiments, at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 or more) cells. In some embodiments, panels described herein further comprising a second series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 or more) cells. In some embodiments, panels described herein further comprising a third series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 or more) cells.

[0097] In some embodiments, panels described herein further comprising a tie layer on at least a portion of the second of the major surface of the first layer. In some embodiments, panels described herein further comprising a tie layer on at least a portion of the first of the major surface of the second layer. Although not wanting to be bound by theory, the tie layer is believed to facilitate adhesion between first or second layer 110, 130 and core layer 120. In some cases, the same polymer used for the skin and core may also be used as the tie layer. This approach forms a desirable recyclable panel as all components have substantially the same composition (i.e., at least 85 percent by weight is the same composition). In some embodiments, similar polymers for both the core and skins can be used. In some embodiments, additives to slow the crystallization rate and/or reduce the viscosity of the tie layer may be used. These minor additives desirably do not affect the recycling of polymers. In some embodiments, additives that promote a chemical bond between the tie layer and the skin and/or the core can be employed. In some embodiments, block copolymers can be useful where the copolymer has blocks containing polymers with affinity for the skin and blocks with affinity for the core. In some embodiments, techniques for compatibilizing incompatible polymer blends may be useful. In some embodiments, hot melt adhesives, pressure sensitive adhesives and/or curable adhesives may be used.

[0098] In some embodiments, panels described herein exhibit indicia (including alphanumerics). In some embodiments, the indicia is in the form of a trademark or copyrighted material, including a registered trademark or registered copyright as defined under any of the countries, territories, etc., of the world (including the United States). In some embodiments, the indicia is on at least one of the first major surface of the first layer, on the second major surface of the second layer. In some embodiments, the panel is in the form of the indicia.

[0099] In some embodiments, panels described herein exhibit at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz, or even less than 1200 Hz). In some embodiments, panels described herein exhibit at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz). The absorption bands of panels described herein are measured as described in the Examples using the “Normal Incidence Acoustical Absorption Test” and the “Reverberation Chamber Test.”

[00100] Advantageously, in some embodiments, panels (or articles comprising one or more panels) described herein have a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz). In some embodiments, panels (or articles comprising one or more panels) described herein have a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz). For instance, each of Examples 5 and 6, described below, include panels comprising a thickness of less than 15 mm (more particularly 6.2 mm) and exhibit at least one absorption band less than 1400 Hz. In some embodiments, laminated articles described herein comprising at least two panels laminated together (or three, four, five, or more stacked panels laminated together) have a thickness in a range from 8 mm to 50 mm, 10 mm to 30 mm, or even 12 mm to 40 mm, and exhibiting at least one absorption band in a range from at least 600 Hz to 1000 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

[00101] In some embodiments, panels described herein exhibit an acoustical absorption of at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even 80) percent. The acoustical absorption of panels described herein are measured as described in the Examples using the “Normal Incidence Acoustical Absorption Test” and the “Reverberation Chamber Test.”

[00102] In some embodiments, panels described herein exhibit a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-

m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width. The flexural rigidity of panels described herein are measured as described in the Examples using the “3 Point Flexure Test.”

[00103] In some embodiments, panels described herein exhibit a compression strength of at least 0.35 MPa (in some embodiments, at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 3 MPa, or even 4 MPa). The compression strength of panels described herein are measured as described in the Examples using the “Compression Test.”

[00104] Advantageously, in some embodiments, panels (or articles comprising one or more panels) described herein exhibit both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz). In some embodiments, panels (or articles comprising one or more panels) described herein exhibits both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz). For instance, Examples 5 and 6, described below, includes panels exhibiting both a flexural rigidity of at least 1 N-m<sup>2</sup> per meter of width and at least one absorption band less than 1400 Hz.

[00105] Both modeling and physical experimental measurements have shown that the acoustic absorption behavior of a panel according to the present disclosure is a function of each of the panel thickness, cell sizes, passageway percentage, skin hole sizes, and number of connected cells. This is demonstrated in Jonza, J., Herdtle, T., Kalish, J., Gerdes, R. et al., “Acoustically Absorbing Lightweight Thermoplastic Honeycomb Panels,” *SAE Int. J. Veh. Dyn., Stab., and NVH* 1(2):2017, doi:10.4271/2017-01-1813, incorporated herein by reference. For instance, 1) as the number of connected cells is increased, the frequency of the peak absorption decreases; 2) as the skin hole size (whether provided by one hole or multiple holes) increases, the frequency of the peak absorption increases; 3) as the width of the cell decreases, more cells need to be connected to exhibit absorption at the same frequency; 4) as the cell height decreases, the frequency of the peak absorption increases; 5) as the passageway size decreases, the frequency of the peak absorption decreases (plus with less total absorption and narrower absorption peaks); and 6) as the skin thickness increases, the frequency of peak absorption decreases. Hence, multiple variables can be



adjusted to optimize (e.g., tune) the acoustic absorption of a panel or article for a particular end use application.

[00106] In an aspect, the present disclosure describes a panel comprising first, second, and third layers, each of the first, second, and third layers having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells and a plurality of walls extending from the second surface of the second layer to the first surface of the third layer, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series. In certain embodiments, the panel further comprises a fourth layer, the fourth layer having first and second opposed major surfaces and a core disposed there between, the fourth layer being free of any openings between the first and second major surfaces of the fourth layer. Likewise, any number of layers may be included in the panels: four, five, six, seven, eight, nine, ten, etc.

[00107] In an aspect, the present disclosure describes an article comprising a panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the panel is a flat panel or a shaped panel.

[00108] Exemplary embodiments of panels described herein can be formed articles such as automotive parts, such as engine covers, wheel well liners, underbody shields, headliners, trunk covers, floor mats, carpet backings, hood liners, and tonneau covers, housings for generators, motors, appliances, tools, etc., and in general, any item emitting sound; architectural walls, panels,

floors, doors, enclosures, ducts, sound barriers, etc., aircraft, watercraft, trucks, trains, agricultural equipment, fork lifts, and trailers.

[00109] When the article is a housing of an item that emits sound, the article typically absorbs at least one acoustical frequency (emitted from the item) of less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz). Similarly, in an aspect, the present disclosure describes a method of absorbing at least one acoustical frequency below 1400 Hz by disposing an article adjacent to an item that emits at least one acoustical frequency below 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz), wherein the article comprises at least one panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series. In certain embodiments, the article comprises an enclosure at least partially surrounding the item that emits at least one acoustical frequency below 1400 Hz, while in others the article comprises a housing of the item that emits at least one acoustical frequency below 1400 Hz. Often, the article is an automotive part, such as the parts disclosed above.

[00110] As sheet metal in automobiles has been reduced to decrease vehicle weight, vibration can occur that is bothersome to the occupants. Some companies are now putting a honeycomb layer between the metal roof and the fabric or nonwoven headliner. Exemplary panels according to the present disclosure can be shaped by compression molding, thermoforming or injection molding to take the roof shape. The panels can be made of a stiff material to maximize roof stiffness, or a flexible material to increase stiffness and also damp vibration. FIG. 28A shows a roof area of an automobile, and FIG. 28B shows a cross-sectional view of a portion of an exemplary headliner. More particularly, a panel according to at least certain embodiments of the present disclosure is shaped, such as to have the curve of the panel 701 shown in FIG. 28B. The figure shows the roof 700 and the fabric or non-woven liner 702 adjacent or adhered to the panel 701.

[00111] Referring to FIG. 24, an exemplary underbody shield is shown. Examples 10-11 below describe the preparation of exemplary underbody shields comprising shaping panels according to the present disclosure. Referring to FIG. 36B, an exemplary hood liner 999 is shown attached to

the underside of an automotive hood 998. FIG 36A shows a schematic perspective view of the top of an automotive hood 33a.

[00112] The panels of at least certain aspects of this disclosure can find utility as an engine cover. In such cases, it will likely be useful to use polymers with high temperature resistance and flame retardant properties. Suitable polymers include for instance and without limitation, polyamides including PA6, PA66, polybutylene terephthalate (PBT), poly ethylene terephthalate (PET), poly ethylene naphthalate (PEN), polyphenylene sulfide (PPS), Polyether imide (PEI), Polyether sulfone (PES), Polyether ketone (PEK) and Polyether ether ketone (PEEK) and fluoropolymers.

[00113] Moreover, additives such as flame retardants are typically added to heat resistant polymeric materials to provide further protection during high temperature applications. Useful flame retardants include for instance and without limitation, inorganics such as alumina trihydrate (ATH), huntite and hydromagnesite, various hydrates, phosphorus, boron compounds, antimony trioxide and pentoxide and sodium antimonate; halogenated compounds such as organochlorines including chlorendic acid derivatives and chlorinated paraffins; organobromines such as decabromodiphenyl ether (decaBDE), decabromodiphenyl ethane, polymeric brominated compounds, brominated carbonate oligomers (BCOs), brominated epoxy oligomers (BEOs), tetrabromophthalic anhydride, tetrabromobisphenol A (TBBPA) and hexabromocyclododecane (HBCD); organophosphates such as triphenyl phosphate (TPP), resorcinol bis(diphenylphosphate) (RDP), bisphenol A diphenyl phosphate (BADP), and tricresyl phosphate (TCP); phosphonates such as dimethyl methylphosphonate (DMMP); and phosphinates such as aluminium diethyl phosphinate; compounds containing both phosphorus and a halogen such as tris(2,3-dibromopropyl) phosphate(brominated tris) and chlorinated organophosphates such as tris(1,3-dichloro-2-propyl)phosphate (chlorinated tris or TDCPP) and tetrakis(2-chlorethyl)dichloroisopentyldiphosphate.

[00114] The engine cover optionally has a design resembling FIGS. 25A-25D. Referring to FIG. 25A, a ridge is formed in the panel for aesthetic or structural purposes by shaping the panel out of the plane and compressing its thickness as shown as C-C' in the figures. At the edge of the mold, shown in regions A and A' of FIG. 25B, the honeycomb core can be completely collapsed so that the top and bottom skins are in contact, then trimmed (e.g., with a rotary tool, a laser or a water jet) for a clean edge that does not show the honeycomb core. Additionally, injection over-molding can be employed to produce attachment points shown as D, D', D'' and D''' in FIGS. 25C and 25D. Depicted are molded threaded regions, but bushings, lock housings, fixturing mechanisms, receptacles and/or lock receptacle regions could also be used. Further, ribs may be molded against

the panel for additional stiffening and/or aesthetic reasons. An exemplary rib is depicted in FIG. 25D, shown as rib E-E'.

[00115] The acoustical spectrum of an engine depends on many factors including engine design, load and rotations per minute (rpm). The panels according to the present disclosure may thus need to be tuned to several prominent frequencies.

[00116] An acoustical panel may be thermoformed as described below in Example 10, then inserted into an injection mold for the attachments and ribbing to be overmolded on the panel. Alternatively, the panel may be preheated outside of the injection mold and the closing of the injection mold shapes the panel, such that the overmolding occurs in a single machine.

[00117] Tire noise is a major contributor to automotive noise. It can be advantageous to absorb this noise close to the source, e.g., the contact patch between the tire and the roadway. Fender liners are thus a useful application for panels according to aspects of this disclosure. Not only does the sound reaching the cabin get reduced, but also some sound that would otherwise reflect off a solid fender liner and remain in the environment is reduced by the panel absorption. As in other embodiments disclosed herein, thermoforming, compression molding and injection molding may all be employed in producing these parts. An exemplary wheel-well liner is shown in FIG. 27.

[00118] Panels according to at least certain aspects of this disclosure can be used in the flooring of the vehicle, again in a position between the roadway (e.g., a major noise source) and the occupant(s) of the vehicle. For example, a floor pan of the vehicle could be made of the panels, such as by laminating multiple panels and/or using fiber reinforced or metal stiff skins to provide the rigidity to no longer necessitate use of metal flooring. Alternatively, or in addition, a floor mat (see, e.g., the exemplary floor mat 2900 depicted in a vehicle in FIG. 29) may be made of an elastomeric or flexible plastic or rubber. An exemplary floor mat design is shown in FIG 30A. The solid skin layer 810 could be positioned toward an occupant so that dirt and sand do not enter the panel and the surfaces may be wiped or washed clean. An additional layer 840 may also be used that potentially has advantageous features such as a designed level of friction, easy clean composition, and abrasion resistance. In this case, the skin layer with the holes or perforations 810 faces the sound source (e.g., the road). Alternatively, a laminated panel could be used with holes facing the road and the occupants. In the latter case, a second chance for absorption within the cabin of the vehicle can further reduce the noise level. Referring to FIG. 30B, another design is depicted that could either comprise a floor mat or carpeting in the vehicle. In this case, the additional layer 850 is an adhesive or tie layer and the layer 860 is carpeting.

[00119] In another aspect, the present disclosure describes a laminated article comprising first and second panels, each of the first and second panels comprising first and second layers each having

first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of either the first layer or the second layer of the second panel. In select embodiments, the laminated article comprises an enclosure (e.g., to at least partially enclose an item that emits at least one acoustical frequency).

[00120] Optionally, the laminated article further comprises a third panel, the third panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the first layer of the second panel, and wherein the second surface of the second layer of the second panel is directly attached to the first surface of the first layer of the third panel. The second surface of the second layer of the first panel may be directly attached to the first surface of the second layer of the second panel. Any number of panels may be laminated together: four, five, six, seven, eight, nine, ten, etc.

[00121] One method for making articles from panels described herein comprises shaping a panel described herein via thermoforming to provide the article. In some embodiments, thermoforming includes heating the panel and applying force to shape the panel against at least one tool. Typically the panel is heated to a processing temperature where it becomes compliant. The panel is then positioned within a mold, between 2 platens prior to the platens closing. The panel is shaped by mechanical force from the tool, or by vacuum or pneumatic pressure followed by a

cooling period to return the panel to a rigid structure. Exemplary polypropylene (PP) panels can be thermoformed, for example, with the panel pre-heat temperature of 310-350°F (154-177°C), mold temperature of 150°F (66°C), clamping force of 4,000 lbs. (1,814 kgf) and cooling time of 30 seconds.

5 [00122] In a further aspect, the present disclosure describes a method of making an article, the method comprising: pre-heating a panel; placing the panel proximate to a thermoforming mold; and applying vacuum to shape the panel to provide the article.

[00123] In an additional aspect, the present disclosure describes a method of making an article, the method comprising: pre-heating a panel; placing the panel between matched halves of a (e.g.,  
10 thermoforming) mold; and applying pressure to close the mold and shape the panel to provide the article.

[00124] Another method for making articles from panels described herein comprises shaping a panel described herein via insert molding to provide the article. In some embodiments, putting a pre-heated panel inside of an injection mold tool, closing the tool, and injection molding plastic to  
15 provide the article. The mold closing action forms the panel into a three dimensional shape while the overmolded plastic may produce additional features such as fastening points, ribbing or other structural/cosmetic features. The mold closing force may be enough to shape the panel, or thermoforming/compression molding performed prior to insert molding may be required; in either case, pre-heating the formed panel may not be necessary.

20 [00125] For instance, in another aspect, a method is provided comprising placing at least a portion of a panel in an injection molding die; and overmolding at least one mold structure on a surface of the panel in the injection molding die, thereby forming a material-to-material connection between the surface of the panel and the mold structure. The method optionally further comprises at least partially shaping a (flat) panel using thermoforming or compression molding prior to placing at  
25 least a portion of the panel within the injection molding die, e.g., using vacuum, pressure, or match metal shaping to shape the panel. Some exemplary mold structures comprise at least one (molded) bushing, lock housing, fixture mechanism, receptacle, or lock receptacle region. Suitable materials for a mold structure are not particularly limited, and include each of a thermoset material, a thermoplastic material, a photocurable material, and a bulk metallic glass (e.g., an amorphous  
30 alloy). Mold structures can be applied to any portion of a panel, such as on at least one major surface of the panel, an edge of the panel, or a shaped part of the panel. Additionally, at least one profile element may be molded directly onto the mold structure, on an edge side of the panel, or both.

[00126] In select embodiments, the injection molding die is configured to reduce or increase a thickness of at least a portion of the panel or of the entire panel by 5% to 95% or to increase a thickness of at least a portion of the panel by 5% to 50%. For example, the injection molding die may be shaped to reduce the thickness of a portion or all of a panel by 5% or more, 10% or more, 15% or more, 20% or more, 25% or more, 30% or more, 35% or more, 40% or more, 45% or more, 50% or more, 55% or more, or even 60% or more; and 95% or less, 90% or less, 85% or less, 80% or less, 75% or less, 70% or less, or 65% or less. Typically, the decrease in thickness is a decrease in the thickness of the core of the panel. Likewise, the injection molding die may be shaped to increase the thickness of a portion or all of a panel by 5% or more, 10% or more, 15% or more, 20% or more, 25% or more, or even 30% or more; and 50% or less, 45% or less, 40% or less, or 35% or less. Increasing the thickness of a panel may involve pulling a vacuum in the injection molding die to draw out the panel material.

[00127] In certain embodiments, the entire panel is inserted into the injection molding die. Further, a thermoplastic material may be injection molded around the panel to form the mold structure. The panel is optionally preheated prior to placing it within the injection molding die.

[00128] A panel undergoing overmolding may be flat or alternatively comprise a (e.g., three dimensional) shape. For a panel that has already been shaped, the method may further comprise altering the shape of the panel (e.g., “reshaping” the panel) in the injection molding die. In certain embodiments, at least one cell is consolidated and folded over to form a reinforcement bead.

When a number of adjacent cells are consolidated and folded over they can form a “hem” having a thickness approximately equal to twice the thickness of the first and second layers of the panel.

[00129] Another method for making articles from panels described herein comprises shaping a panel described herein via compression molding to provide the article. In some embodiments, putting a panel inside of a mold between 2 platens, heating the mold, closing the platens to shape the panel while maintaining pressure during a mold cooling stage provides the article. In some embodiments, the panel must be pre-heated prior to closing the mold to ensure material compliance. Exemplary polypropylene (PP) panels can be compression molded, for example, without panel pre-heating, thermal cycling mold temperatures of 305°F (152°C) and 150°F (66°C), clamping force of 30,000 lbs. (13,607 kgf) and cooling/pressure holding time of 30 seconds.

[00130] Another method for making articles from panels described herein comprises:

- providing the first layer;
- providing the second layer;
- extruding the core; and
- laminating the first and second layers to the core.

In some embodiments, laminating the first layer to the core occurs during extrusion of the core. For example, a film die can be configured to drop the extrudate into the first nip of a 3-roll stack, such that it is between the skin film and the tooling (middle) roll. The extrudate will solidify while in contact with the tooling roll, and adhere to the first layer. After travelling about 180° around the tooling roll, the first layer side contacts the silicone (third) roll. A belt puller located beyond the silicone roll can be used to control the pulling with a force sufficient to remove the solidified extrudate from the tooling roll. The second layer may be unwound over the top of the belt puller and continuously contacting the top belt. A molten tie layer can be delivered (e.g., from a film die connected to another extruder) onto the top of the open honeycomb just prior to contacting the second layer in the entrance to the belt puller. The tie layer solidifies, bonding the honeycomb to the second layer while being held flat by the belt puller. A panel with first and second layers adhered to the core exits the belt puller.

[00131] In some embodiments, an adhesive may be used to laminate the first and second layers to the extruded core. In some embodiments, two tie layers may be used to laminate the first and second layers to the extruded core.

[00132] There may be a need for thicker panels, for example, either for increased mechanical rigidity or lower frequency absorption. It is possible to combine two panels into a thicker one in several configurations and by several methods. For example, in FIG. 31, two panels may be positioned so that the honeycomb walls align in the thickness direction and the panels are welded together. As used herein, “weld” refers to the attachment of two polymeric materials using heat. The heat may be provided through various mechanisms, including for instance and without limitation, conduction, vibration, oscillation, radiant energy (e.g., laser or infrared energy), or convection of a fluid. Typically, two polymeric materials are welded together by applying heat to a surface of each of the materials, bringing the two heated surfaces together, and allowing the heated surfaces to cool and form a bond, such as through entanglement of polymers from each surface. Pressure is usually applied to hold the two polymeric materials together and promote the formation of a weld between the two polymeric materials as they cool. These welding techniques have the advantage that no new materials are introduced into the construction, so that recyclability of the finished parts is more facile.

[00133] In an aspect, the present disclosure describes a method of making a laminated article comprising first and second panels, the method comprising welding the first and second panels together, wherein each of the first and second panels comprise first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the



core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the first layer of the second panel. In certain embodiments, the welding comprises: bringing the second surface of the second layer of the first panel to a temperature above the melting point of the second surface of the second layer of the first panel; bringing the first surface of the first layer of the second panel to a temperature above the melting point of the first surface of the first layer of the second panel; and holding the second surface of the second layer of the first panel in contact with the first surface of the first layer of the first surface of the second panel to form a bond between the first panel and the second panel as each of the second surface of the second layer of the first panel and the first surface of the first surface of the second panel cools.

[00134] Alternatively, adhesives may be used to join two or more panels together. Pressure sensitive or structural adhesives may be used depending on the required properties of the finished article. The adhesives may be triggered by radiation, such as including ultraviolet, visible, infrared, gamma, or e-beam, or by heating to effect curing. Contact pressure may be sufficient for the pressure sensitive adhesives. Another alternative includes using an extruded tie layer of the same polymer composition to bond two panels together in a continuous process. Preheating of the pre-made panel surfaces and/or a sufficiently high tie layer temperature may be required to provide an adequate bond between the panels.

[00135] The configuration of the panels comprising two or more panels may have the holes or perforations on one side of the panel or both sides of the panel. FIGS. 31-33 depict some possible geometries. For example, FIG. 31 depicts two panels with the honeycomb walls aligned in the thickness direction and the hole from the top skin 990 extends through the middle layers 992 to interconnect channels. The holes do not have to be of the same size. This is useful to absorb lower frequencies by doubling the length and the volume of the channels. FIG. 32 shows two panels aligned like FIG. 31, with a hole in the top skin 993 and one in the bottom skin 995, but there are no holes interconnecting the top and bottom panels. In this case, the stiffness of the panel is increased, and sound may be absorbed that is incident on either side of the panel. In this case the channel lengths and volumes are not doubled. The hole sizes or perforations in each skin can

be of different sizes to tune each side of the panels to a different frequency band. It should be noted that 3, 4, 5 or even 10 or more panels could be connected by welding or adhesives to make a single thicker laminated article.

[00136] In an aspect, the present disclosure describes a method of making an article, the method comprising: obtaining first and second panels; contacting the first and second panels such that the core of the first panel is aligned with the core of the second panel; and holding the first panel and the second panel in contact to form a bond between the core of the first panel and the core of the second panel as the first and second panels cool to form the article, wherein the core of the first panel and the core of the second panel together form a core disposed between the layer of the first panel and the layer of the second panel. The heating is typically provided by conduction, vibration, oscillation, radiant energy, or convection of a fluid. In certain embodiments, the method is a continuous method of forming the article whereas in other embodiments the method is a batch method of forming the article.

[00137] A means of aligning the panels is typically required for all of these panels made by combining multiple panels, unless a random combination of channel lengths and volumes will provide suitable acoustical absorption. For example, FIG. 33 shows two panels with one of them flipped over 180 degrees. The honeycomb walls are not likely to be aligned in this case, so some channels will be very short and of low volume, while others may be longer and still other may have a hole in both the top and bottom skin.

[00138] In an additional aspect, the present disclosure describes a method of making a panel, the method comprising: generating a panel by an additive manufacturing method; wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series. In certain embodiments, the opposed first major surface is obtained and the remainder of the panel is generated on the first major surface by the additive manufacturing method. In alternate embodiments, the entire panel is generated by the additive manufacturing method. Often, the additive manufacturing process comprises a layer-by-layer process.

[00139] In a further aspect, the present disclosure describes a method of manufacturing an article, the method comprising: modeling an acoustical performance and a structural performance of a plurality of walls forming interconnected channels within the core of a panel; and producing the article comprising a plurality of the walls having the acoustical performance, the structural performance, or both, by an additive manufacturing method.

#### Exemplary Embodiments

1A. A panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of opposed sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even at least 80; in some embodiments, in a range from 50 to 80) percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2A. The panel of Exemplary Embodiment 1A, wherein at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, 80, 85, 90, 95, or even at least 100) percent of the openings in a cell wall emanate from either the first or second layer.

3A. The panel of any preceding A Exemplary Embodiment, wherein the series of cells has a first cell in the series and a last cell in the series, and wherein first opening extends into either the first or last cell in the series.

4A. The panel of Exemplary Embodiment 3A, wherein the series of cells includes a middle cell in the series.

5A. The panel of any preceding A Exemplary Embodiment, wherein the series of cells has a first cell in a series, a last cell in the series, and at least one cell between the first and second cells, and wherein first opening extends into one of the cells between the first and second cells.

5 6A. The panel of Exemplary Embodiment 5A, wherein one of the cells between the first and second cells is a middle cell.

7A. The panel of any preceding A Exemplary Embodiment, wherein the series of cells is in a regular pattern.

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8A. The panel of any preceding A Exemplary Embodiment, wherein at least one of the first or second layer is free of openings.

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9A. The panel of any preceding A Exemplary Embodiment, wherein each cell has at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, or even at least 10) walls.

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10A. The panel of any preceding A Exemplary Embodiment, wherein each cell has a largest distance between two opposed walls of at least 3 mm (in some embodiments, at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, or even at least 30 mm; in some embodiments, in a range from 9 mm to 30 mm, 10 mm to 30 mm, 15 mm to 30 mm, or even 20 mm to 30 mm).

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11A. The panel of any preceding A Exemplary Embodiment, wherein each cell has a largest distance between two opposed vertices of at least 5 mm (in some embodiments, at least 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, or even at least 40 mm; in some embodiments, in a range from 15 mm to 40 mm, 20 mm to 40 mm, or even 30 mm to 40 mm).

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12A. The panel of any preceding A Exemplary Embodiment, wherein each cell has a distance from the second surface of the first layer to the first surface of the second layer of at least 2 mm (in some embodiments, at least 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 15 mm, 7 mm to 15 mm, or even 10 mm to 15 mm).

13A. The panel of any preceding A Exemplary Embodiment, wherein each cell has a volume of at least  $0.04 \text{ cm}^3$  (in some embodiments, at least  $0.5 \text{ cm}^3$ ,  $1 \text{ cm}^3$ ,  $2 \text{ cm}^3$ ,  $3 \text{ cm}^3$ ,  $4 \text{ cm}^3$ ,  $5 \text{ cm}^3$ ,  $10 \text{ cm}^3$ ,  $15 \text{ cm}^3$ ,  $20 \text{ cm}^3$ ,  $25 \text{ cm}^3$ , or even at least  $30 \text{ cm}^3$ ; in some embodiments, in a range from  $0.04 \text{ cm}^3$  to  $30 \text{ cm}^3$ ,  $0.1 \text{ cm}^3$  to  $30 \text{ cm}^3$ ,  $0.5 \text{ cm}^3$  to  $30 \text{ cm}^3$ ,  $2 \text{ cm}^3$  to  $30 \text{ cm}^3$ , or even  $15 \text{ cm}^3$  to  $30 \text{ cm}^3$ ).

14A. The panel of any preceding A Exemplary Embodiment, wherein a series of cells has a cumulative volume of at least  $0.5 \text{ cm}^3$  (in some embodiments, at least  $1 \text{ cm}^3$ ,  $1.5 \text{ cm}^3$ ,  $2 \text{ cm}^3$ ,  $3 \text{ cm}^3$ ,  $4 \text{ cm}^3$ ,  $5 \text{ cm}^3$ ,  $10 \text{ cm}^3$ ,  $25 \text{ cm}^3$ ,  $50 \text{ cm}^3$ ,  $75 \text{ cm}^3$ ,  $100 \text{ cm}^3$ ,  $150 \text{ cm}^3$ , or even at least  $200 \text{ cm}^3$ ; in some embodiments, in a range from  $1.5 \text{ cm}^3$  to  $200 \text{ cm}^3$ ,  $10 \text{ cm}^3$  to  $120 \text{ cm}^3$ , or even  $50 \text{ cm}^3$  to  $200 \text{ cm}^3$ ).

15A. The panel of any preceding A Exemplary Embodiment, wherein a series of cells has a cumulative length of at least  $20 \text{ mm}$  (in some embodiments, at least  $30 \text{ mm}$ ,  $40 \text{ mm}$ ,  $50 \text{ mm}$ ,  $75 \text{ mm}$ ,  $100 \text{ mm}$ ,  $150 \text{ mm}$ , or even at least  $200 \text{ mm}$ ; in some embodiments, in a range from  $30 \text{ mm}$  to  $200 \text{ mm}$ ,  $50 \text{ mm}$  to  $200 \text{ mm}$ , or even  $100 \text{ mm}$  to  $200 \text{ mm}$ ).

16A. The panel of any preceding A Exemplary Embodiment, wherein the first layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

17A. The panel of any preceding A Exemplary Embodiment, wherein the second layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

18A. The panel of any preceding A Exemplary Embodiment, wherein the core comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

19A. The panel of any preceding A Exemplary Embodiment, wherein the first layer has a thickness of at least  $0.01 \text{ mm}$  (in some embodiments, at least  $0.05 \text{ mm}$ ,  $0.1 \text{ mm}$ ,  $0.25 \text{ mm}$ ,  $0.5 \text{ mm}$ ,

1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

5 20A. The panel of any preceding A Exemplary Embodiment, wherein the second layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

10 21A. The panel of any preceding A Exemplary Embodiment having a thickness of at least 3 mm (in some embodiments, at least 4 mm, 7 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm).

15 22A. The panel of any preceding A Exemplary Embodiment, wherein the cell walls have a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.2 mm, or even at least 0.5 mm; in some embodiments, in a range from 0.01 mm to 0.2 mm, 0.05 mm to 0.5 mm, or even 0.1 mm to 0.5 mm).

20 23A. The panel of any preceding A Exemplary Embodiment, wherein the first series of cells comprises at least 4 (in some embodiments, at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, or more) cells.

25 24A. The panel of any preceding A Exemplary Embodiment further comprising a second series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, or more) cells.

26 25A. The panel of any preceding A Exemplary Embodiment, further comprising a third series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, or more) cells.

30 26A. The panel of any preceding A Exemplary Embodiment, wherein further comprising a first tie layer on at least a portion of the second of the major surface of the first layer.

27A. The panel of any preceding A Exemplary Embodiment further comprising a second tie layer on at least a portion of the first of the major surface of the second layer.

5 28A. The panel of any preceding A Exemplary Embodiment exhibiting trademark indicia on the first major surface of the first layer.

29A. The panel of any preceding A Exemplary Embodiment exhibiting copyrightable indicia on the first major surface of the first layer.

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30A. The panel of any preceding A Exemplary Embodiment exhibiting trademark indicia on the second major surface of the second layer.

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31A. The panel of any preceding A Exemplary Embodiment exhibiting copyrightable indicia on the second major surface of the second layer.

32A. The panel of any preceding A Exemplary Embodiment that exhibits at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

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33A. The panel of any preceding A Exemplary Embodiment that exhibits at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

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34A. The panel of any preceding A Exemplary Embodiment that exhibits an acoustical absorption of at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even 80) percent.

35A. The panel of any preceding A Exemplary Embodiment that exhibits a flexural rigidity of at least  $1 \text{ N-m}^2$  (in some embodiments, at least  $5 \text{ N-m}^2$ ,  $10 \text{ N-m}^2$ ,  $15 \text{ N-m}^2$ ,  $20 \text{ N-m}^2$ ,  $25 \text{ N-m}^2$ ,  $30 \text{ N-m}^2$ ,  $35 \text{ N-m}^2$ ,  $40 \text{ N-m}^2$ ,  $45 \text{ N-m}^2$ ,  $50 \text{ N-m}^2$ ,  $55 \text{ N-m}^2$ , or even  $60 \text{ N-m}^2$ ) per meter of width.

36A. The panel of any preceding A Exemplary Embodiment that exhibits a compression strength of at least 0.35 MPa (in some embodiments, at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 3 MPa, or even 4 MPa).

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37A. The panel of any preceding A Exemplary Embodiment, wherein a series of cells has a cumulative length of at least 20 mm (in some embodiments, at least 25 mm, 30 mm, 40 mm, or even at least 50 mm).

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38A. The panel of any preceding A Exemplary Embodiment, wherein components thereof have substantially the same composition.

1B. A method of making an article, the method comprising shaping a panel of any A Exemplary Embodiment via thermoforming to provide the article.

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1C. A method of making an article, the method comprising shaping a panel of any A Exemplary Embodiment via insert molding to provide the article.

1D. A method of making an article, the method comprising shaping a panel of any A Exemplary Embodiment via compression molding to provide the article.

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1E. A method of making the panel of any A Exemplary Embodiment, the method comprising:  
providing the first layer;  
providing the second layer;  
extruding the core; and  
laminating the first and second layers to the core.

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2E. The method of Exemplary Embodiment 1E, wherein laminating the first layer to the core occurs during extrusion of the core.

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1F. A panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, 80, 85, 90, 95, or even at least 100) percent of the openings in a cell wall emanate from either the first or second layer, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2F. The panel of Exemplary Embodiment 1F, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even at least 80; in some embodiments, in a range from 50 to 80) percent of the area of a side of that cell wall.

3F. The panel of any preceding F Exemplary Embodiment, wherein the series of cells has a first cell in the series and a last cell in the series, and wherein the first opening extends into either the first or last cell in the series.

4F. The panel of Exemplary Embodiment 3F, wherein the series of cells includes a middle cell in the series.

5F. The panel of any preceding F Exemplary Embodiment, wherein the series of cells has a first cell in the series, a last cell in the series, and at least one cell between the first and second cells, and wherein the first opening extends into one of the cells between the first and second cells.

6F. The panel of Exemplary Embodiment 5F, wherein one of the cells between the first and second cells is a middle cell.

7F. The panel of any preceding F Exemplary Embodiment, wherein the series of cells is in a regular pattern.

8F. The panel of any preceding F Exemplary Embodiment, wherein the second layer is free of openings.

9F. The panel of any preceding F Exemplary Embodiment, wherein each cell has at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, or even at least 10) walls.

10F. The panel of any preceding F Exemplary Embodiment, wherein each cell has a largest distance between two opposed walls of at least 3 mm (in some embodiments, at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, or even at least 30 mm; in some embodiments, in a range from 9 mm to 30 mm, 10 mm to 30 mm, 15 mm to 30 mm, or even 20 mm to 30 mm).

11F. The panel of any preceding F Exemplary Embodiment, wherein each cell has a largest distance between two opposed vertices of at least 5 mm (in some embodiments, at least 10 mm, 20 mm, 25 mm, 30 mm, 35 mm, or even at least 40 mm; in some embodiments, in a range from 15 mm to 40 mm, 20 mm to 40 mm, or even 30 mm to 40 mm).

12F. The panel of any preceding F Exemplary Embodiment, wherein each cell has a distance from the second surface of the first layer to the first surface of the second layer of at least 4 mm (in some embodiments, at least 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 15 mm, 7 mm to 15 mm, or even 10 mm to 15 mm).

13F. The panel of any preceding F Exemplary Embodiment, wherein each cell has a volume of at least 0.04 cm<sup>3</sup> (in some embodiments, at least 0.5 cm<sup>3</sup>, 1 cm<sup>3</sup>, 2 cm<sup>3</sup>, 3 cm<sup>3</sup>, 4 cm<sup>3</sup>, 5 cm<sup>3</sup>, 10 cm<sup>3</sup>, 15 cm<sup>3</sup>, 20 cm<sup>3</sup>, 25 cm<sup>3</sup>, or even at least 30 cm<sup>3</sup>; in some embodiments, in a range from 0.04 cm<sup>3</sup> to 30 cm<sup>3</sup>, 0.1 cm<sup>3</sup> to 30 cm<sup>3</sup>, 0.5 cm<sup>3</sup> to 30 cm<sup>3</sup>, 2 cm<sup>3</sup> to 30 cm<sup>3</sup>, or even 15 cm<sup>3</sup> to 30 cm<sup>3</sup>).

14F. The panel of any preceding F Exemplary Embodiment, wherein a series of cells has a cumulative volume of at least 0.5 cm<sup>3</sup> (in some embodiments, at least 1 cm<sup>3</sup>, 1.5 cm<sup>3</sup>, 2 cm<sup>3</sup>, 3 cm<sup>3</sup>,

4 cm<sup>3</sup>, 5 cm<sup>3</sup>, 10 cm<sup>3</sup>, 25 cm<sup>3</sup>, 50 cm<sup>3</sup>, 75 cm<sup>3</sup>, 100 cm<sup>3</sup>, 150 cm<sup>3</sup>, or even at least 200 cm<sup>3</sup>; in some embodiments, in a range from 1.5 cm<sup>3</sup> to 200 cm<sup>3</sup>, 10 cm<sup>3</sup> to 120 cm<sup>3</sup>, or even 50 cm<sup>3</sup> to 200 cm<sup>3</sup>).

5 15F. The panel of any preceding F Exemplary Embodiment, wherein a series of cells has a cumulative length of at least 20 mm (in some embodiments, at least 30 mm, 40 mm, 50 mm, 75 mm, 100 mm, 150 mm, or even at least 200 mm; in some embodiments, in a range from 30 mm to 200 mm, 50 mm to 200 mm, or even 100 mm to 200 mm).

10 16F. The panel of any preceding F Exemplary Embodiment, wherein the first layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

15 17F. The panel of any preceding F Exemplary Embodiment, wherein the second layer comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

20 18F. The panel of any preceding F Exemplary Embodiment, wherein the core comprises at least one of polymeric, metallic, ceramic, or composite materials (e.g., fiber reinforced, woven or non-woven in a resin matrix).

25 19F. The panel of any preceding F Exemplary Embodiment, wherein the first layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

30 20F. The panel of any preceding F Exemplary Embodiment, wherein the second layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

21F. The panel of any preceding F Exemplary Embodiment having a thickness of at least 3 mm (in some embodiments, at least 4 mm, 7 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm).

5 22F. The panel of any preceding F Exemplary Embodiment, wherein the cell walls have a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.2 mm, or even at least 0.5 mm; in some embodiments, in a range from 0.01 mm to 0.2 mm, 0.05 mm to 0.5 mm, or even 0.1 mm to 0.5 mm).

10 23F. The panel of any preceding F Exemplary Embodiment, wherein the first series of cells comprises at least 4 (in some embodiments, at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, or more) cells.

15 24F. The panel of any preceding F Exemplary Embodiment further comprising a second series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, or more) cells.

20 25F. The panel of any preceding F Exemplary Embodiment, further comprising a third series of at least 3 (in some embodiments, at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, or more) cells.

26F. The panel of any preceding F Exemplary Embodiment, further comprising a first tie layer on at least a portion of the second of the major surface of the first layer.

25 27F. The panel of any preceding F Exemplary Embodiment, further comprising a second tie layer on at least a portion of the first of the major surface of the second layer.

28F. The panel of any preceding F Exemplary Embodiment exhibiting trademark indicia on the first major surface of the first layer.

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29F. The panel of any preceding F Exemplary Embodiment exhibiting copyrightable indicia on the first major surface of the first layer.

30F. The panel of any preceding F Exemplary Embodiment exhibiting trademark indicia on the second major surface of the second layer.

31F. The panel of any preceding F Exemplary Embodiment exhibiting copyrightable indicia on the second major surface of the second layer.

32F. The panel of any preceding F Exemplary Embodiment that exhibits at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

33F. The panel of any preceding F Exemplary Embodiment that exhibits at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

34F. The panel of any preceding F Exemplary Embodiment that exhibits an acoustical absorption of at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even 80) percent.

35F. The panel of any preceding F Exemplary Embodiment that exhibits a rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width.

36F. The panel of any preceding F Exemplary Embodiment that exhibits a compression strength of at least 0.35 MPa (in some embodiments, at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 3 MPa, or even 4 MPa).

37F. The panel of any preceding F Exemplary Embodiment, wherein a series of cells has a cumulative length of at least 20 mm (in some embodiments, at least 25 mm, 30 mm, 40 mm, or even at least 50 mm).

38F. The panel of any preceding F Exemplary Embodiment, wherein components thereof have substantially the same composition.

5 1G. A method of making an article, the method comprising shaping a panel of any F Exemplary Embodiment via thermoforming to provide the article.

1H. A method of making an article, the method comprising shaping a panel of any F Exemplary Embodiment via insert molding to provide the article.

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1I. A method of making an article, the method comprising shaping a panel of any F Exemplary Embodiment via compression molding to provide the article.

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1J. A method of making the panel of any F Exemplary Embodiment, the method comprising:  
providing the first layer;  
providing the second layer;  
extruding the core; and  
laminating the first and second layers to the core.

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2J. The method of Exemplary Embodiment 1J, wherein laminating the first layer to the core occurs during extrusion of the core.

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1K. An article comprising a panel, the panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein

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the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the panel is a flat panel or a shaped panel.

2K. The article of Exemplary Embodiment 1K, wherein the article is an automotive part.

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3K. The article of any preceding K Exemplary Embodiment, wherein the article is selected from the group consisting of an engine cover, a wheel well liner, an underbody shield, a headliner, a trunk cover, a tonneau cover, a floor mat, a hood liner, and a carpet backing.

10 4K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is an engine cover.

5K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a wheel well liner.

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6K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is an underbody shield or a portion of the floor of a vehicle.

7K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a headliner.

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8K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a trunk cover or trunk floor.

9K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a tonneau cover.

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10K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a floor mat.

11K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a carpet backing.

12K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a hood liner.

13K. The article of any of Exemplary Embodiments 1K to 3K, wherein the article is a panel or part in a vehicle.

14K. The article of Exemplary Embodiment 1K, wherein the article is an enclosure, a duct, or a sound barrier.

15K. The article of Exemplary Embodiment 1K, wherein the article is a housing of an item that emits sound, wherein the article absorbs at least one acoustical frequency of less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

16K. The article of Exemplary Embodiment 1K, wherein the article is selected from the group consisting of a wall, a floor, a ceiling and a door or panels added to a wall, a floor, a ceiling or a door.

17K. The article of any preceding K Exemplary Embodiment, wherein the first layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

18K. The article of any preceding K Exemplary Embodiment, wherein the second layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).



19K. The article of any preceding K Exemplary Embodiment, having a thickness of at least 3 mm (in some embodiments, at least 4 mm, 7 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm).

5 20K. The article of any preceding K Exemplary Embodiment that exhibits at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

10 21K. The article of any preceding K Exemplary Embodiment that exhibits at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

22K. The article of any preceding K Exemplary Embodiment, that exhibits an acoustical absorption of at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even 80) percent.

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23K. The article of any preceding K Exemplary Embodiment that exhibits a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width.

20 24K. The article of any preceding K Exemplary Embodiment that exhibits a compression strength of at least 0.35 MPa (in some embodiments, at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 3 MPa, or even 4 MPa).

25 25K. The article of any preceding K Exemplary Embodiment having a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

30 26K. The article of any preceding K Exemplary Embodiment having a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

27K. The article of any preceding K Exemplary Embodiment that exhibits both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

28K. The article of any preceding K Exemplary Embodiment that exhibits both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

1L. A panel comprising first, second, and third layers, each of the first, second, and third layers having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells and a plurality of walls extending from the second surface of the second layer to the first surface of the third layer, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2L. The panel of claim Exemplary Embodiment 1L, further comprising a fourth layer, the fourth layer having first and second opposed major surfaces and a core disposed there between, the fourth layer being free of any openings between the first and second major surfaces of the fourth layer.

1M. A laminated article comprising first and second panels, each of the first and second panels comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of either the first layer or the second layer of the second panel.

2M. The laminated article of Exemplary Embodiment 1M, further comprising a third panel, the third panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the first layer of the second panel, and wherein the second surface of the second layer of the second panel is directly attached to the first surface of the first layer of the third panel.

3M. The laminated article of Exemplary Embodiment 1M, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the second layer of the second panel.

1N. A method of absorbing at least one acoustical frequency below 1400 Hz by disposing an article adjacent to an item that emits at least one acoustical frequency below 1400 Hz (in some

embodiments, less than 1300 Hz or even less than 1200 Hz), wherein the article comprises at least one panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2N. The method of Exemplary Embodiment 1N, wherein the article comprises an enclosure at least partially surrounding the item that emits at least one acoustical frequency below 1400 Hz.

3N. The method of Exemplary Embodiment 1N, wherein the article comprises a housing of the item that emits at least one acoustical frequency below 1400 Hz.

4N. The method of Exemplary Embodiment 1N, wherein the article is an automotive part.

5N. The method of any of Exemplary Embodiments 1N, 2N, or 4N, wherein the article is selected from the group consisting of an engine cover, a wheel well liner, an underbody shield, a headliner, a trunk cover, a tonneau cover, a floor mat, a hood liner, and a carpet backing.

6N. The method of any preceding N Exemplary Embodiment, wherein the first layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

7N. The method of any preceding N Exemplary Embodiment, wherein the second layer has a thickness of at least 0.01 mm (in some embodiments, at least 0.05 mm, 0.1 mm, 0.25 mm, 0.5 mm,

1 mm, 1.5 mm, 2 mm, 2.5 mm, or even at least 3 mm; in some embodiments, in a range from 0.025 mm to 0.5 mm, 0.1 mm to 2 mm, 0.25 mm to 3 mm or even 0.5 mm to 3 mm).

8N. The method of any preceding N Exemplary Embodiment, having a thickness of at least 3 mm (in some embodiments, at least 4 mm, 7 mm, 10 mm, or even at least 15 mm; in some embodiments, in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm).

9N. The method of any preceding N Exemplary Embodiment that exhibits at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

10N. The method of any preceding N Exemplary Embodiment that exhibits at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

11N. The method of any preceding N Exemplary Embodiment that exhibits an acoustical absorption of at least 50 (in some embodiments, at least 55, 60, 65, 70, 75, or even 80) percent.

12N. The method of any preceding N Exemplary Embodiment that exhibits a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width.

13N. The method of any preceding N Exemplary Embodiment that exhibits a compression strength of at least 0.35 MPa (in some embodiments, at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 3 MPa, or even 4 MPa).

14N. The method of any preceding N Exemplary Embodiment having a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

15N. The method of any preceding N Exemplary Embodiment having a thickness in a range from 4 mm to 8 mm, 6 mm to 10 mm, or even 8 mm to 15 mm, and exhibiting at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

16N. The method of any preceding N Exemplary Embodiment that exhibits both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz).

17N. The method of any preceding N Exemplary Embodiment that exhibits both a flexural rigidity of at least 1 N-m<sup>2</sup> (in some embodiments, at least 5 N-m<sup>2</sup>, 10 N-m<sup>2</sup>, 15 N-m<sup>2</sup>, 20 N-m<sup>2</sup>, 25 N-m<sup>2</sup>, 30 N-m<sup>2</sup>, 35 N-m<sup>2</sup>, 40 N-m<sup>2</sup>, 45 N-m<sup>2</sup>, 50 N-m<sup>2</sup>, 55 N-m<sup>2</sup>, or even 60 N-m<sup>2</sup>) per meter of width and at least one absorption band in a range from at least 800 Hz to 1200 Hz (in some embodiments, in a range from at least 500 Hz to 1300 Hz, at least 200 Hz to 1400 Hz, or even at least 20 Hz to 1400 Hz).

10. A method of making an article, the method comprising:

placing a panel in an injection mold;

closing the injection mold; and

injection molding plastic onto the panel in the injection mold to provide the article,

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a

first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2O. The method of Exemplary Embodiment 1O, further comprising pre-heating the panel prior to placing the panel in the injection mold.

1P. A method of making an article, the method comprising:

pre-heating a panel;

placing the panel proximate to a thermoforming mold; and

applying vacuum or pressure to shape the panel to provide the article,

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer

providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

1Q. A method of making an article, the method comprising:

pre-heating a panel;

placing the panel between matched halves of a thermoforming mold; and

applying pressure to close the mold and shape the panel to provide the article,

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer

providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides,

wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

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1R. A method of making a laminated article comprising first and second panels, the method comprising welding the first and second panels together,

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wherein each of the first and second panels comprise first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of the first layer of the second panel.

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2R. The method of Exemplary Embodiment 1R, wherein the welding comprises:

bringing the second surface of the second layer of the first panel to a temperature above the melting point of the second surface of the second layer of the first panel;

optionally bringing the first surface of the first layer of the second panel to a temperature above the melting point of the first surface of the first layer of the second panel;

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holding the second surface of the second layer of the first panel in contact with the first surface of the first layer of the first surface of the second panel to form a bond between the first panel and the second panel as each of the second surface of the second layer of the first panel and the first surface of the first layer of the first surface of the second panel cools.

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1S. A method of making an article, the method comprising:

obtaining first and second panels, wherein each panel comprises a layer having first and second opposed major surfaces and a core disposed on the layer, wherein the core has a plurality of walls



extending from the second surface of the layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the layer has at least a first opening extending between the first and second major surfaces of the layer into at least one cell in the series;

heating the first and second panels;

contacting the first and second panels such that the core of the first panel is aligned with the core of the second panel; and

holding the first panel and the second panel in contact to form a bond between the core of the first panel and the core of the second panel as the first and second panels cool to form the article, wherein the core of the first panel and the core of the second panel together form a core disposed between the layer of the first panel and the layer of the second panel.

2S. The method of Exemplary Embodiment 1R or 1S, wherein the heating is provided by conduction, vibration, oscillation, radiant energy, or convection of a fluid.

3S. The method of Exemplary Embodiment 1R or 1S, wherein the method is a continuous method of forming the article.

4S. The method of Exemplary Embodiment 1R or 1S, wherein the method is a batch method of forming the article.

1T. An article comprising the laminated article of any M Exemplary Embodiment, wherein the article comprises an enclosure.

1U. A method of making a panel, the method comprising:

generating a panel by an additive manufacturing method;

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between

the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2U. The method of Exemplary Embodiment 1U, wherein the opposed first major surface is obtained and the remainder of the panel is generated on the first major surface by the additive manufacturing method.

3U. The method of Exemplary Embodiment 1U, wherein the entire panel is generated by the additive manufacturing method.

4U. The method of any preceding U Exemplary Embodiment, wherein the additive manufacturing method comprises a layer-by-layer process.

1V. A method of manufacturing an article, the method comprising:  
modeling an acoustical performance and a structural performance of a plurality of walls forming interconnected channels within the core of a panel; and  
producing the article comprising a plurality of the walls having the acoustical performance, the structural performance, or both, by a method of any preceding U Exemplary Embodiment.

1W. A method of making an article, the method comprising:  
placing at least a portion of a panel in an injection molding die; and  
overmolding at least one mold structure on a surface of the panel in the injection molding die, thereby forming a material-to-material connection between the surface of the panel and the mold structure,

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2W. The method of Exemplary Embodiment 1W, wherein the mold structure comprises at least one molded bushing, lock housing, fixture mechanism, receptacle, or lock receptacle region.

3W. The method of Exemplary Embodiment 1W or Exemplary Embodiment 2W, wherein the mold structure comprises a thermoset material, a thermoplastic material, a photocurable material, or a bulk metallic glass (amorphous alloy).

4W. The method of any preceding W Exemplary Embodiment, wherein the mold structure is applied to at least one major surface of the panel.

5W. The method of any preceding W Exemplary Embodiment, wherein the entire panel is inserted into the injection molding die; and further comprising injection molding a thermoplastic material around the panel to form the mold structure.

6W. The method of any preceding W Exemplary Embodiment, wherein the panel comprises a shape, and the method further comprises altering the shape of the panel in the injection molding die.

7W. The method of any preceding W Exemplary Embodiment, wherein at least one cell is consolidated and folded over to form a reinforcement bead.

8W. The method of any preceding W Exemplary Embodiment, further comprising at least one profile element molded directly onto the mold structure, on an edge side of the panel, or both.

9W. The method of any preceding W Exemplary Embodiment, wherein the injection molding die is configured to reduce a thickness of at least a portion of the panel by 5% to 95% or to increase a thickness of at least a portion of the panel by 5% to 50%.

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10W. The method of any preceding W Exemplary Embodiment, wherein the injection molding die is configured to reduce a thickness of the entire panel by 5% to 95% or to increase a thickness of the entire panel by 5% to 50%.

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11W. The method of any preceding W Exemplary Embodiment, further comprising preheating the panel prior to placing it within the injection molding die.

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12W. The method of any preceding W Exemplary Embodiment, further comprising at least partially shaping the panel using thermoforming or compression molding prior to placing at least a portion of the panel within the injection molding die.

13W. The method of Exemplary Embodiment 12W, wherein the thermoforming or compression molding process utilizes vacuum, pressure, or match metal shaping to shape the panel.

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[00140] Advantages and embodiments of this invention are further illustrated by the following examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this invention. All parts and percentages are by weight unless otherwise indicated.

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### Test Methods

#### Normal Incidence Acoustical Absorption Test

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[00141] In general, ASTM E-1050 (2008), the disclosure of which is incorporated herein by reference, was employed to measure the acoustic absorption with normal incidence acoustic wave. Specifically, for the honeycomb panel test, a 100 mm inner diameter impedance tube (obtained from Bruel & Kjaer, Naerum, Denmark, under the trade designation "Impedance Tube Kit Type 4206") was used. In the tube, a speaker (obtained from Bruel & Kjaer, as Impedance Tube Kit Type 4206) was used to generate broad band frequency from 10 Hz to 6400 Hz at one end of the tube with the test specimen in place at the other end. The specimen was mounted so as to touch

the hard wall on the back side of the impedance tube, with the side of the specimen having holes facing the noise source. To avoid acoustic leakage around the honeycomb specimen, thin tape (obtained under the trade designation “SCOTCH BRAND TAPE” from the 3M Company, St. Paul, MN) was wrapped around the circumference, sufficient to provide a snug fit. In the middle of the tube, there were two 6.35 mm (0.25 inch) microphones (obtained from Bruel & Kjaer, as Impedance Tube Kit Type 4206), to measure the sound pressure inside the tube. Using the measured sound pressures from two microphones with known distance, and using acoustic plane wave theory, the amount of acoustic energy absorbed by the material was calculated. In the 100 mm diameter tube, the absorption coefficient was measured within the frequency range of 50 Hz to 1600 Hz, where plane wave theory is known to be valid.

### Reverberation Chamber Test

[00142] SAE Test Method J2883 (2015), the disclosure of which is incorporated herein by reference, was used to measure the acoustic absorption of a material in a diffused field in which sound comes from random directions (0° to 180° angle of incidence) measured in a reverberation chamber (obtained from Autoneum, Winterthur, Switzerland, under the trade designation “ALPHA CABIN”). Specifically, the three speakers in the reverberation chamber were used to generate one third or one twelfth center frequency tones from 400 Hz to 10,000 Hz and five microphones (obtained from PCB Piezotronics, Buffalo, NY, as Type 130E20) were used to measure the sound pressure levels in the reverberation chamber. Each microphone measured how fast the noise decayed in time. A faster decay was an indication of better absorption performance of the material being tested. From the decay rate, the random incidence absorption coefficient was calculated by averaging the five microphone results. The samples were situated in the middle of the reverberation chamber, which was held in a controlled temperature (23°C) and humidity (55% relative humidity) environment to ensure consistent acoustical performance results.

### 3-Point Flex Test

[00143] In general, mechanical properties were measured in flexure following ASTM D790 (2007), the disclosure of which is incorporated herein by reference. Specifically, a screw-driven mechanical testing machine obtained under the trade designation “INSTRON” as Model 1122, from Instron, (Norwood, MA) was used with two 0.5 inch (12.7 mm) support cylinders and a loading nose cylinder of 0.5 inch (12.7 mm). The test specimen width was about 1 inch (25.4 mm), the span was 6 inch (152.4 mm), and the crosshead speed 0.25 inch/min (6.35 mm/min).

The flexural rigidity ( $D$  in  $\text{N}\cdot\text{m}^2$ ) is defined by this equation:  $D = 12Ebd^3$  where  $b$  = specimen width (m),  $d$  = specimen thickness (m) and  $E$  is the modulus of elasticity of the specimen ( $\text{Pa} = \text{N}/\text{m}^2$ ) as defined in ASTM D790 (2007, eqn. 6). Flexural rigidity ( $\text{N}\cdot\text{m}^2$ ) per meter of width is:  $D/b = 12Ed^3$ .

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### Compression Test

[00144] In general, specimens were tested in compression, following ASTM C 365 / C 365 M (2005), the disclosure of which is incorporated herein by reference. Specifically, test specimens were cut in length and width to 1.5 inch x 1.5 inch (38 mm x 38 mm) and the thickness was measured for each specimen. Thicknesses were about 0.25 inch (6.35 mm). The test apparatus' 15.24 cm (6 inch) diameter parallel plates were compressed together at 0.2 in./min. (5.08 mm/min.). The machine compliance (deflection as a function of load) correction was used to calculate the sample strain in the modulus calculation. The test was carried out to a maximum load of at least 34 kN. This occurred at greater than 60% strain (sample thickness up to 40% of the original thickness). The compression strength is reported as the peak load at yield. The yield strain occurred at 6-11% strain.

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### Examples 1-4

[00145] Commercial modeling software (acoustics module of software obtained under the trade designation "COMSOL MULTIPHYSICS" from COMSOL, Inc., Burlington, MA) was used to model the acoustical absorption of 14 mm hexagons of two wall heights: 10 mm and 12.7 mm.

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[00146] These designs were printed using a 3-D printer (obtained under the trade designation "PROJET 7000 HD SLA" from 3D Systems, Rock Hill, SC) using a resin obtained under the trade designation "VISIJET FLEX" from 3D Systems. FIG. 14 shows the pattern of connected hexagons and holes located that were both modeled and 3D-printed. Each specimen had two sets of 5 connected hexagons (1460, 1460'), a first pair of 6 connected hexagons (1470, 1470'), a second pair of 6 connected hexagons (1471, 1471'), and three sets of 7 connected hexagons (1480, 1480', 1480''). The upper skin was printed to leave holes (see FIG. 14, 1460a through 1480c) in the upper skin (and Table 1, below).

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30

Table 1

Example	Hole Diameters, mm				Wall heights, mm
	Sets of 5 connected cells (1460, 1460') holes 1460a,b	First pair of sets of 6 connected cells (1470, 1470') holes 1470a,b	Second pair of sets of 6 connected cells (1471, 1471') holes 1471a,b	Sets of 7 connected cells (1480, 1480', 1480'') holes 1480a,b,c	
1	2.543	3.354	2.798	3.290	10.0
2	3.434	4.025	3.078	3.290	10.0
3	2.543	3.354	2.798	3.290	12.7
4	3.434	4.025	3.078	3.290	12.7

[00147] Example 1 and 3 specimens were tested, and then the holes were expanded by drilling to create additional Example 2 and 4 specimens, which were also tested. Table 1, above, shows the dimensions of the “original” and “larger” hole sizes for Examples 1-4.

[00148] FIGS. 15 and 16 show the acoustical absorption coefficient modeled and measured using the Normal Incidence Acoustical Absorption Test for the 10 mm tall cell walls with the “original” (Example 1) and “larger” (Example 2) hole sizes, respectively. FIGS. 17 and 18 show the acoustical absorption coefficient modeled and measured using the Normal Incidence Acoustical Absorption Test for the 12.7 mm tall cell walls with the “original” (Example 3) and “larger” (Example 4) hole sizes, respectively.

#### Examples 5 and 6

[00149] A honeycomb panel with 11.5 mm hexagonal cells was prepared by extrusion replication lamination, then passageways were machined to make a number of linear chambers of 5 hexagons and 7 hexagons, and twice as many chambers of 6 hexagons. Holes were drilled in the top skin, then the bottom skin was laminated in a dual belt laminator. Details of the acoustical panel preparation are given below.

#### -Skin Preparation

[00150] A 35 wt. % glass-fiber filled polypropylene (GFPP) resin (obtained under the trade designation “XMOD GB306” from Borealis, Vienna, Austria) was extruded in a 2.5 inch (6.25 cm) extruder (obtained under the trade designation “NRM” from Davis-Standard, Pawcatuck, CT) at a screw speed of 90 rpm, and with barrel zones ramped up, from the feed end to the discharge

end, from 290°F (143°C) to 460°F (238°C). An 18 inch (457 mm) film die at 460°F (238°C) was used to drop the extrudate into a three-roll stack. The extrudate was nipped between a first chrome roll at 90°F (32°C) and a second chrome roll at 120°F (49°C) and stripped off the second chrome roll to a silicone rubber roll at 90°F (32°C). The line speed was 10 feet/minute and the resulting  
5 0.023 inch (0.58 mm) thick GFPP film was wound onto 6 inch (13.5 cm) outside diameter cores.

#### -Honeycomb Panel Preparation

[00151] The film described above was unwound into the nip of the three-roll stack casting station, but with the center chrome roll replaced by a tooling roll that had multiple 11.5 mm connected  
10 hexagons (width dimension) cut 0.30 inch (7.6 mm) deep into its surface. The grooves forming the hexagonal pattern had a draft angle of 2° and were 0.024 inch (0.6 mm) wide at the bottom and 0.51 inch (1.3 mm) wide at the roll surface. Polypropylene resin (obtained under the trade designation “PRO-FAX 8523” from LyondellBasell, Rotterdam, Netherlands) was fed to the extruder (“NRM”), operated at 48 rpm, with barrel zone temperatures ramped from 350°F (177°C)  
15 to 450°F (232°C). The film, intended to become a skin layer, had about 90 degrees of wrap on the chrome nip roll that was set to 150°F (66°C) and the gap between this roll and the tooling roll was 0.043 inch (1.09 mm). The line speed was 3 feet/minute (0.91 m/min.) and the honeycomb tooling roll was set to 200°F (93°C). The film die was set to 430°F (221°C), and was configured to drop the extrudate into the nip such that it was between the skin film and the tooling roll. The extrudate  
20 crystallized while in contact with the tooling roll, and after travelling about 180° around the tooling roll, the skin side contacts the silicone (third) roll. A belt puller located beyond the silicone roll was used to control the pulling force at 250 lbs. (1110 N); a force sufficient to remove the solidified extrudate from the tooling roll onto the silicone roll, but insufficient to elongate (distort) the hexagonal geometry. The honeycomb, adhered to the GFPP bottom skin, was measured to  
25 have 0.270 inch (6.86 mm) wall height. A second GFPP film intended to be the second skin was unwound over the top of the belt puller and continuously contacted the top belt. A molten tie layer of the polypropylene (“PROFAX 8523”) was extruded, using a 1.5 inch (3.75 cm) extruder (obtained from Davis-Standard) operating at 50 rpm, onto the top of the open honeycomb just prior to contacting the top skin in the entrance to the belt puller. The barrel temperatures of the tie layer  
30 extruder were ramped from 280°F (138°C) to 500°F (260°C) and the die was set to 550°F (288°C). The resulting panel was 0.30 inch (7.6 mm) thick.



#### -Acoustical Panel Preparation

[00152] Three honeycomb panels about 44 inch x 13 inch (1118 mm x 330 mm), produced as described above, were machined in a vertical machining center (obtained as Model 84 CNC from Hurco Companies, Inc., Indianapolis, IN). A panel was first mounted with bottom skin taped, using double-sided tape, to the machine's stage. Then, the top skin was removed by end-mill machining, and a 7/32 inch (5.55 mm) ball end mill was used to remove material from some honeycomb walls to within 0.015 inch (0.38 mm) of the bottom skin. The pattern cut in each panel is shown in FIG. 19. There are twice as many sets of 6-connected cells as 5-connected cells and 7-connected cells. FIG. 19 shows only a portion of the panel, which extended in both length and width. Holes were then drilled through the bottom skin at locations indicated in FIG. 19, and the hole diameters are listed in FIG. 19.

[00153] A new top skin was laminated to the workpiece having the drilled bottom skin and honeycomb walls, using a dual belt laminator (obtained under the trade designation "KFK-E 1500" from Meyer Co., Riverside, CT). A 0.5 mm thick skin, as described in the skin preparation section, was fed onto the bottom belt along with 0.8 mm impact-polypropylene sheeting (obtained under the trade designation "MC100-F" from Optimum Plastics, Bloomer, WI), which was in contact with the honeycomb so as to serve as a sealing layer. The belt speed was 3 fpm (0.9 m/min.), the bottom belt was set to 180°C, the top belt was set to 130°C, the belt gap was set to 6.5 mm, and the nip was fixed at 0.1 mm. The cross-section of the laminated panel is shown in FIG. 20, with the laminated new skin shown as being on the bottom of the structure.

[00154] Three panels, made as above, were then taped together to form a 1118 mm x 990 mm panel (Example 5) and measured for random incidence acoustical absorption using the Reverberation Chamber Test. Following this measurement, the holes labelled A and C in FIG. 19, in the 3 panels of the specimen of Example 5, were re-drilled for the set of 5 connected cells from 0.1495 inch (3.80 mm) to 0.359 inch (9.12 mm) and for one of the sets of 6 connected cells from 0.166 inch (4.22 mm) to 0.359 inch (9.12 mm) to produce the specimen for Example 6.

[00155] Because the hexagons were not aligned with the edges of the sample, the effective area of the panel is 75% of the actual area. FIG. 21 shows the geometry of the hexagons relative to the edge of the panel. An area correction was applied to the acoustical absorption coefficient plotted vs. frequency in FIG. 22. A clear peak centered at about 1000 Hz is seen for the specimen of Example 5. A second peak is found at 1320 Hz for the specimen of Example 6 (with its enlarged holes).

Examples 7-9

[00156] The skin preparation and honeycomb panel preparation procedures were as described for Example 5.

5 -Acoustical Panel Preparation

[00157] Three honeycomb panels about 39 inch x 15 inch (1143 x 432 mm), produced as described above, were machined in the vertical machining center. A panel was first mounted using double stick tape. Then, the top skin was removed and a 7/32 inch (5.55 mm) ball end mill was used to remove honeycomb walls to within 0.015 inch (0.38 mm) of the bottom skin. The pattern of interconnected hexagons was changed to be the nested hexagon array shown in FIG. 1. There are two sets of 5 interconnected hexagons, two sets of 6 interconnected hexagons and two sets of 7 interconnected hexagons in the larger 37 hexagon repeat unit that was repeated in these panels.

The holes were drilled in the top skin and their sizes are given in Table 2, below.

15

Table 2

Example	5 Hexes	6 Hexes	7 Hexes
7	2 mm (0.079 inch)	2 mm (0.079 inch)	2 mm (0.079 inch)
8	3 mm (0.118 inch)	2 mm (0.079 inch)	2 mm (0.079 inch)
9	4 mm and 3 mm (0.1575 inch and 0.118 inch)	3 mm and 2 mm (0.118 inch and 0.079 inch)	3.5 mm and 2 mm (0.138 inch and 0.079 inch)

[00158] Some holes already drilled to yield the specimen of Example 7 were enlarged by re-drilling with larger bits to make the specimen of Example 8, and the process was applied again to half of the holes to make the specimen of Example 9. As in Examples 5 and 6, three sheets were taped together to form a single, larger (in this case, 1143 mm x 1296 mm) panel.

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[00159] The 75% effective area correction was also applied to the absorption coefficient vs. frequency data shown in FIG. 23. As in Example 6, making a set of holes larger produced another band for Example 8 as compared to Example 7. With the hole sizes used for Example 9, the multiple peaks became a band of absorption about 570 Hz wide. The absorption band (750 Hz

to 1320 Hz) for Example 9 is useful, for example in absorbing frequencies produced by tires rolling on a road.

[00160] The mechanical properties of Example 6 were measured in flexure using the 3-Point Flex Test. The flex test results are shown in Table 3, below.

5

Table 3

Specimen	Thickness, mm	Width, mm	Maximum Load, kgf	Maximum Stress, MPa	Flex Modulus, MPa	Rigidity, N*m <sup>2</sup>	Rigidity, N*m <sup>2</sup> per m
Example 6 MD holes down	6.35	26.6	15.6	32.7	2619	1.49	56.0
Example 6 MD holes up	6.35	26.1	14.6	31.1	2573	1.43	55.0
Example 6 TD holes down	6.35	26.7	6.9	14.4	1204	0.69	25.7
Example 6 TD holes up	6.35	26.1	9.2	19.6	1178	0.66	25.2

[00161] The designation MD means machine direction and TD means transverse direction as indicated in FIG. 21. The Compression Test was performed on the specimens of Examples 6 and 9. The results are shown in Table 4, below.

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Table 4

Example	Compressive Modulus (MPa)	Compression Strength (MPa)
6	3.7	4.3
9	63.0	3.4

[00162] There are numerous variables that can be adjusted to tune the absorption band to a region of interest and to the breadth desired. Examples some of the variables are listed in Table 5, below.

Table 5

	Variables
General	Shape and number of sides for the cells
	Pattern of connected cells
	Length of connected cells
	Volume of connected cells
Core	Width
	Height
	Wall thickness
	Air passageway (% of wall area)
	Modulus
	Tan delta
Skin	Thickness
	Hole sizes
	Hole locations
	Multiple smaller holes vs. single hole
	% hole / cell area
	Modulus
	Tan delta

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[00163] Tan delta in Table 5 refers to the ratio of out of phase mechanical modulus to the in-phase modulus ( $E''/E'$ ) as described generally in polymer science textbooks, for example: Introduction to Polymer Viscoelasticity, Aklonis et al., John Wiley & Sons, Inc., 1972.

10 [00164] Further, for example, a scrim may be substituted for the solid skin with holes if most of the scrim is filled in to fill the space between fibers, except for the region of the cell where the sound wave enters the panel (see, e.g., 150a in FIG. 1A).

[00165] Also, for example, the control flexural stiffness and compression strength of the panel can be adjusted by the choice of skin and core modulus (see, e.g., Ch. 12, "Composite Construction Materials Handbook", Robert Nicholls, Prentice-Hall, 1976.

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Examples 10-13

[00166] Thermoformed Underbody Panel (Example 10)

[00167] An acoustically absorbing polypropylene (PP) panel with 0.5 mm PP skins with the design depicted in Figure 4 (with cell 480 connected to channel 460'') had holes drilled into one skin with the following sizes: 490a = 3mm, 490b = 2.6 mm, 490c = 2.6 mm, 490d = 4 mm, 490e = 2.6 mm and 490f = 3 mm. This 8.35 mm thick panel was thermoformed into an automotive underbody panel depicted in Figure 24. The panel was preheated for 25 seconds between two infrared emitting panels positioned approximately 250 mm from the top and bottom surfaces of the panel until its surface temperature reached 170°C. Then the panel was transported within the opening between male and female mold halves and the clamps released the panel simultaneously with the mold closing motion. The mold temperature was at 25°C. Once the tool was closed and locked in position, pneumatic cells were inflated to 103.4 KPa to provide approximately 134.5 kN of force that was maintained for 30 seconds, then released to re-open the mold. Fans were subsequently used to cool the part for an additional 10 seconds before it was removed from the mold.

[00168] The part was placed in the Alpha cabin and the random incidence Acoustical Absorption Coefficient measured using the Reverberation Chamber Test (following SAE Test Method J2883). The results for Example 10 are shown in FIG. 26.

[00169] Smaller hole size panel (Example 11)

[00170] An acoustically absorbing polypropylene (PP) panel with 0.5 mm PP skins with the design depicted in Figure 4 (with cell 480 connected to channel 460'') had 1 mm holes drilled in locations 490a, 490b, 490c, 490d, 490e and 490f. The part was placed in the Alpha cabin and the random incidence Acoustical Absorption Coefficient measured using the Reverberation Chamber Test (following SAE Test Method J2883). The results for Example 11 are also shown in FIG. 34. Note that the smaller hole size has shifted the absorption band from the 700-1250 Hz range in Figure 26 to a narrow band at 400-630 Hz and a broader high order band from 950 to 1700 Hz in Figure 34.

[00171] Laminate of two panels (Example 12)

[00172] Two 6'' x 6'' (152 mm x 152 mm) pieces of the starting panel described in Example 10 (not thermoformed) were laminated together as described below. 3M transfer adhesive 467MP (3M Company (St. Paul, MN) (50 µm thickness) was adhered to the bottom of the top piece, then a drill was used to drill through the bottom layer and the adhesive layer with the same sized bit as the holes in the top layer. PTFE alignment pins of 3.95 mm diameter and 17 mm length were

placed into four of the 4 mm holes in the bottom piece. Then the top piece was aligned with the PTFE pins from the bottom piece extending into the just-drilled holes. A platen press was used to put the two panels into intimate contact with 4000 lb force to provide a pressure of 111 psi (766 kPa) for 90 seconds. This 18 mm thick sample was then machined to a 100 mm diameter and some tape used around the perimeter to provide a good seal to the ID of the impedance tube. The sample has one active set of 37 hexagons, that comprise about 55% of the area of the 100mm diameter impedance tube. The normal incidence acoustical absorption test was used to measure the data shown in Figure 35. One can see that the peak absorption has moved from the 700-1250 Hz range in Figure 26 to the 460-860 Hz range in Figure 35. No area correction was applied to this data, although certainly it understates the absorption of a larger panel with much fewer ineffective cells.

[00173] Panel enclosure (Example 13)

The panel of Example 10 was cut into pieces of the following dimensions: Two of 11.3 inch (288 mm) x 9.66 inch (245.5mm), two of 11 inch (279 mm) x 9.66 inch (245.5 mm) and one of 12 inch (305 mm) x 11 inch (279 mm). These were taped together around the backside (without holes) edges to form a box with a bottom but no top and the holes facing the inside of the box. This absorbing panel box fit snugly into a 3/8 inch (9.5 mm) thick polycarbonate box that had dimensions of 12 inch (305 mm) width x 11 inch (279 mm) length x 10 inch (254 mm) height. For the sound source, an iPhone 6 (Apple (Cupertino, CA)) played seven individual tones generated from the NCH Tone Generator application at the phone's full volume. The frequencies were 783.99 Hz, 830.61 Hz, 932.33 Hz, 987.77 Hz, 1046.5 Hz, 1108.73 Hz and 1174.66 Hz. The iPhone playing the seven tones was placed on the bottom of the empty polycarbonate box, and a sound level meter from Radio Shack (CAT NO. 33-2055) (General Wireless Operations, Inc. (Fort Worth, TX)) was held even with the top of the box. 88 dBA was measured as the sound level. The experiment was repeated after sliding the absorbing panel box inside the polycarbonate box. The meter level now read 75 dBA (e.g., a 13 dBA noise level reduction).

[00174] Foreseeable modifications and alterations of this disclosure will be apparent to those skilled in the art without departing from the scope and spirit of this invention. This invention should not be restricted to the embodiments that are set forth in this application for illustrative purposes.

What is claimed is:

1. A panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

2. The panel of claim 1 that exhibits at least one absorption band less than 1400 Hz.

3. The panel of any preceding claim that exhibits a flexural rigidity of at least 1 N-m<sup>2</sup> per meter of width.

4. The panel of any preceding claim that exhibits a compression strength of at least 0.35 MPa.

5. A method of making the panel of any preceding claim, the method comprising:  
providing the first layer;  
providing the second layer;  
extruding the core; and  
laminating the first and second layers to the core.

6. A panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid

communication between a series of at least 3 cells, wherein at least 50 percent of the openings in a cell wall emanate from either the first or second layer, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

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7. An article comprising a panel, the panel comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the panel is a flat panel or a shaped panel.

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8. The article of claim 7, wherein the article is an automotive part selected from the group consisting of an engine cover, a wheel well liner, an underbody shield, a headliner, a trunk cover, a tonneau cover, a floor mat, a hood liner, and a carpet backing.

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9. The article of claim 7, wherein the article is an enclosure, a duct, or a sound barrier; wherein the article is a housing of an item that emits sound, wherein the article absorbs at least one acoustical frequency of less than 1400 Hz (in some embodiments, less than 1300 Hz or even less than 1200 Hz); or wherein the article is selected from the group consisting of a wall, a floor, a ceiling and a door or panels added to a wall, a floor, a ceiling or a door.

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10. A panel comprising first, second, and third layers, each of the first, second, and third layers having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of connected cells and a plurality of walls extending from the second surface of the second layer to the first surface of the third layer, wherein some of the cell walls have openings providing fluid communication between a series of

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at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the series.

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11. A laminated article comprising first and second panels, each of the first and second panels comprising first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the  
10 second surface of the first layer to the first surface of the second layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening  
15 extending between the first and second major surfaces of the first layer into at least one cell in the series, wherein the second surface of the second layer of the first panel is directly attached to the first surface of either the first layer or the second layer of the second panel.

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12. A method of making a panel, the method comprising:

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generating a panel by an additive manufacturing method;

wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer  
25 providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least  
30 one cell in the series.

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13. A method of making an article, the method comprising:

shaping a panel using a forming process to provide the article, wherein the forming process utilizes pressure, vacuum, or match metal shaping; and

optionally overmolding the panel in an injection molding die during or after the forming process,

5 wherein the panel is optionally pre-heated prior to the forming process, and wherein the panel comprises first and second layers each having first and second opposed major surfaces and a core disposed there between, the second layer being free of any openings between the first and second major surfaces of the second layer, wherein the core has a plurality of walls extending from the second surface of the first layer to the first surface of the second layer providing a series of  
10 connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a first opening extending between the first and second major surfaces of the first layer into at least one cell in the  
15 series

14. A method of making an article, the method comprising:

obtaining at least first and second panels, wherein each panel comprises a layer having first and second opposed major surfaces and a core disposed on the layer, wherein the core has a  
20 plurality of walls extending from the second surface of the layer providing a series of connected cells, wherein some of the cell walls have openings providing fluid communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides, wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that is at least 50 percent of the area of a side of that cell wall, and wherein the layer has at least a first opening extending between  
25 the first and second major surfaces of the layer into at least one cell in the series;

heating at least one of the first and second panels;

contacting the first and second panels such that the core of the first panel is aligned with the core of the second panel; and

holding the first panel and the second panel in contact to form a bond between the core of  
30 the first panel and the core of the second panel as the first and second panels cool to form the article, wherein the core of the first panel and the core of the second panel together form a core disposed between the layer of the first panel and the layer of the second panel and wherein the heating is provided by conduction, vibration, oscillation, radiant energy, or convection of a fluid.

15. A method of making an article, the method comprising:

placing at least a portion of a panel in an injection molding die; and

overmolding at least one mold structure on a surface of the panel in the injection molding

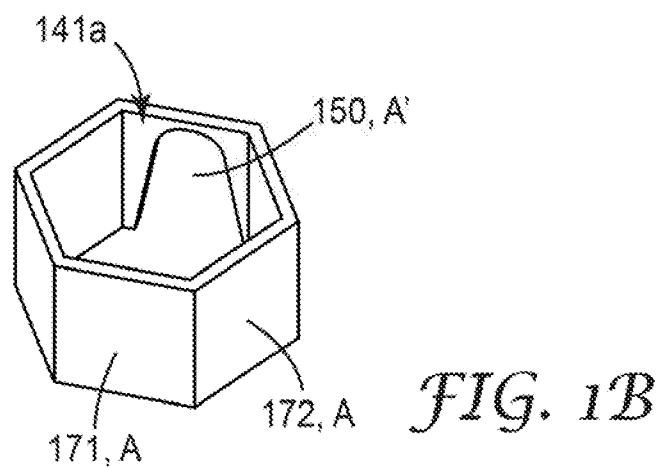
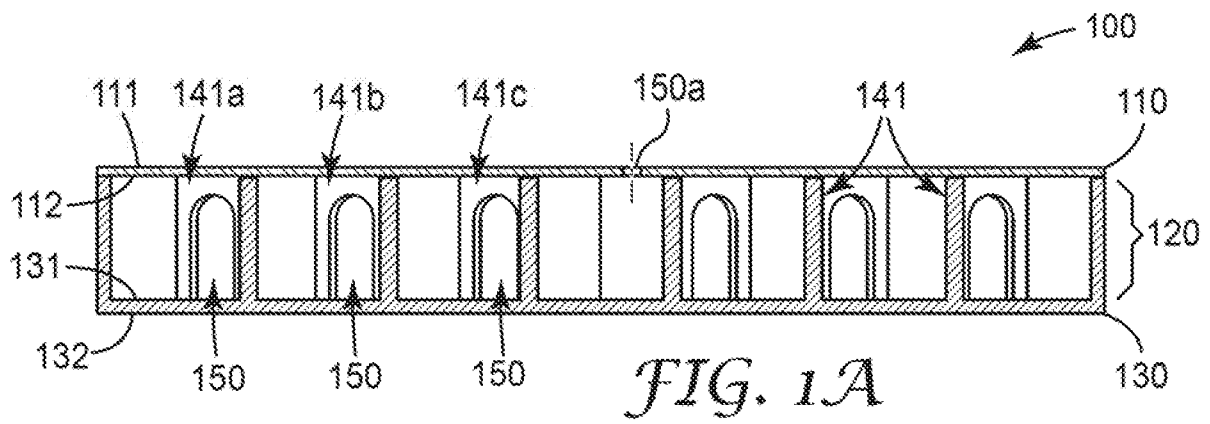
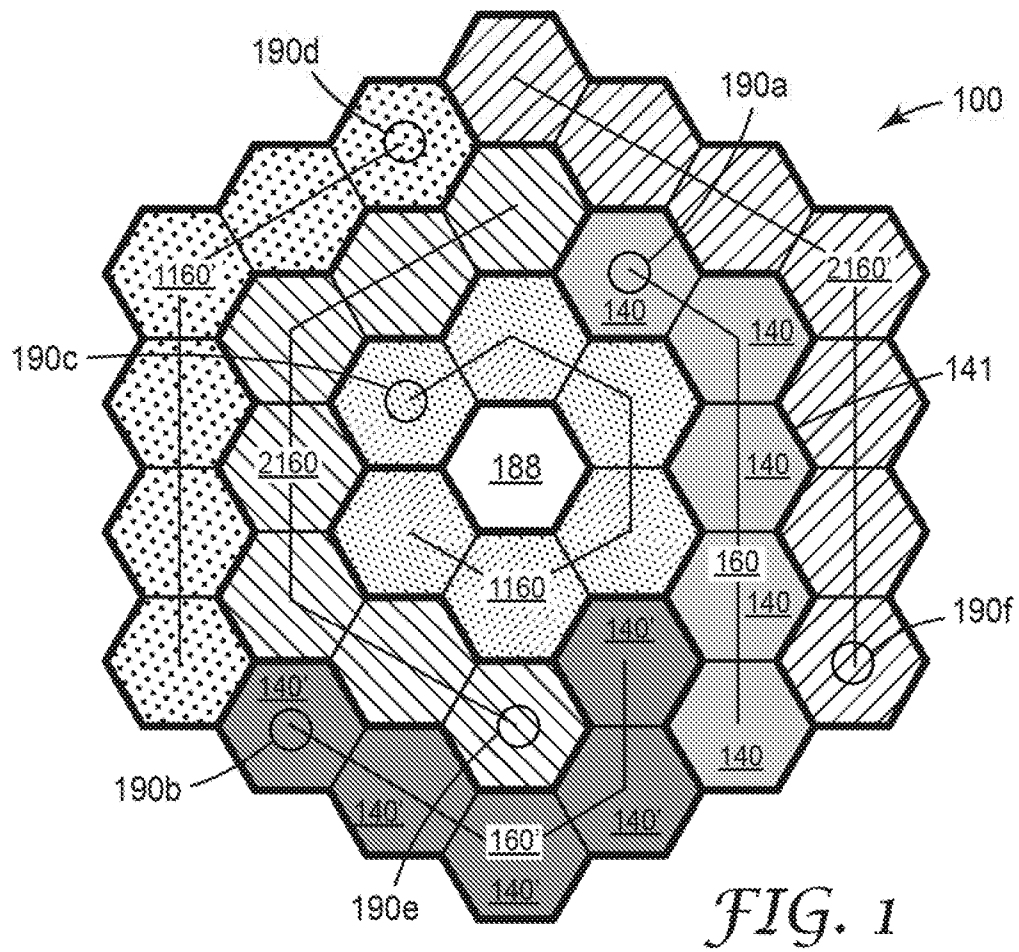
die, thereby forming a material-to-material connection between the surface of the panel and the  
5 mold structure,

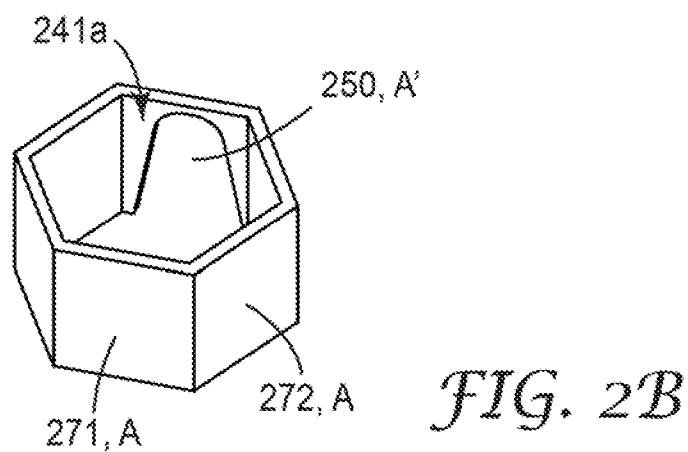
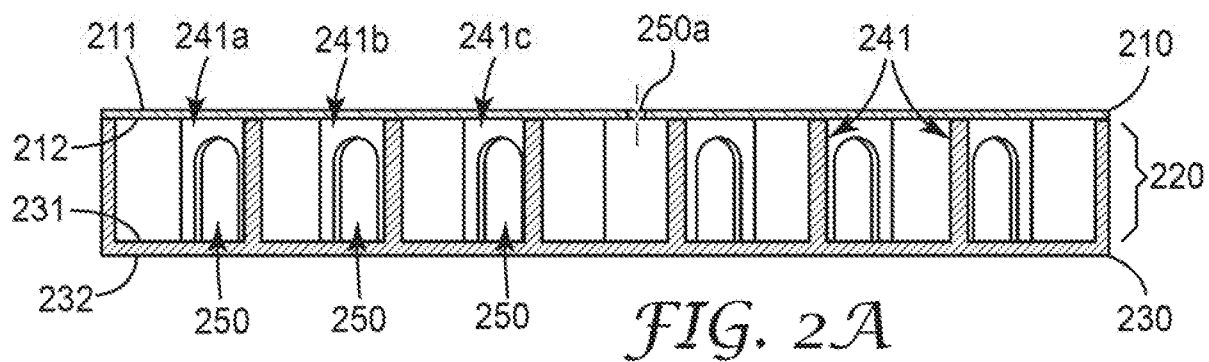
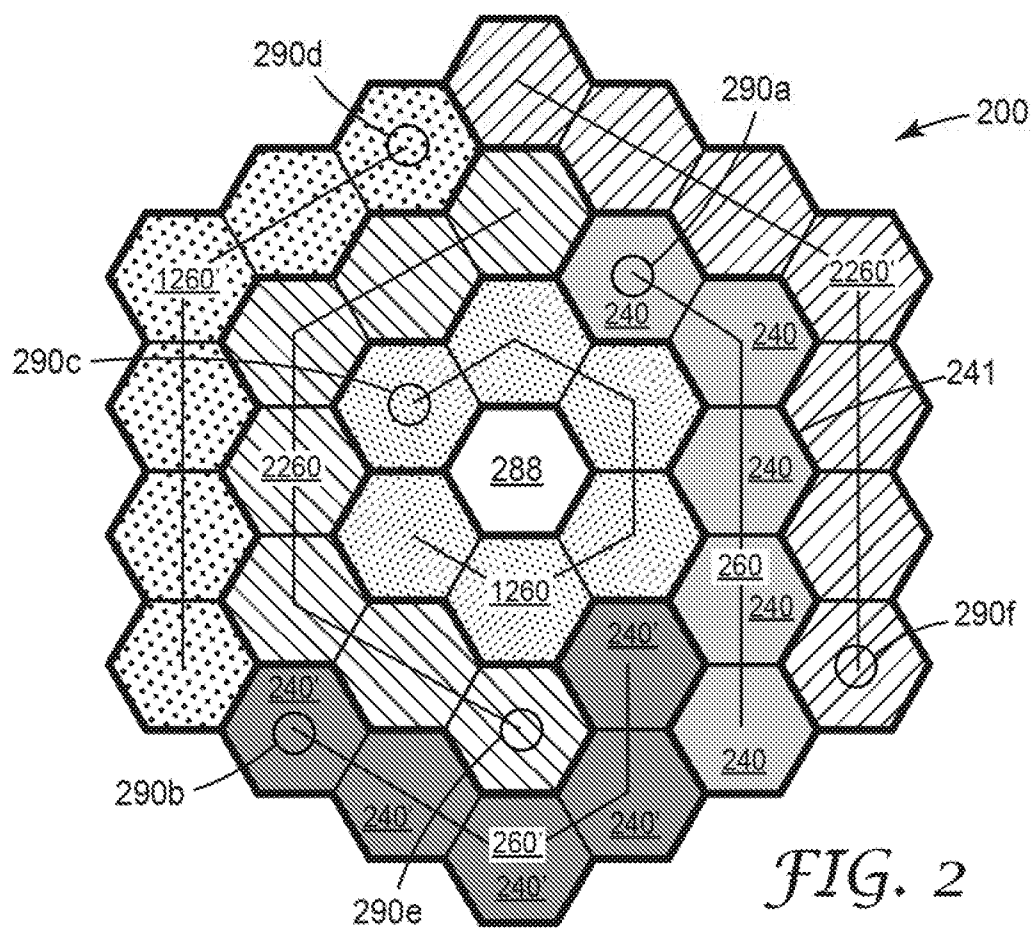
wherein the panel comprises first and second layers each having first and second opposed major  
surfaces and a core disposed there between, the second layer being free of any openings between  
the first and second major surfaces of the second layer, wherein the core has a plurality of walls

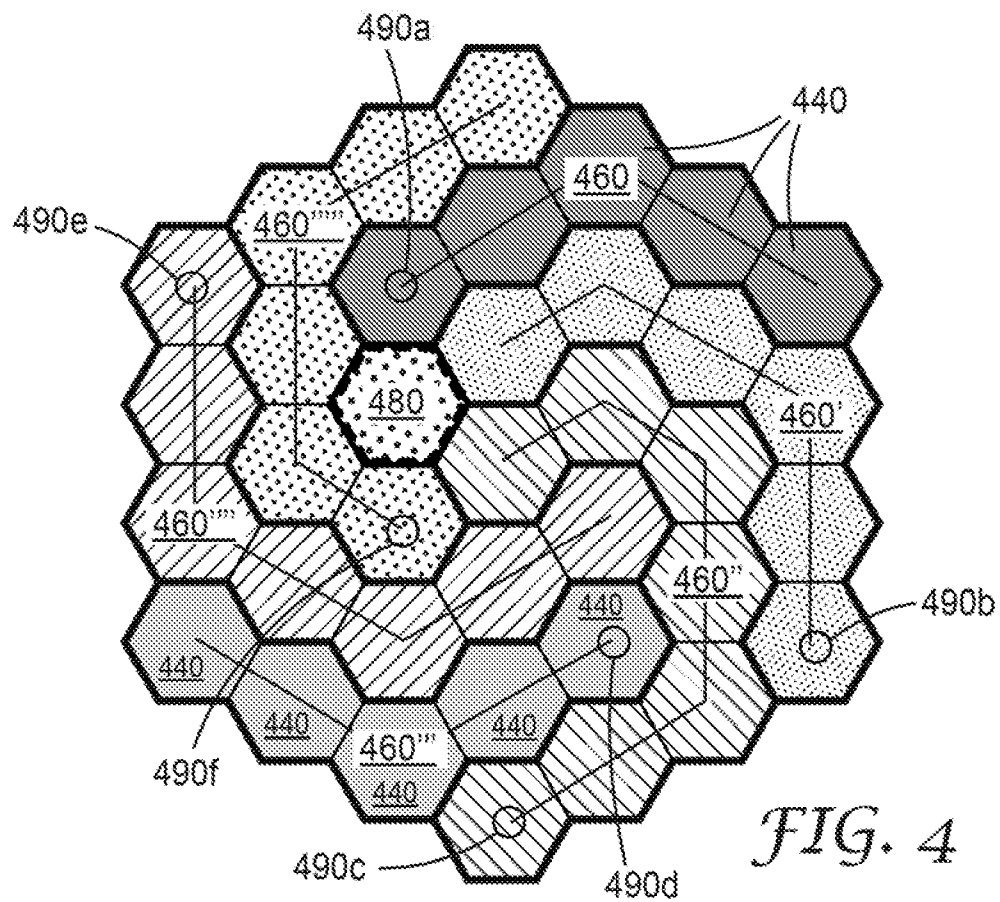
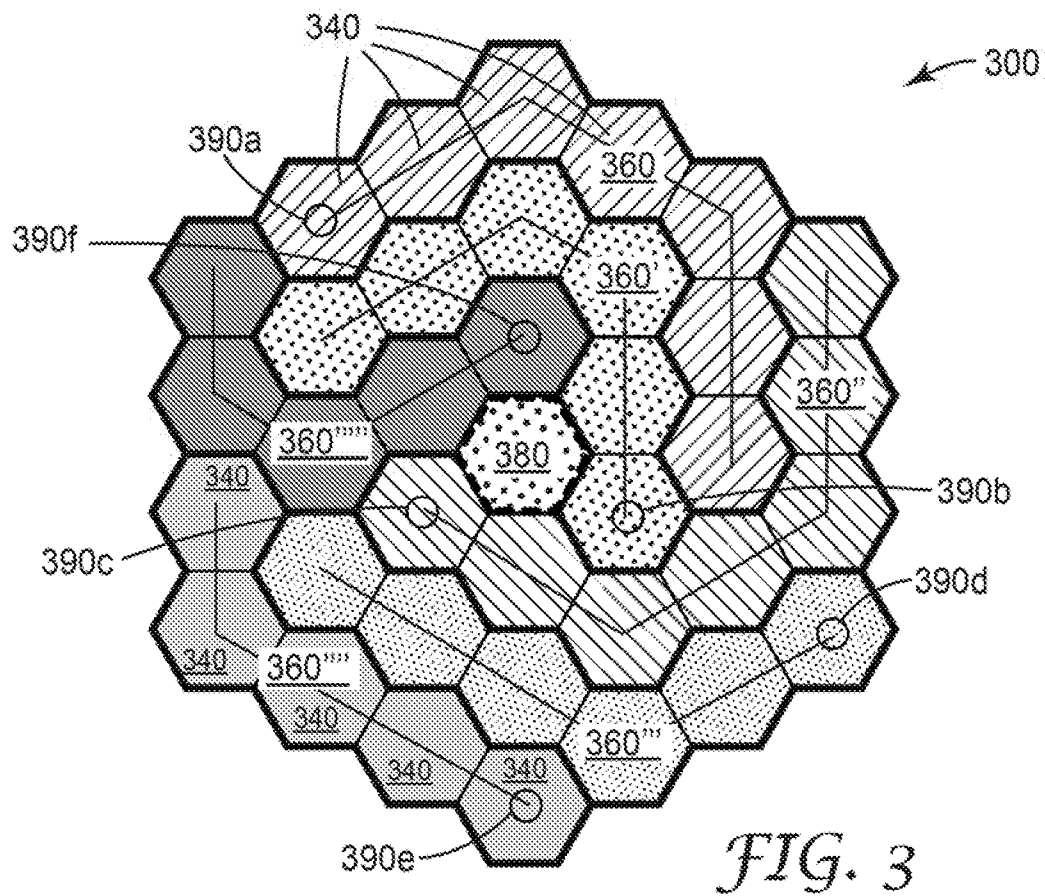
10 extending from the second surface of the first layer to the first surface of the second layer

providing a series of connected cells, wherein some of the cell walls have openings providing fluid  
communication between a series of at least 3 cells, wherein each cell wall has a plurality of sides,  
wherein each side of a cell wall has an area, and wherein the opening in a cell wall has an area that

15 is at least 50 percent of the area of a side of that cell wall, and wherein the first layer has at least a  
first opening extending between the first and second major surfaces of the first layer into at least  
one cell in the series.







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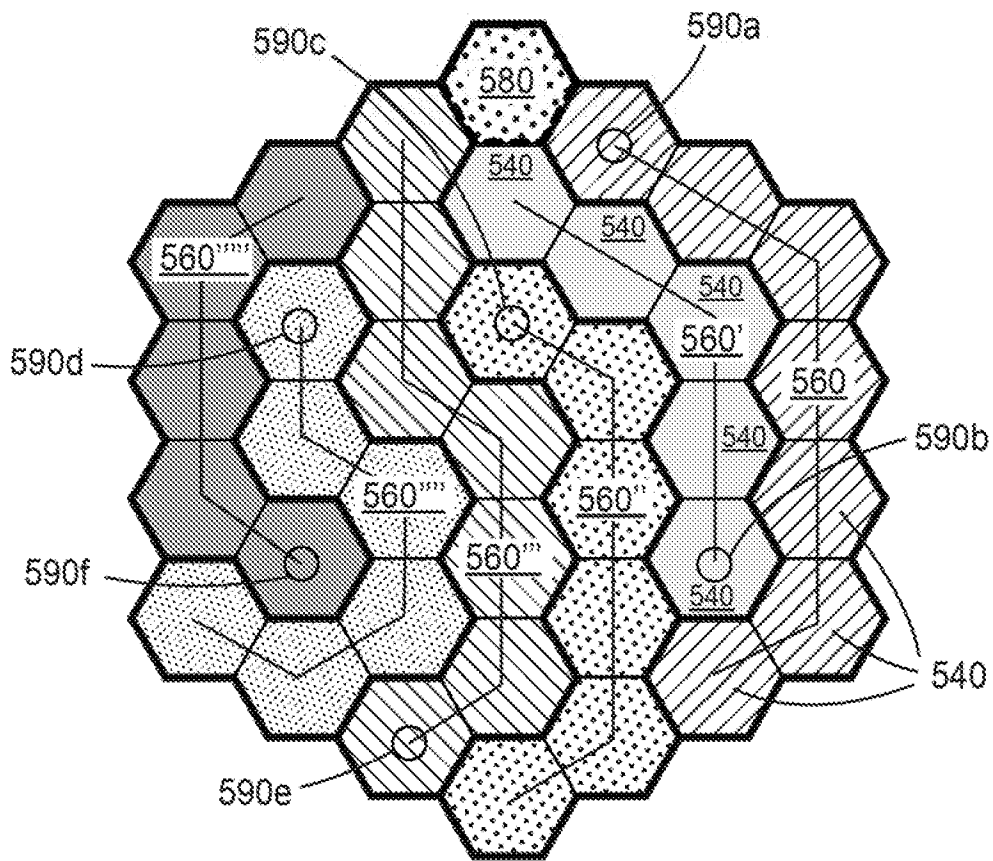


FIG. 5

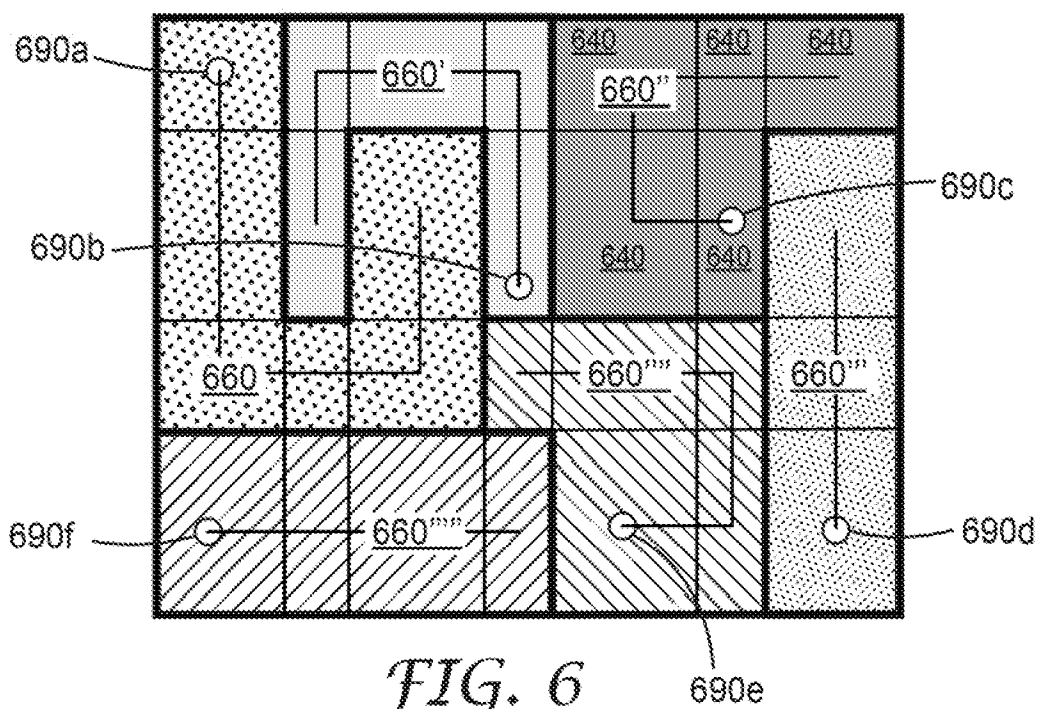
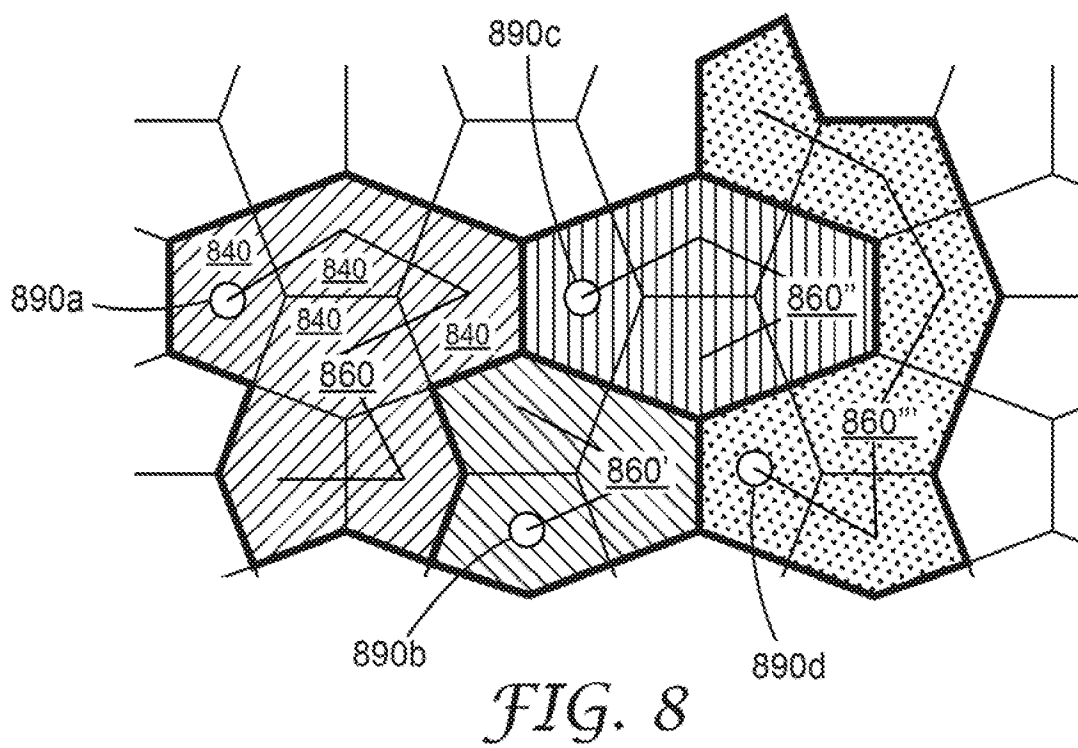
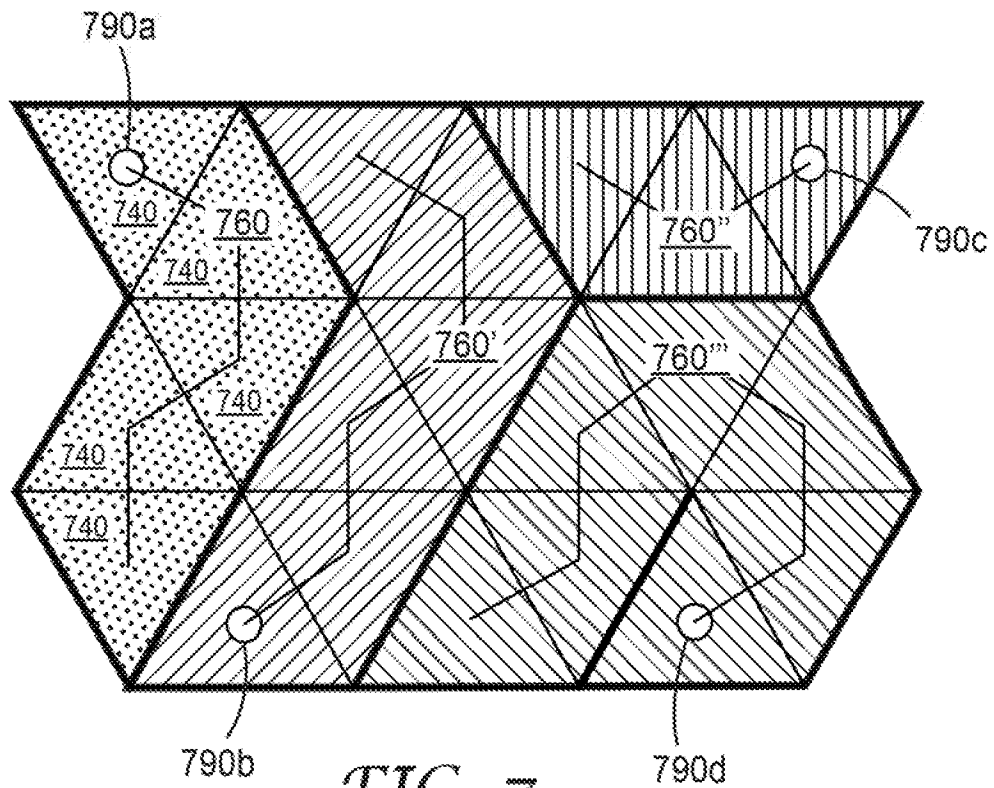


FIG. 6

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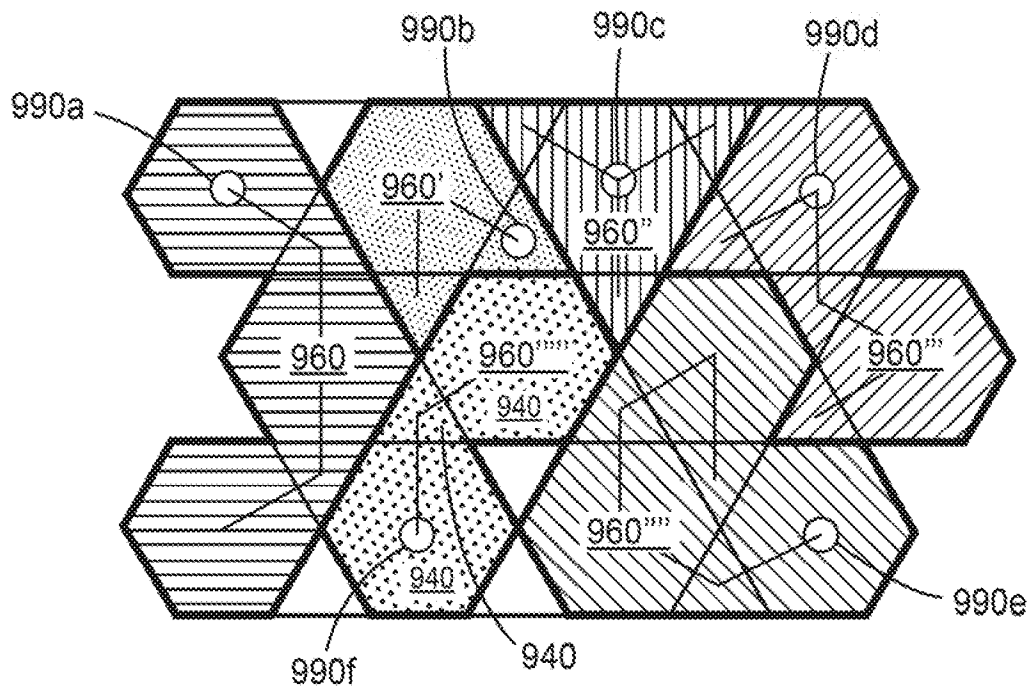


FIG. 9

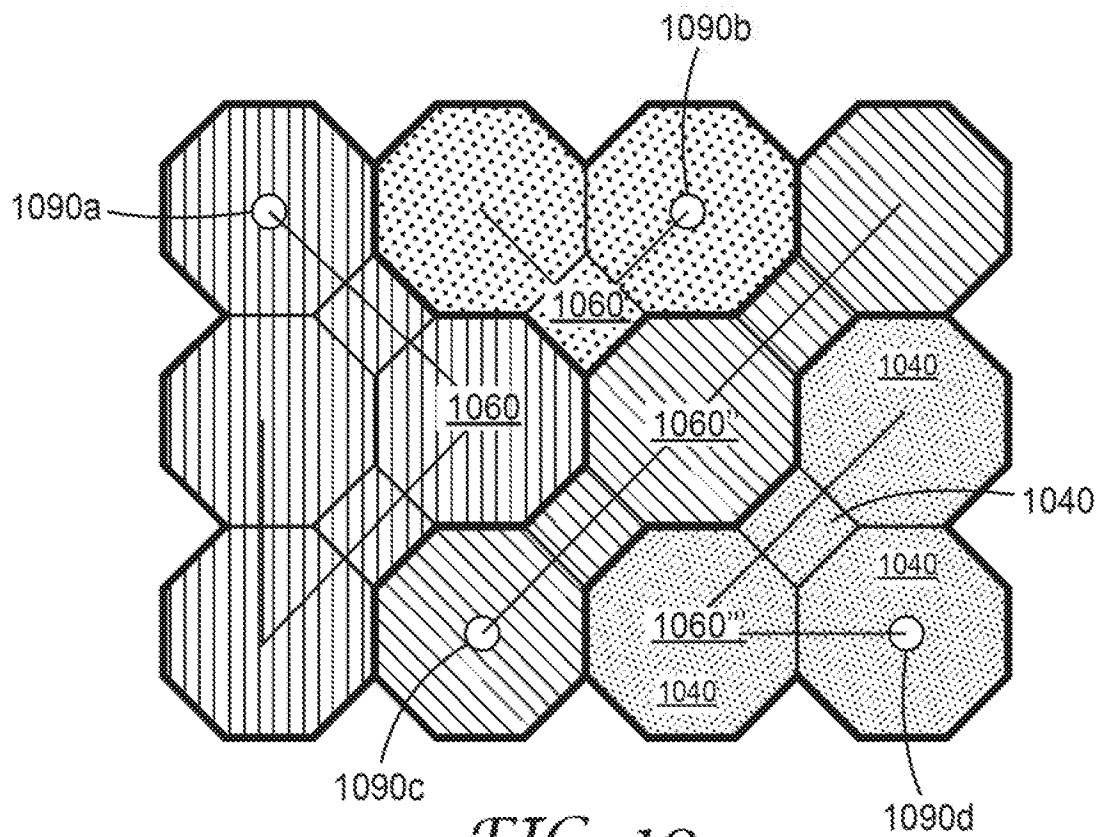
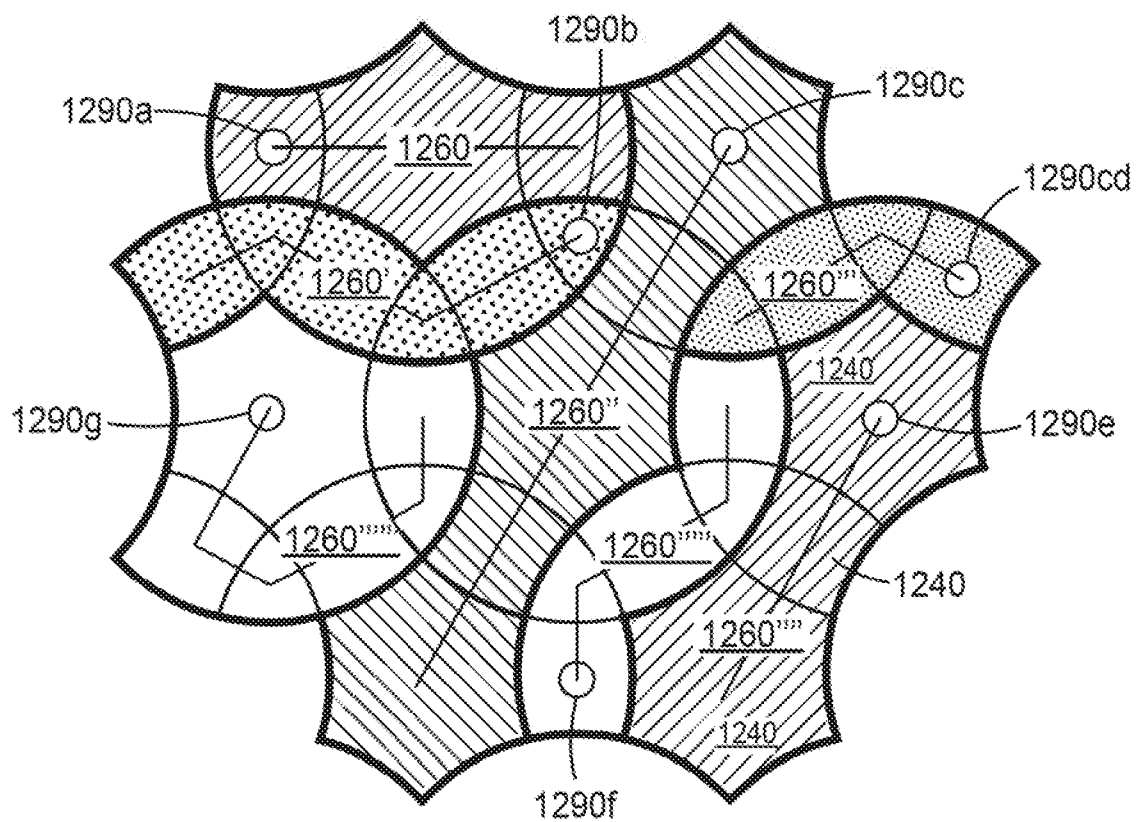
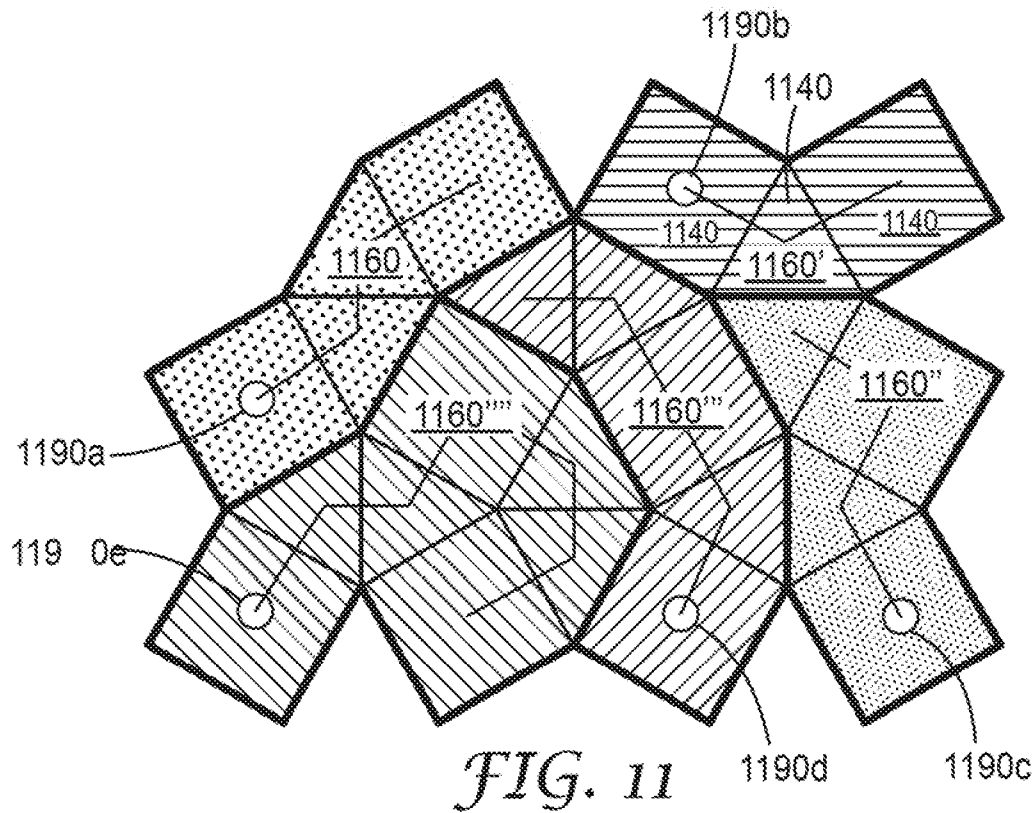
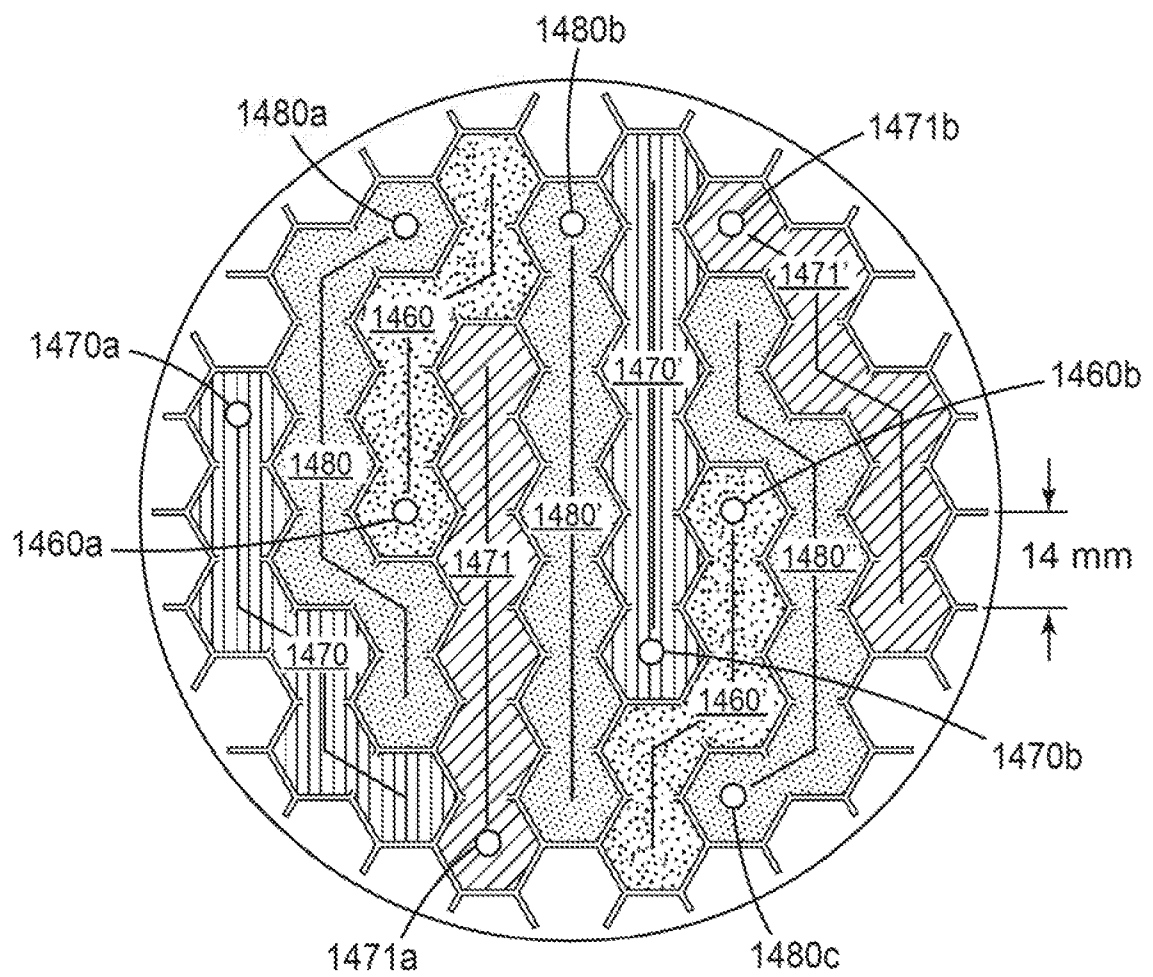
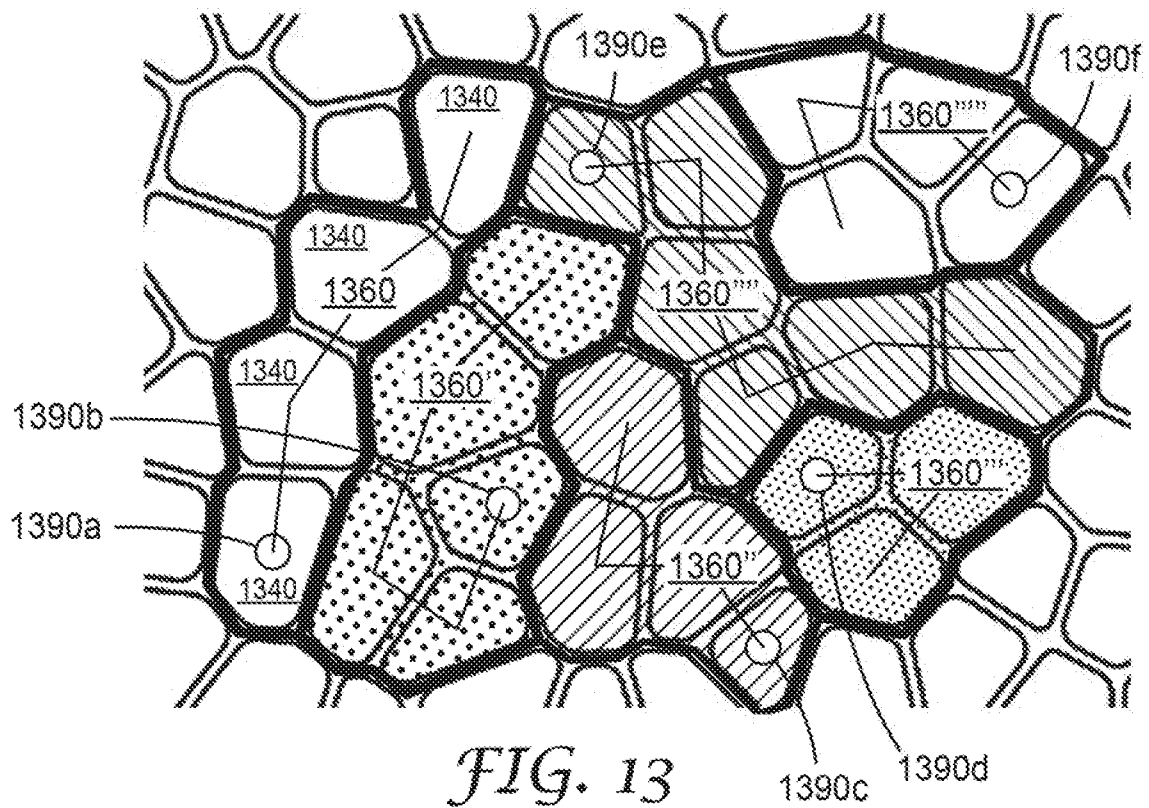


FIG. 10

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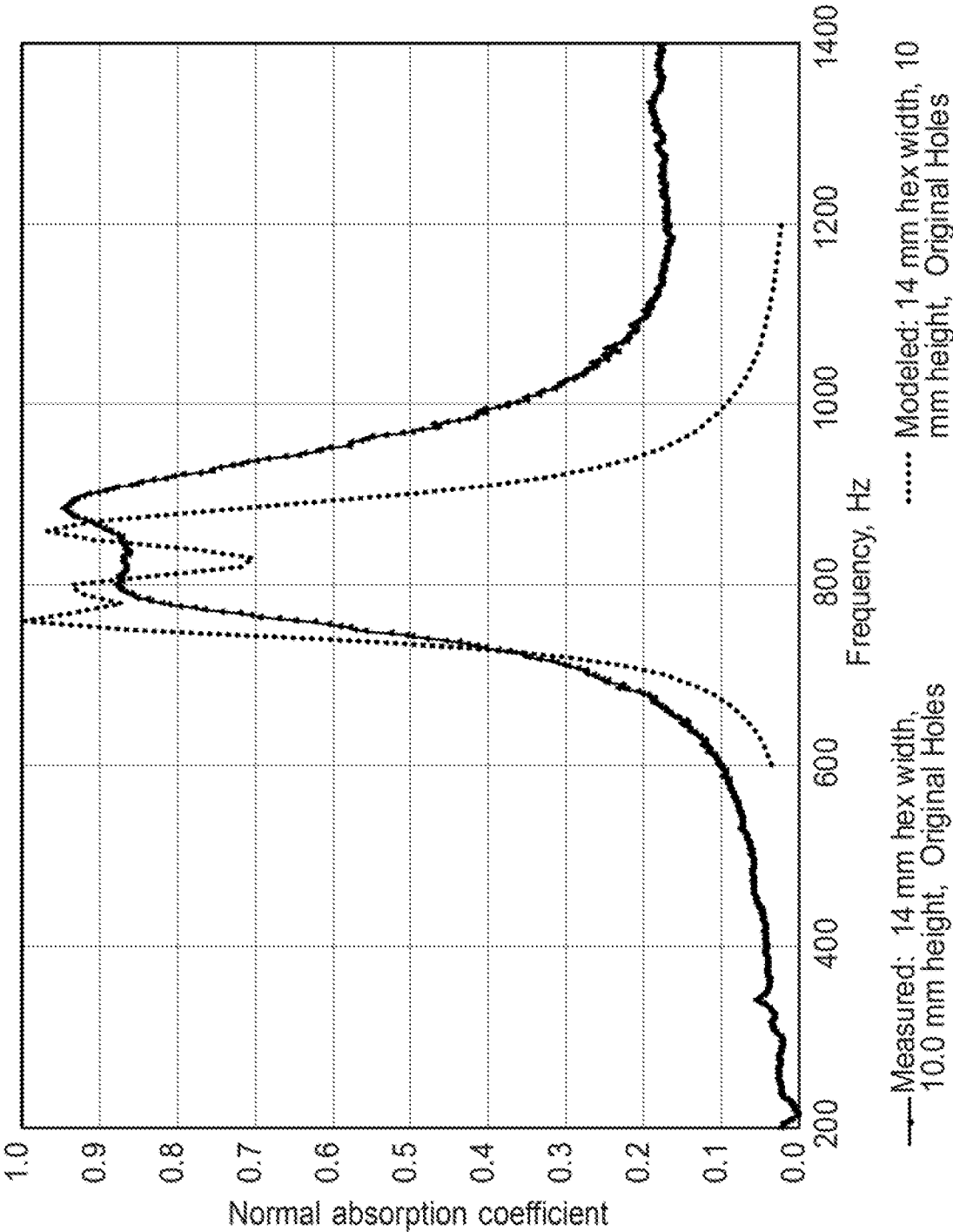


FIG. 15

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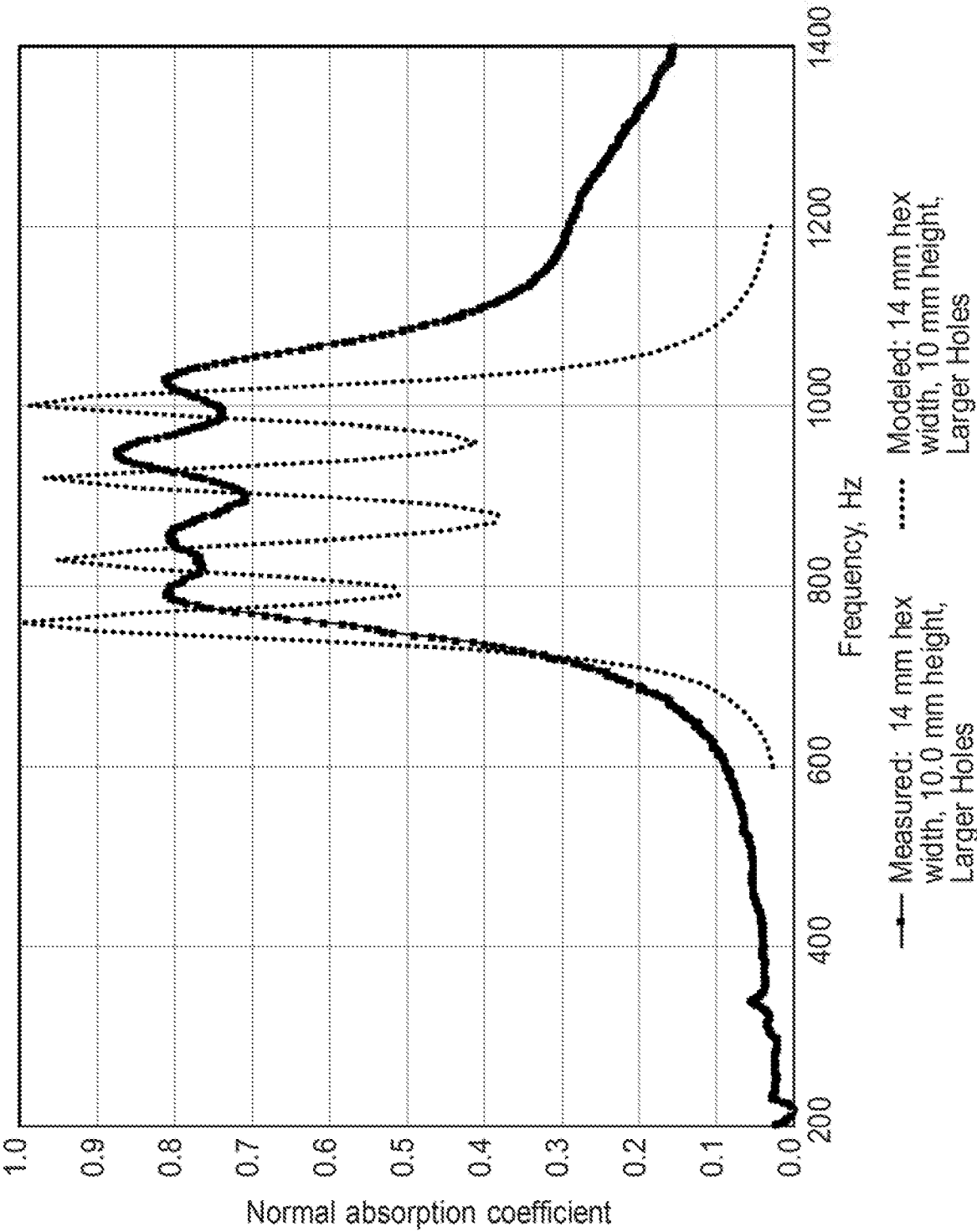


FIG. 16

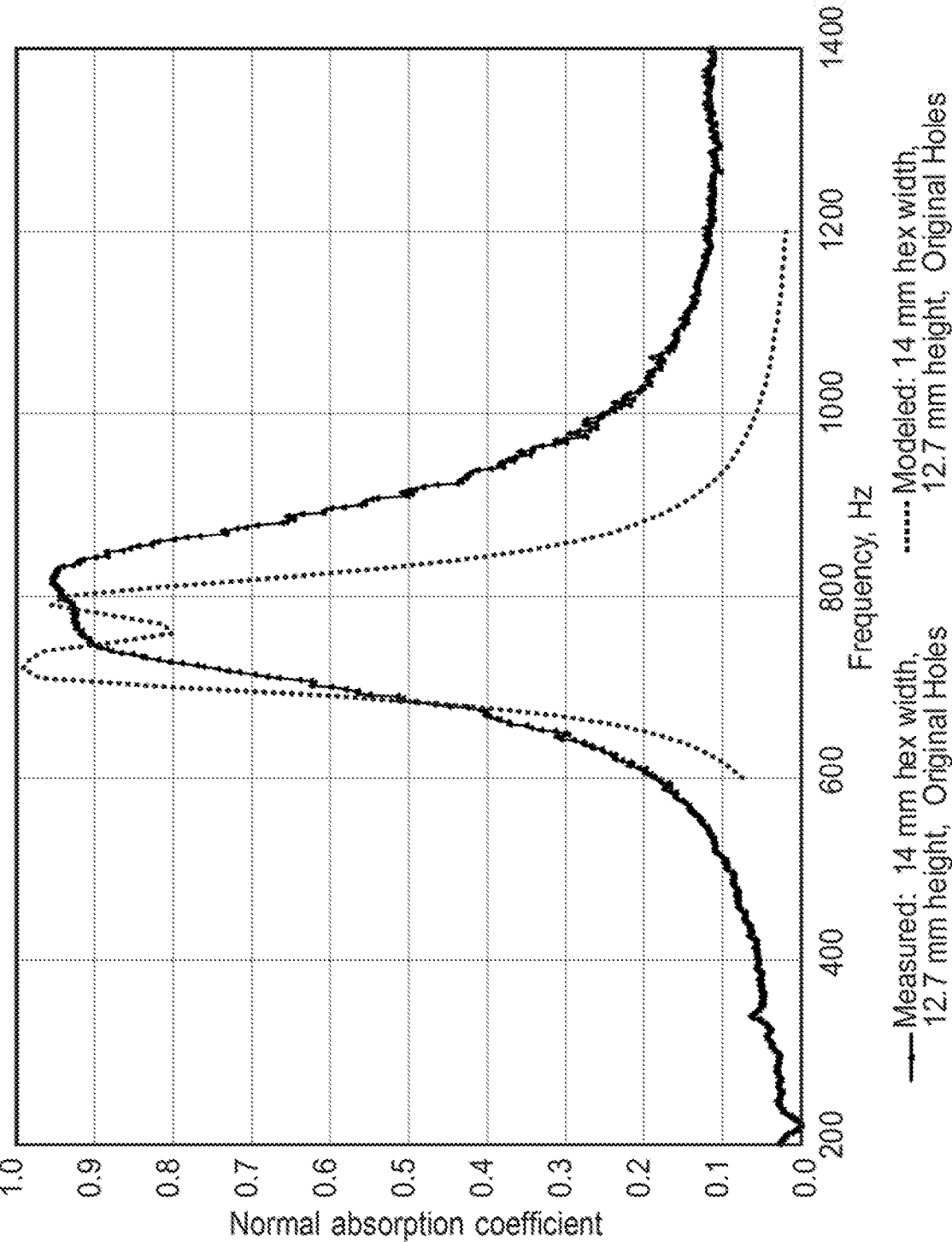


FIG. 17

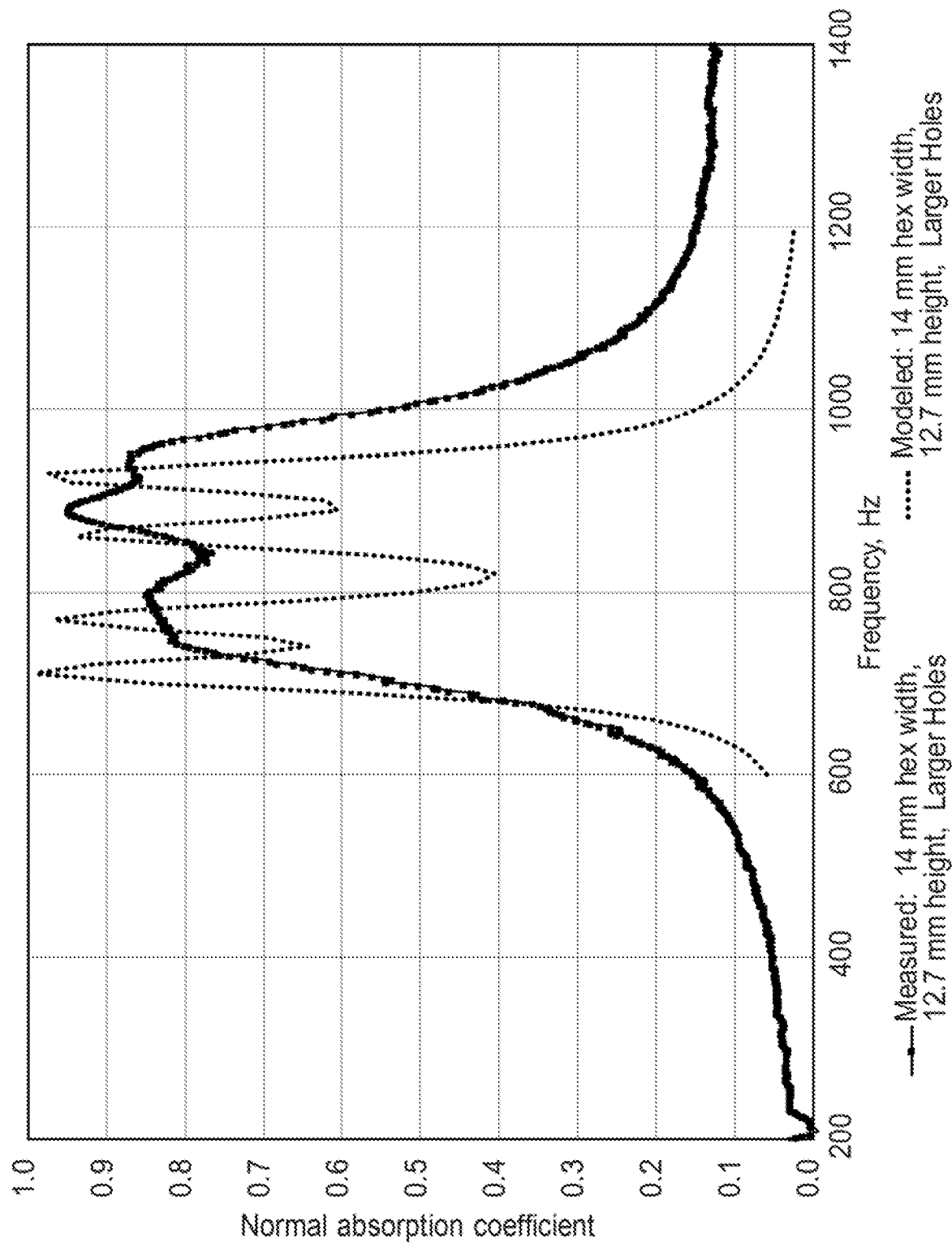


FIG. 18

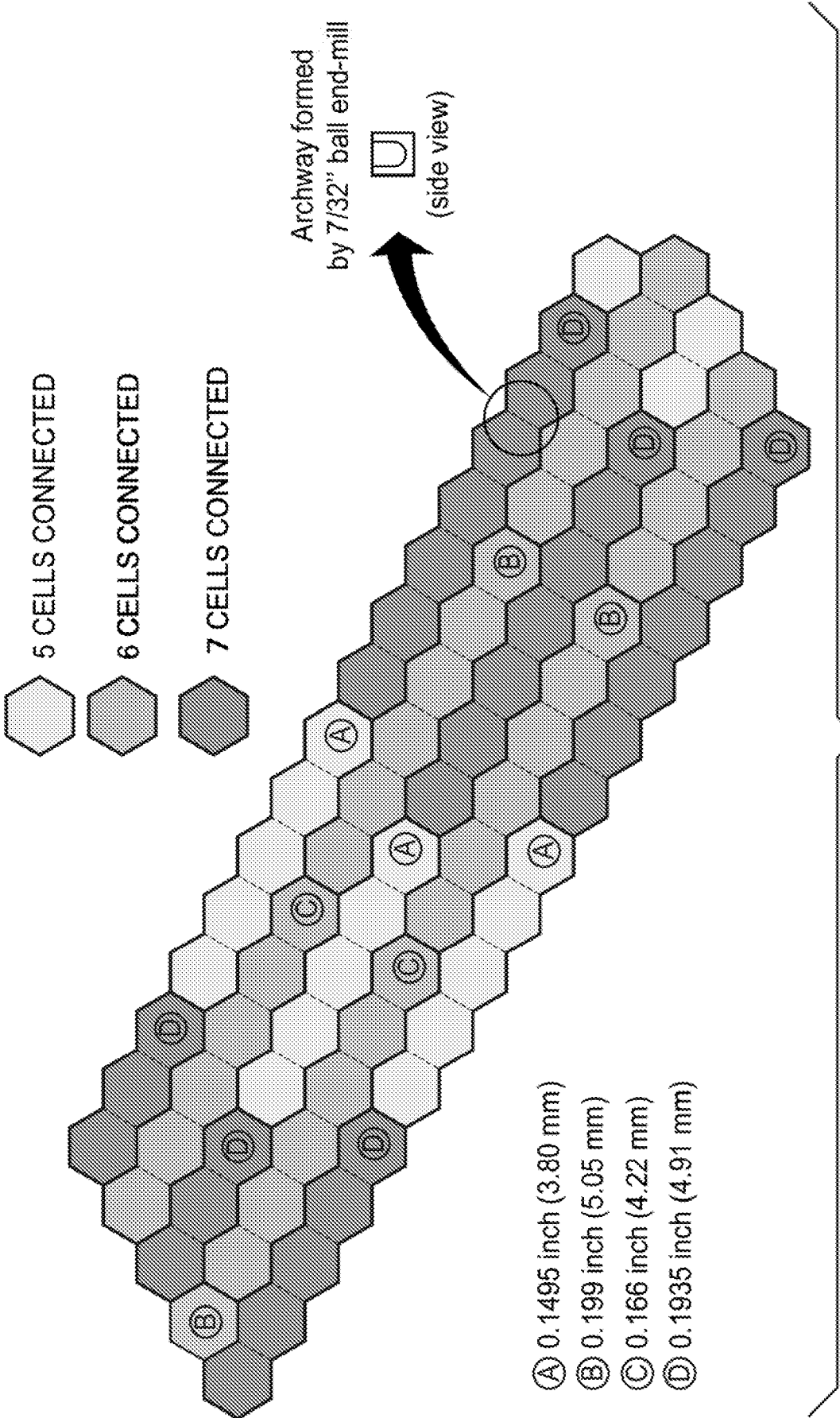
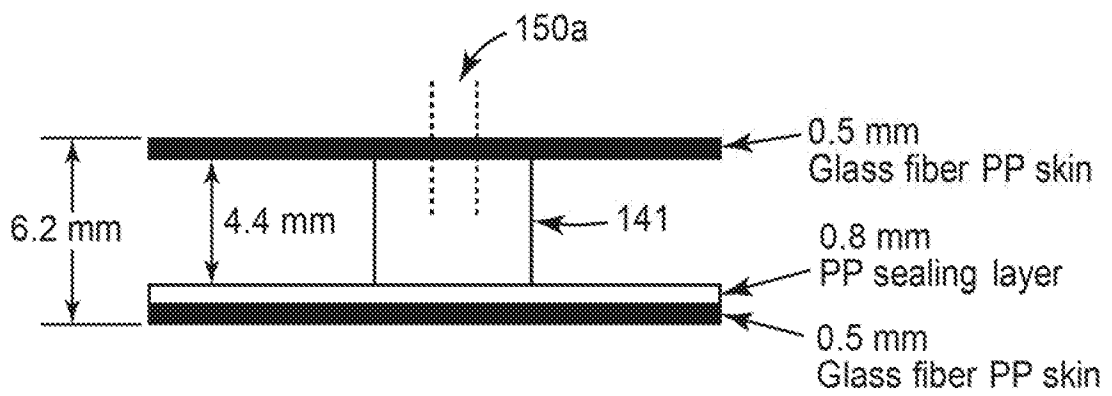


FIG. 19



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*FIG. 20*

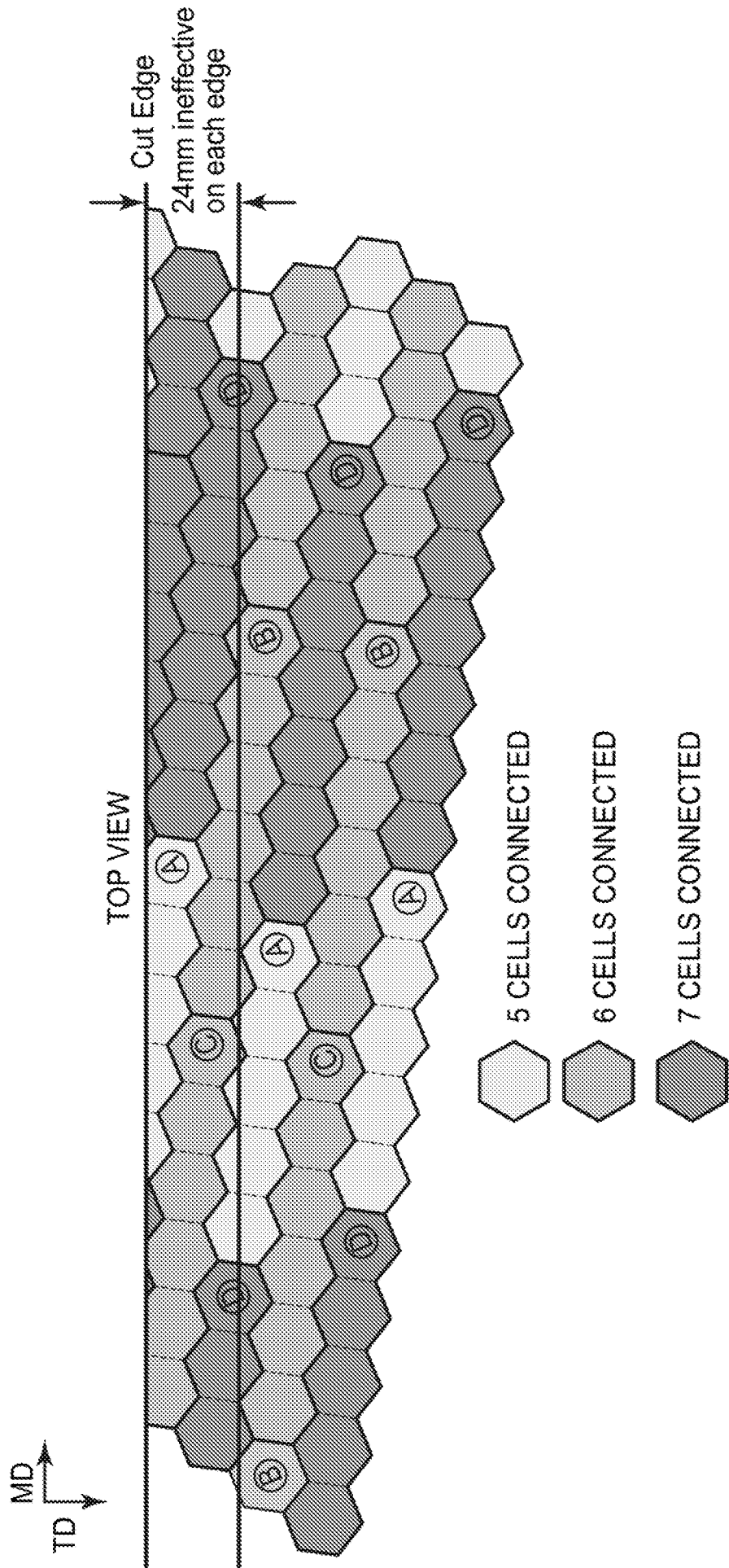


FIG. 21

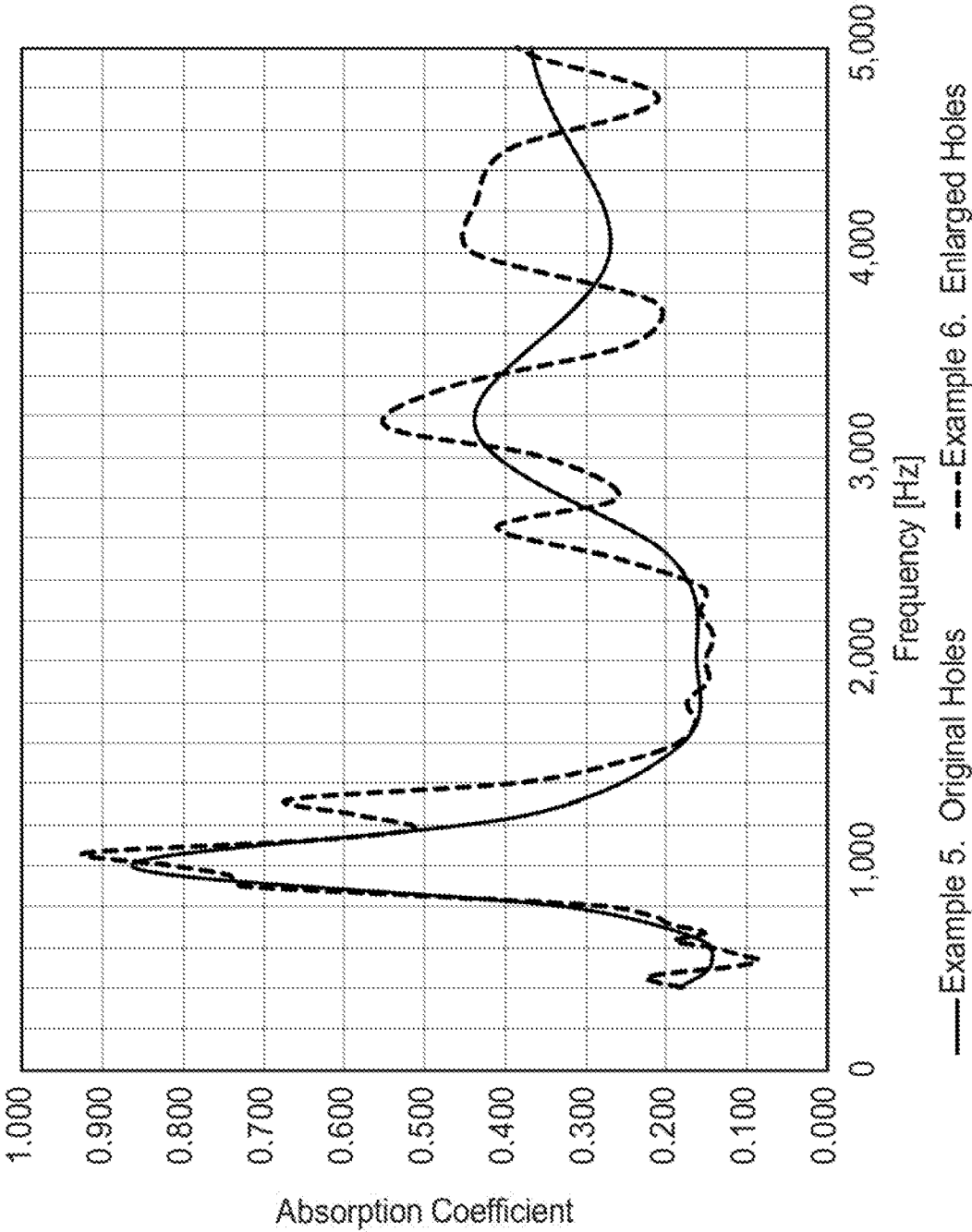
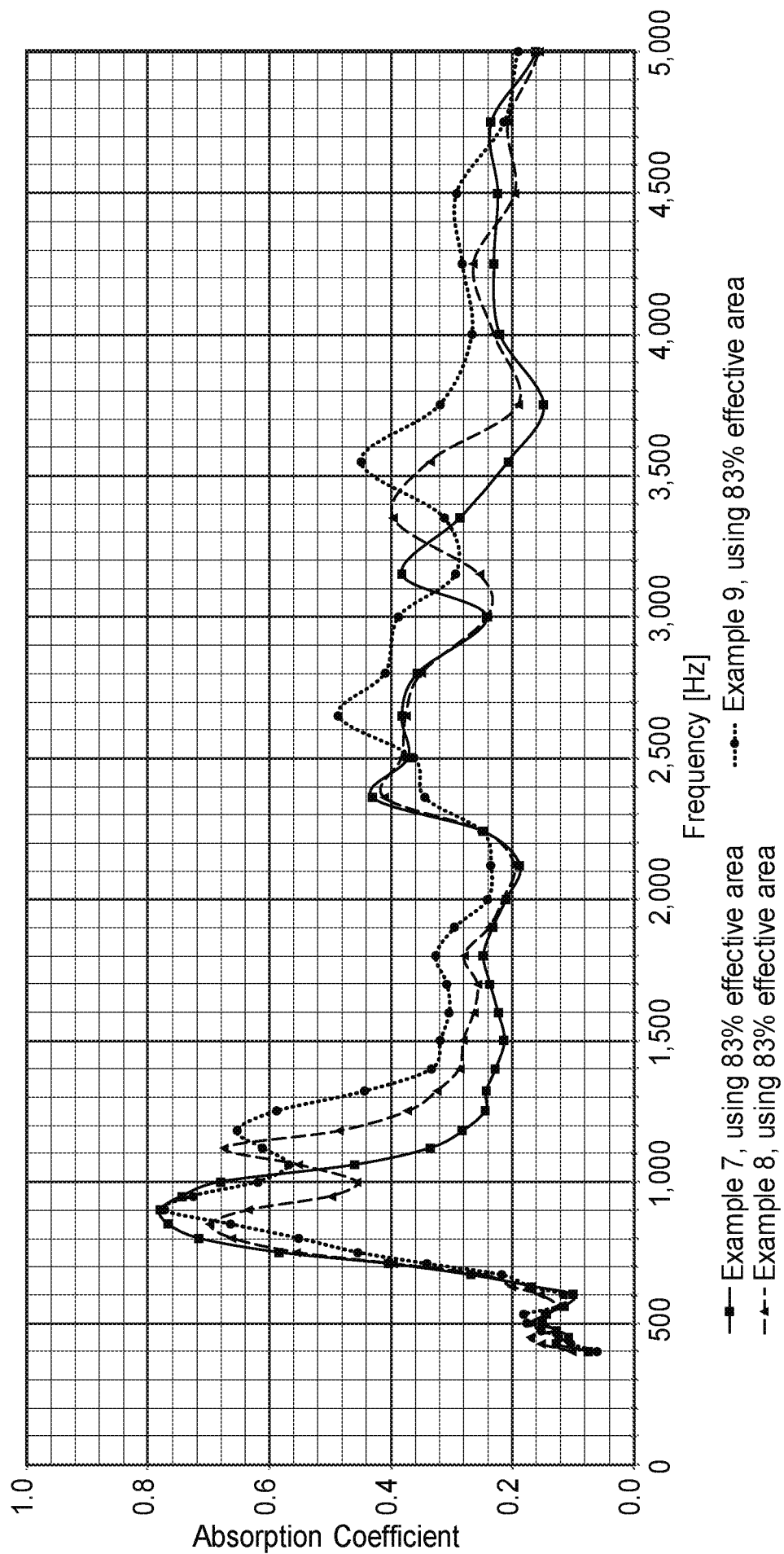
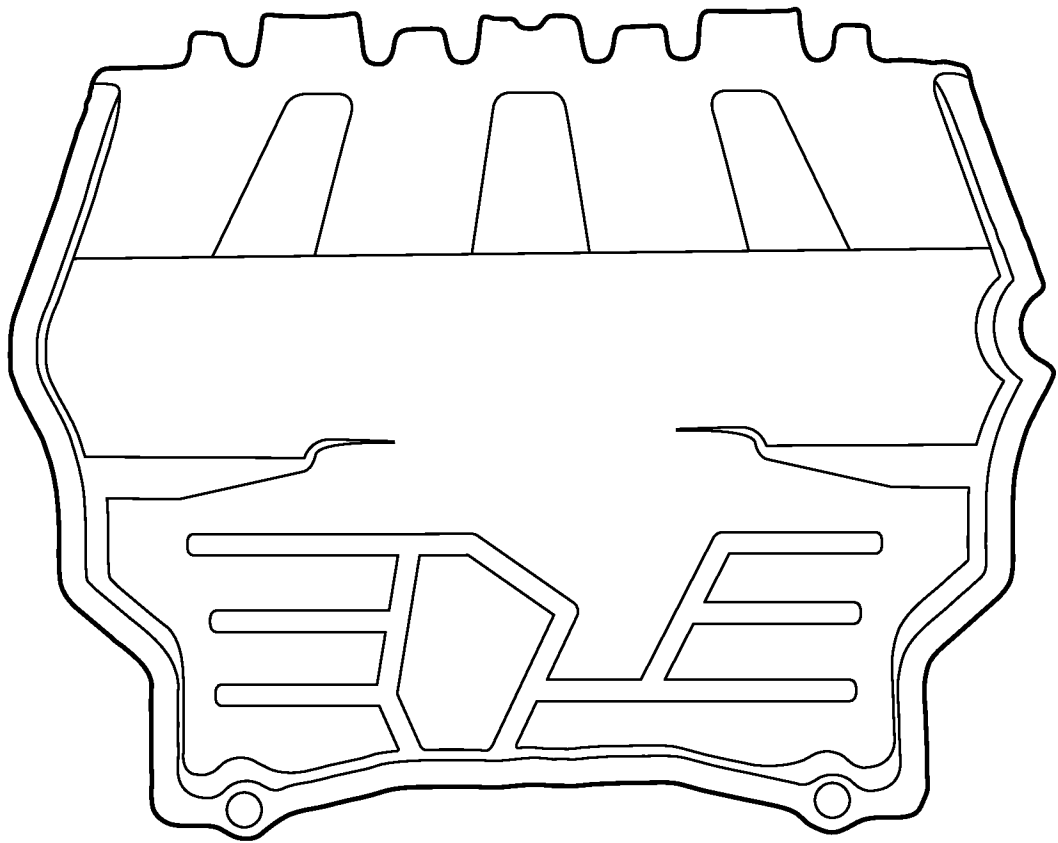


FIG. 22

*FIG. 23*

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*FIG. 24*

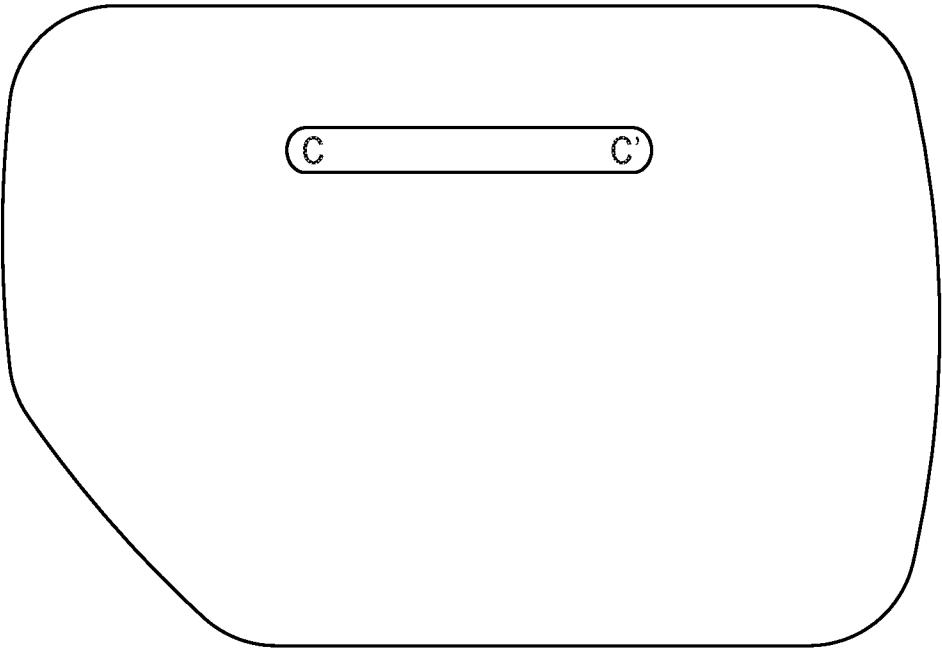


FIG. 25A

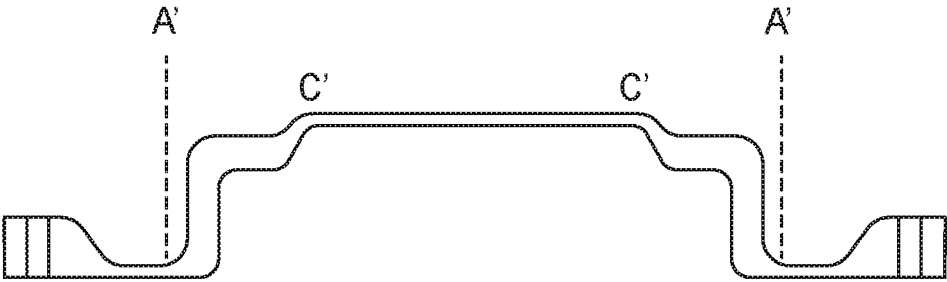


FIG. 25B

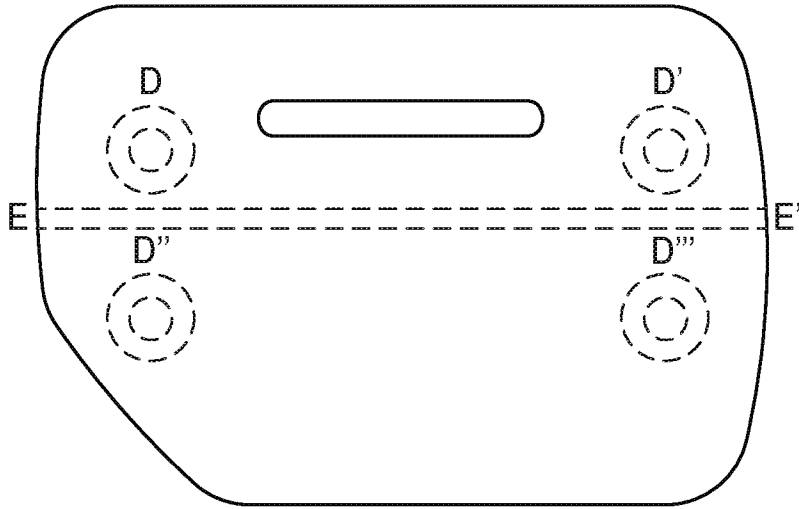


FIG. 25C

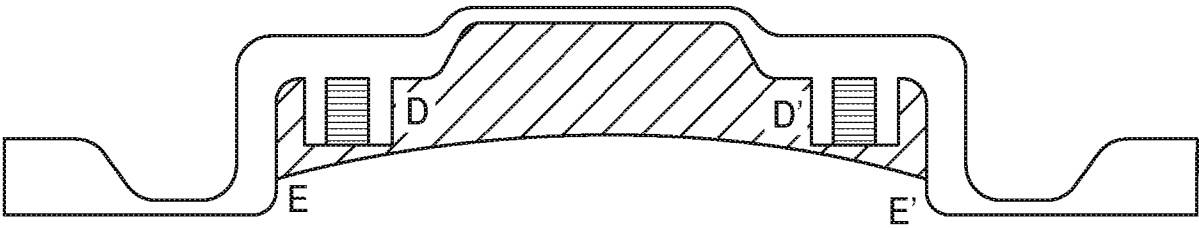


FIG. 25D

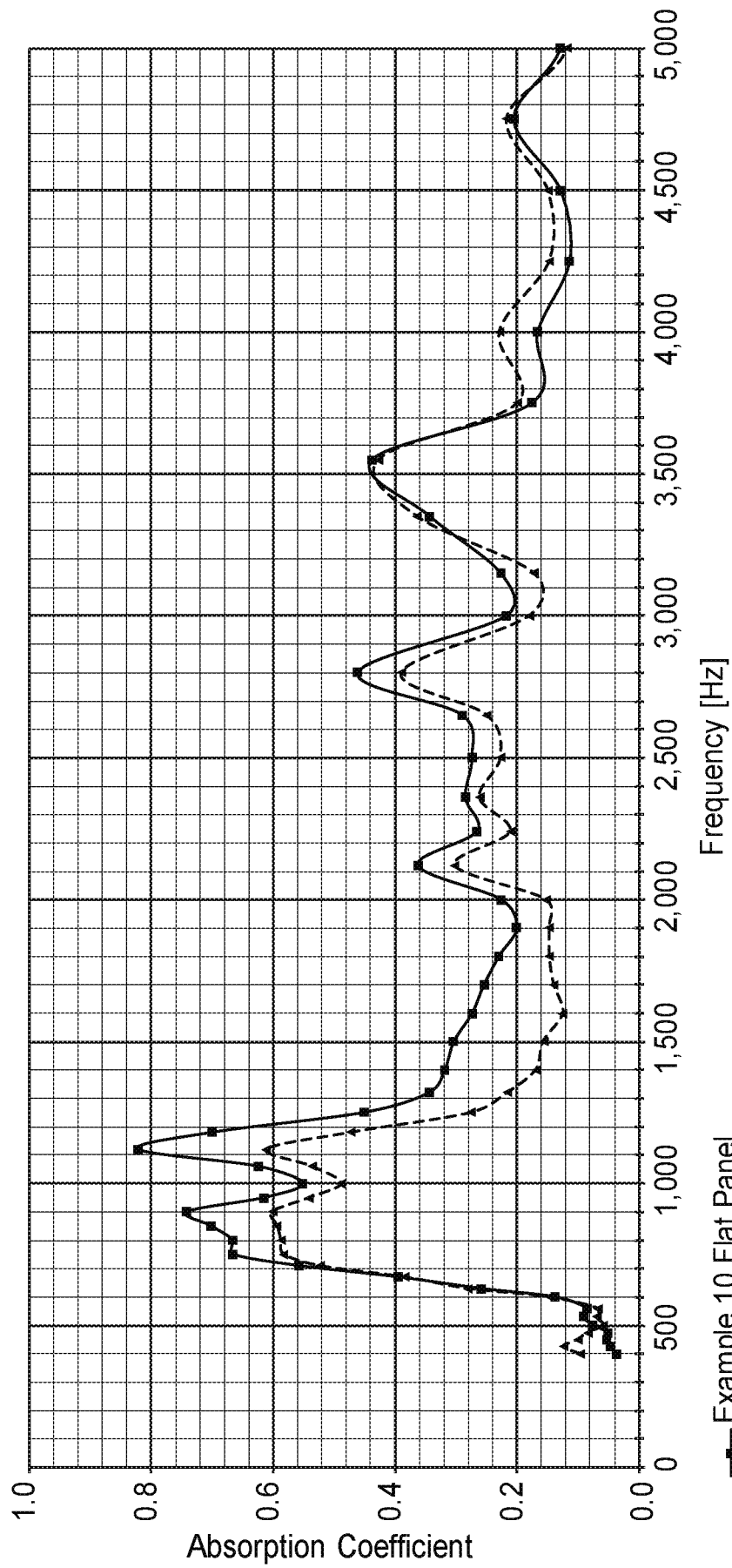
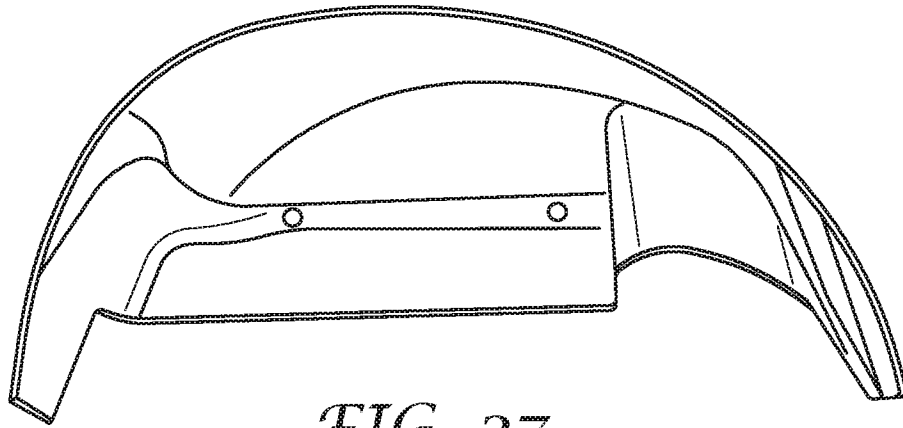


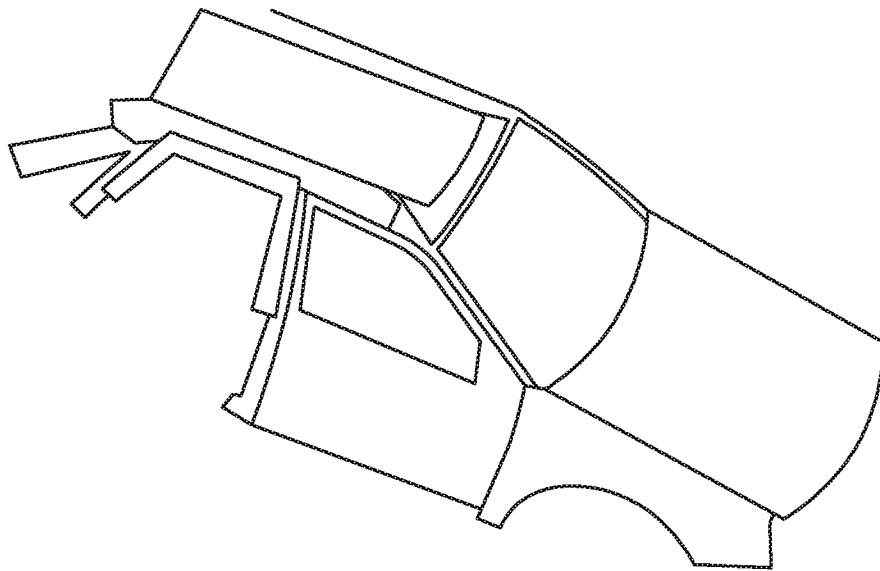
FIG. 26



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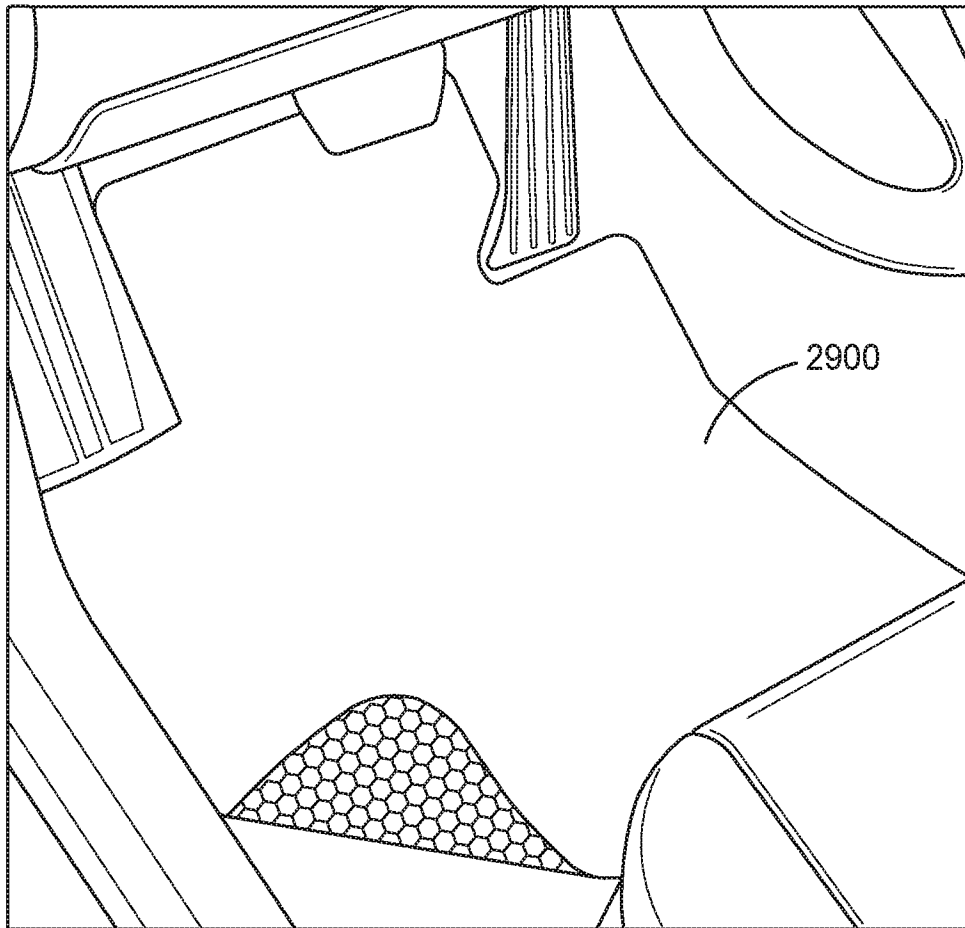
*FIG. 27*



*FIG. 28A*

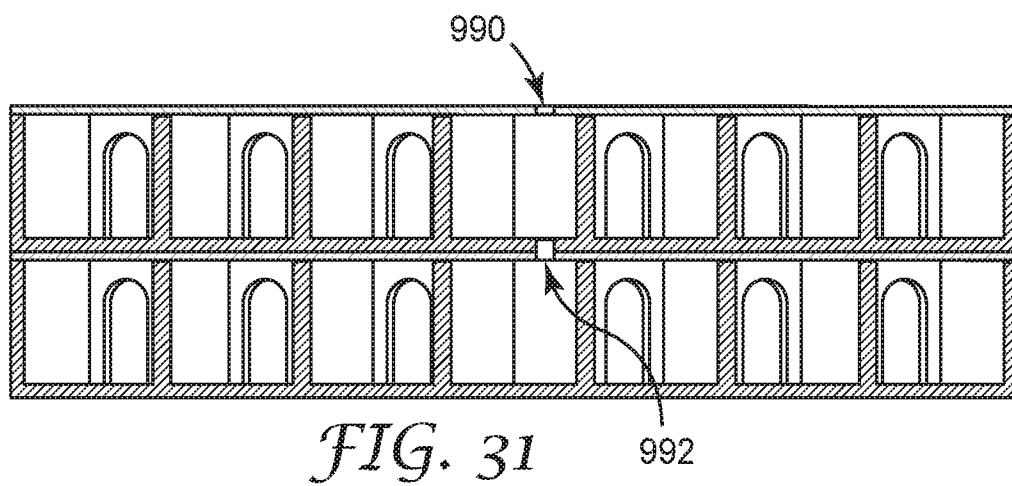
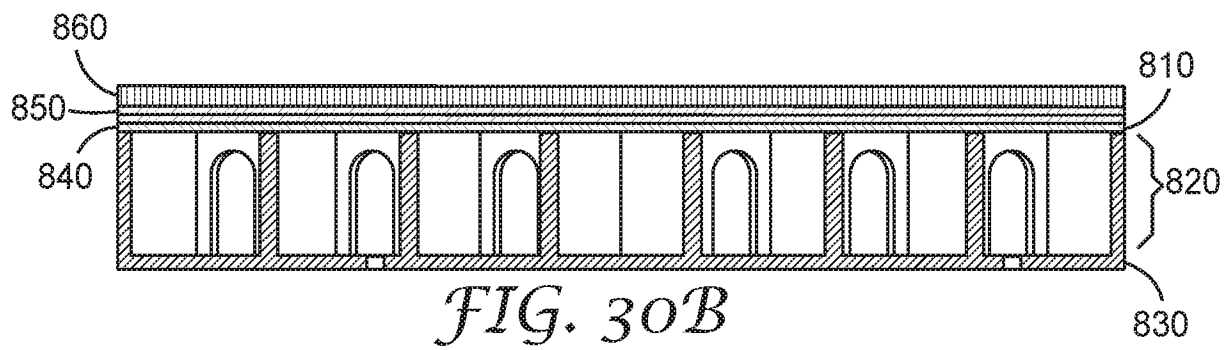
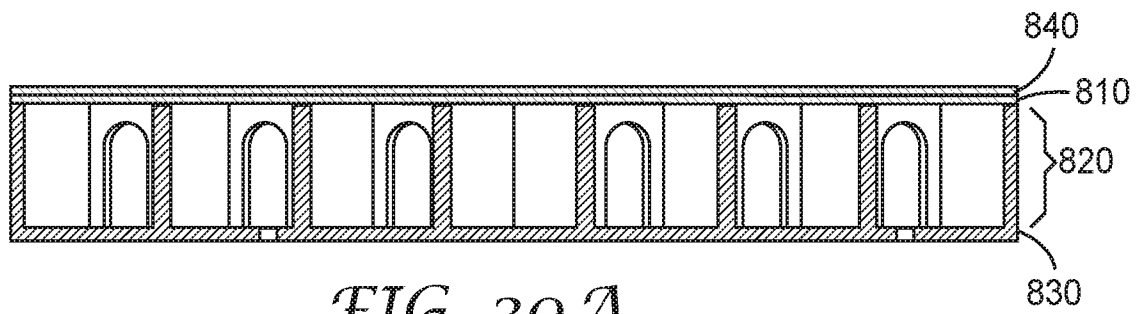


*FIG. 28B*



*FIG. 29*

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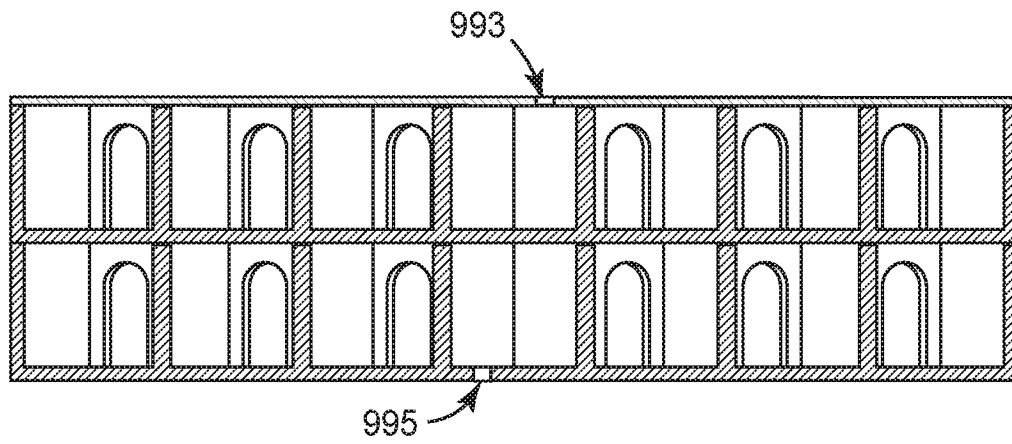


FIG. 32

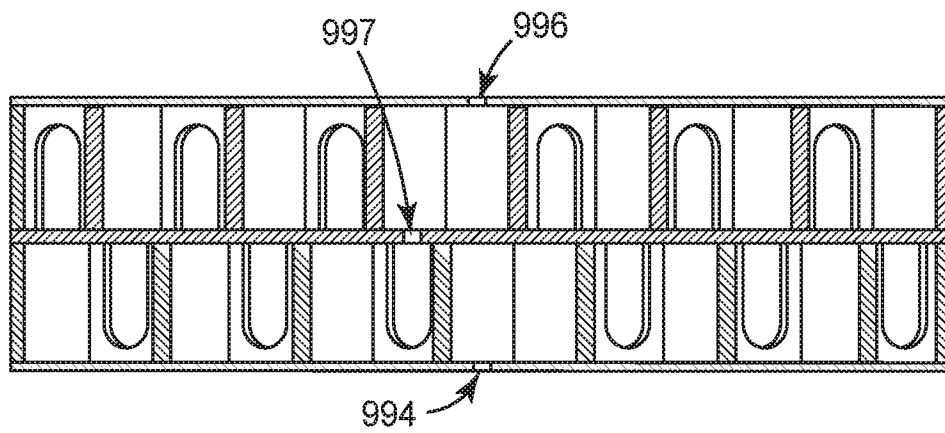


FIG. 33

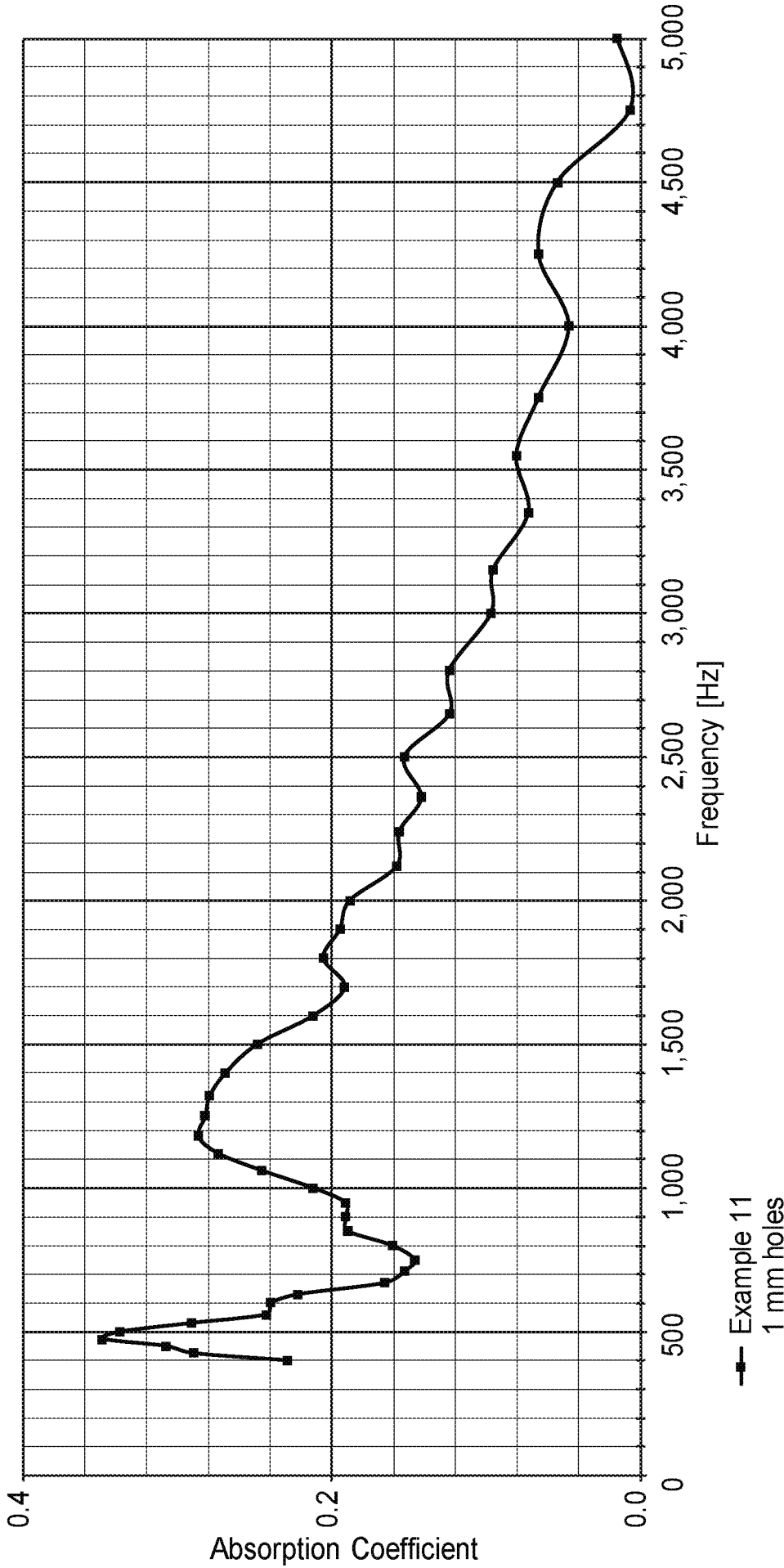


FIG. 34

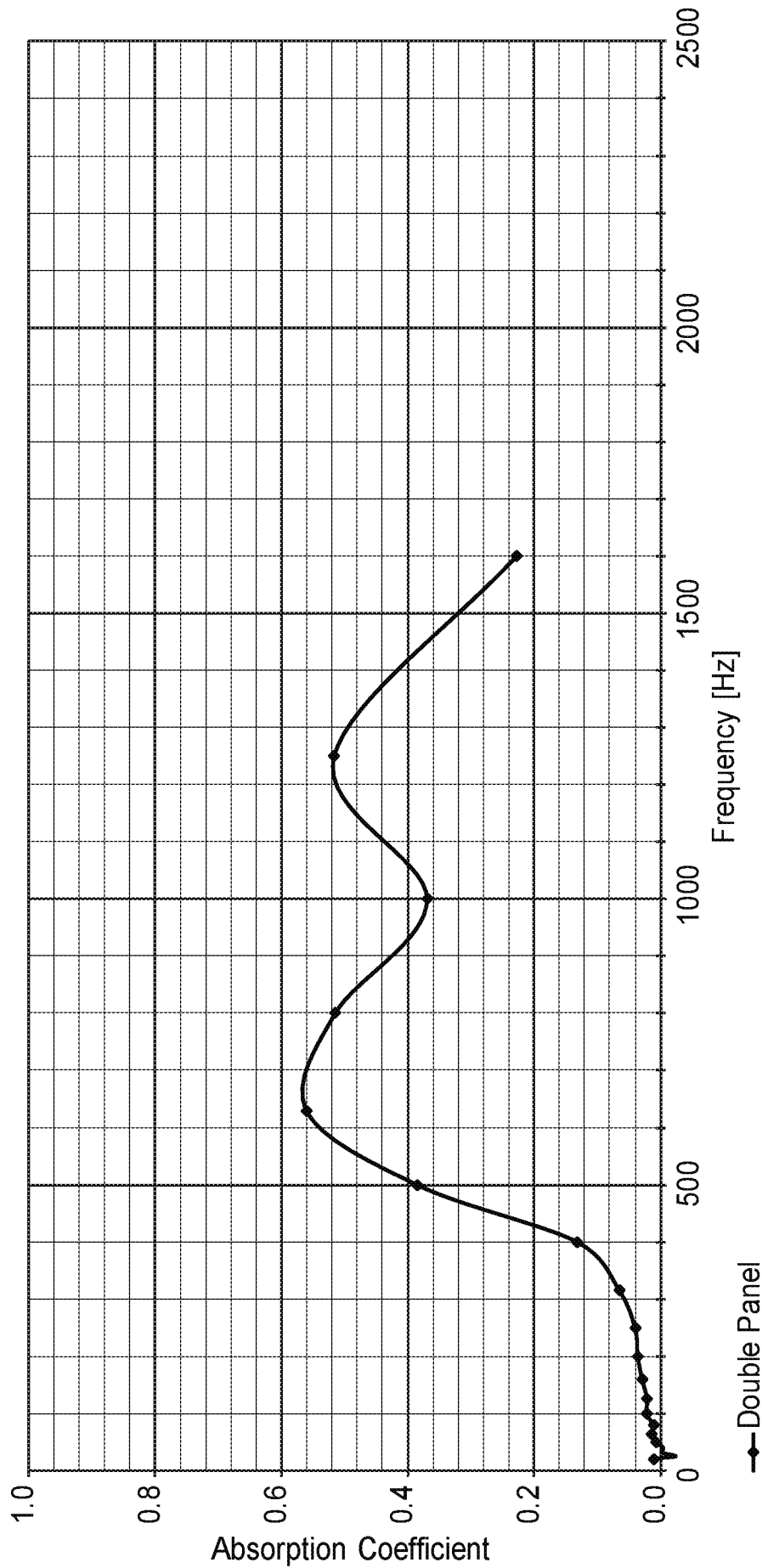
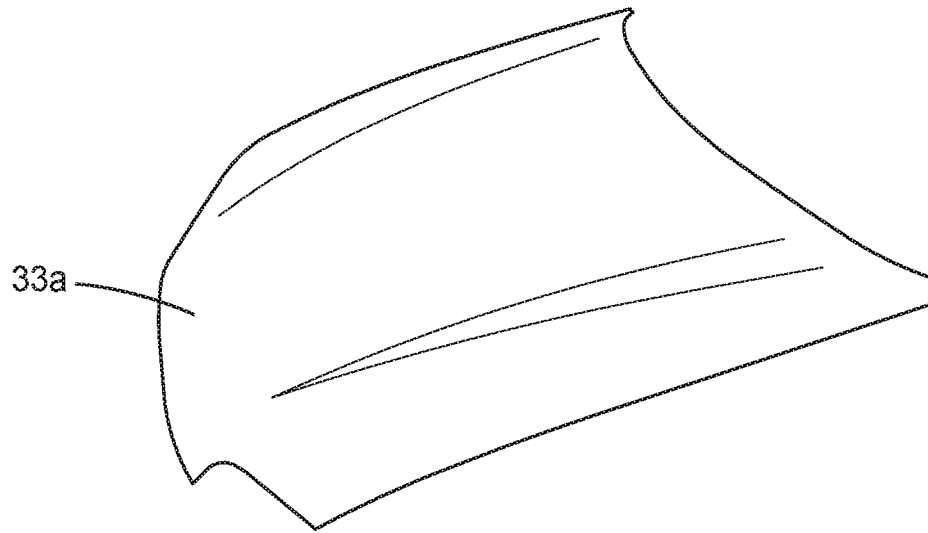
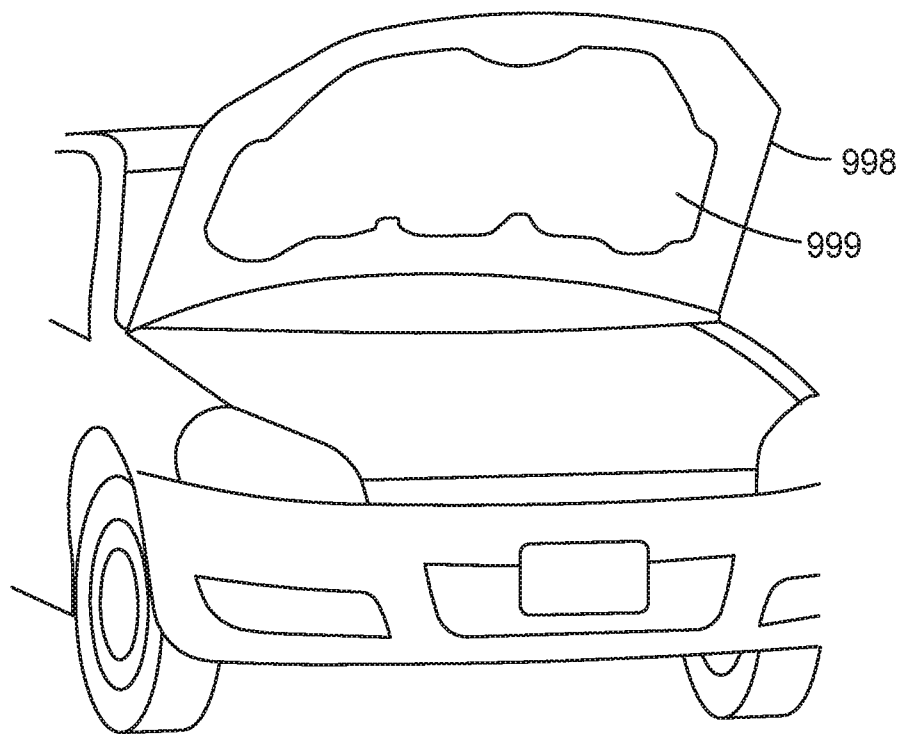


FIG. 35

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*FIG. 36A*



*FIG. 36B*

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2017/046399

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	B32B3/12 G10K11/168	B32B3/26 G10K11/172
	E04B1/84 B60R13/08	E04B1/86 G10K11/16
ADD.		
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) B32B E04B G10K F02C F02K B60R		
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.
X	GB 2 486 120 A (GKN AEROSPACE SERVICES LTD [GB]) 6 June 2012 (2012-06-06) claims 1,5; figures 2c,3,4 page 28, line 12 - line 18 page 29, line 22 - line 24 -----	6
X	US 2009/166127 A1 (THOMAS CHRISTIAN [DE] ET AL) 2 July 2009 (2009-07-02)	12,13,15
Y	claim 1; figures 1,4-6 paragraph [0007] paragraph [0025] - paragraph [0028] ----- -/-	1-5, 7-11,14
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> 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  20 October 2017		Date of mailing of the international search report  30/10/2017
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  Matthijssen, J-J



## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/046399

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/044621 A1 (STRAUSS BEN [US]) 21 February 2008 (2008-02-21) paragraph [0002] - paragraph [0003] paragraph [0087] paragraph [0105] paragraph [0189] paragraph [0192] claims 1-3; figures 1,33,34,42 -----	1-5, 7-11,14
T	JAMES M. JONZA ET AL: "Acoustically Absorbing Lightweight Thermoplastic Honeycomb Panels", SAE INTERNATIONAL JOURNAL OF VEHICLE DYNAMICS, STABILITY, AND NVH, vol. 1, no. 2, 15 January 2017 (2017-01-15), pages 445-454, XP055417551, ISSN: 2380-2170, DOI: 10.4271/2017-01-1813 -----	1-15

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/046399

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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US 2009166127	A1	02-07-2009	DE 102007060662 A1	18-06-2009
			US 2009166127 A1	02-07-2009
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US 2008044621	A1	21-02-2008	US 2008044621 A1	21-02-2008
			WO 2007149535 A1	27-12-2007
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