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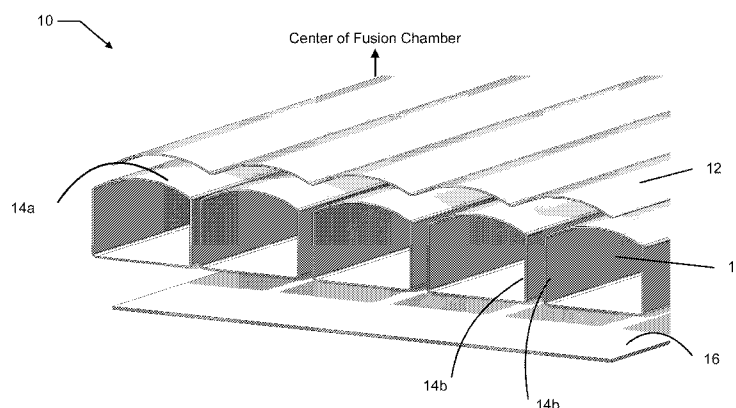
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(54) **Title:** SYSTEM AND METHOD FOR MULTI-LAYER HEAT TRANSFER PANEL**FIGURE 1**

(57) **Abstract:** The present disclosure is related to a high heat flux resistant metallic wall structure. The wall structure may have an outer wall sheet adapted to face the high heat flux. A plurality of tubes may be included and disposed adjacent one another. The tubes may be adapted to flow a cooling medium there through. A backing sheet may also be incorporated. The outer wall sheet, the plurality of tubes and the backing sheet may be formed into a unitary assembly. The wall structure may be adapted for use in a wide variety of applications but is especially well suited to extremely high heat flux applications such as a first wall within a nuclear fusion chamber.

SYSTEM AND METHOD FOR MULTI-LAYER HEAT TRANSFER PANEL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/841,568, filed July 1, 2013 and U.S. Provisional Application No. 61/785,355, filed March 14, 2013. The entire disclosures of each of the above applications are incorporated herein by reference.

STATEMENT OF GOVERNMENT RIGHTS

10 **[0002]** The United States Government has rights in this invention pursuant to Contract No. DE-AC52-07NA27344 between the U.S. Department of Energy and Lawrence Livermore National Security, LLC, for the operation of Lawrence Livermore National Laboratory.

FIELD

[0003] The present disclosure relates to structural components used for heat absorption or heat rejection, and more particularly to a multi-layer heat transfer panel especially well adapted for absorbing extremely high heat flux experienced by or within a structure or system, for example within a fusion chamber of a nuclear fusion energy system.

BACKGROUND

[0004] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

25 **[0005]** In various present day systems often associated with nuclear
fusion, fission, solar thermal, high temperature gas furnaces, gas turbines and
other high temperature or high power systems, one or more structural wall
portions of the system may be exposed to extremely high heat loads. This is
particularly so in a nuclear fusion system such as the LIFE (Laser Inertial Fusion
30 Energy) system being developed by Lawrence Livermore National Laboratory.
The LIFE system makes use of a 15- to 40-megawatt (MW) high-average-power
laser system that produces fusion reactions at 8 to 16 times per second.

Multiple LIFE laser beams will precisely converge on deuterium–tritium fusion targets passing thorough a target (i.e., fusion) chamber, thereby producing an anticipated 1 to 2 gigawatts of fusion energy. The pulsed fusion reactions will produce high-energy neutrons which bombard and pass through a first wall of the fusion chamber and then impinge a spherical blanket containing lithium or a high-heat-capacity lithium-based molten salt. The spherical blanket can convert the energy of the neutrons into heat to produce either steam or another hot gas that will be used to generate electricity. The first wall is expected to experience a heat flux on its fusion chamber-facing surface on the order of about 300-600 degrees C, and it is important that the first wall operate to absorb a significant degree of the heat flux that is generated at the chamber-facing surface of the first wall so that the spherical blanket is not damaged by excessive heat flux.

[0006] The extremely high heat flux that the first wall will be exposed to presents significant challenges in uniformly cooling the entire first wall surface and maintaining the spherical blanket behind it at a suitable temperature. If the first wall is constructed from multiple independent spherical sections that are welded together to form a unitary first wall, then this construction will produce a large plurality of surface seam welds around the fusion chamber-facing surface of the first wall. A significant cooling challenge will exist if the first wall has a large number of weld seams. Simply including flow channels behind each panel and flowing a suitable cooling medium, (e.g., liquid lithium) through the flow channels would help to cool the surface portions between the surface seam welds, but the coolant would not be flowing directly over the surface seam welds, and would thus not provide the same degree of cooling to the surface seam welds. Such an arrangement might thus provide a sufficient degree of high convective heat transfer for portions of the panel separated or bounded by the surface seam welds, but not to those areas of the first wall where the surface seam welds are present. In the fusion chamber of the LIFE system, over 1000 meters of welding may be expected to be incorporated, so the overall cross-sectional area of the surface seam welds is not insignificant.

[0007] Moreover, simply using a plurality of layers of independent fluid flowing tubes could dramatically increase the number of fluid connections

required to the first wall, and thus the overall complexity and cost of construction of the fusion chamber. The expansion and contraction of layers of independent tubes in response to thermal loading may also give rise to other challenges in using suitable supports to support the layers of independent tubes because the supports themselves will also be exposed to extremely high heat flux. Maintaining fluid tight connections with each of the tubes may also be challenging in view of the cyclic expansion and contraction of the tubes. Accordingly, a significant challenge still exists in providing a uniform degree of cooling to a panel surface exposed to a high heat flux, and where the panel has a plurality of surface weld seams that must be adequately cooled through a convective cooling medium.

SUMMARY

[0008] In one aspect the present disclosure relates to a high heat flux resistant metallic wall structure. The wall structure may comprise an outer wall sheet adapted to face the high heat flux and a plurality of tubes disposed adjacent one another. The tubes may be adapted to flow a cooling medium there through. A backing sheet and an outer wall sheet may be also be incorporated. The tubes, the backing sheet and the outer wall sheet may be formed into a unitary assembly.

[0009] In another aspect the present disclosure relates to a high heat flux resistant metallic wall structure that includes a corrugated outer panel, a corrugated intermediate panel and a backing sheet. The corrugated intermediate panel may be disposed adjacent to the corrugated outer panel, and the backing sheet may be disposed adjacent to the corrugated intermediate panel. The corrugated outer panel, the corrugated intermediate panel and the backing sheet may be assembled into a unitary assembly via a plurality of weld seams. The outer and intermediate corrugated panels may cooperate to define a plurality of first flow channels separated by a first plurality of the weld seams to enable a flow of a cooling medium there through. The intermediate corrugated panel and the backing sheet may cooperate to form a second plurality of flow channels between a second plurality of the weld seams to enable flow of the

cooling medium through the second plurality of flow channels. The second plurality of flow channels may be offset from the first plurality of flow channels such that the first plurality of weld seams is able to be cooled by the cooling medium flowing in the second plurality of flow channels.

5 **[0010]** In still another aspect the present disclosure relates to a high heat flux resistant metallic wall structure comprising a corrugated outer panel, a corrugated intermediate panel and a planar, non-corrugated backing sheet. The corrugated intermediate panel may be disposed adjacent the corrugated outer panel. The planar, non-corrugated backing sheet may be disposed adjacent to
10 the corrugated intermediate panel. The corrugated outer panel, the corrugated intermediate panel and the backing sheet may be assembled into a unitary assembly via a plurality of weld seams. The outer and intermediate corrugated panels may have a common corrugated configuration and may cooperate to define a plurality of first flow channels separated by a first plurality of the weld
15 seams, to enable a flow of a cooling medium through the first flow channels. The intermediate corrugated panel and the back sheet may cooperate to form a second plurality of flow channels between a second plurality of the weld seams to enable flow of the cooling medium there through. The second plurality of flow channels may be offset by about one-half the width of each of each said flow
20 channel from the first plurality of flow channels, such that the first plurality of weld seams is able to be cooled by the cooling medium flowing in the second plurality of flow channels, and such that the cooling medium flowing in the first plurality of flow channels is able to cool the second plurality of weld seams.

[0011] Further areas of applicability will become apparent from the
25 description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

30 **[0012]** The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0013] Figure 1 is an exploded perspective view of one embodiment of a representative portion of a wall structure adapted for use in a high heat flux environment, for example as a first wall within a nuclear fusion chamber;

5 **[0014]** Figure 2 is a perspective view of the assembled wall structure of Figure 1;

[0015] Figure 3 is a perspective view illustrating how the wall structure of Figure 2 may be formed to wrap around a blanked structure (indicated in phantom) used in a containment wall of a nuclear fusion chamber;

10 **[0016]** Figure 4 is a perspective view of another embodiment of a wall structure in accordance with the present disclosure in which the wall structure includes a plurality of corrugated panels;

[0017] Figure 5 is a perspective view of a plurality of sections of the wall structure of Figure 4 illustrating how differently dimensioned sections of the wall structure may be coupled together via a plurality of plenums to enable a
15 high degree of flexibility in forming wall shapes having varying curvatures and dimensions;

[0018] Figure 6 is a cross sectional end view of another embodiment of the present disclosure, somewhat similar to the embodiment of Figure 1, illustrating the tubes having a more pronounced curvature on one surface;

20 **[0019]** Figures 7-9 illustrate a first wall structure in accordance with another embodiment of the present disclosure which makes use of perpendicularly arranged castellations to further promote even expansion of material surfaces and improve distribution of the thermal load experienced by the structure during use;

25 **[0020]** Figures 10-12 further illustrate how modular sections of a first wall structure (i.e., first wall blanket) may be constructed to meet the specific shape/contour of a fusion chamber;

[0021] Figure 13 illustrates a method of forming corrugated panels for use in a first wall structure; and

30 **[0022]** Figure 14 shows another embodiment of the first wall structure employing roll formed tubes welded adjacent one another between outer layers of material.

DETAILED DESCRIPTION

[0023] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

[0024] Referring to Figures 1 and 2, a wall structure 10 is shown in accordance with one embodiment of the present disclosure. The wall structure 10 may be formed from a plurality of independent sheets of metal which include a corrugated or undulating outer sheet 12, a plurality of independent metal tubes 14 and a metal backing sheet 16. The outer sheet 12 is referred to as the “outer” sheet because, in one particular application, it is intended to face an interior of a nuclear fusion chamber, and thus is required to withstand the high heat flux that is generated with the fusion chamber. As will be described more fully in the following paragraphs, the wall structure 12 is expected to find utility in a plurality of environments possibly including furnaces or with any other device or system where a wall structure is required to withstand high temperature, or where the temperature of a wall structure needs to be managed or controlled within a predetermined temperature range.

[0025] The tubes 14 may be constructed using any suitable manufacturing process, but extrusion from seamless blanks of material is one widely available and cost effective construction technology that may be employed. Extrusion provides the benefit of being able to form the tubes 14 with no welds or seams along the entire lengths of the tubes 14. Alternatively, the tubes 14 could be roll formed and seam welded. The corrugated shape of the outer sheet 12 may be obtained through a stamping process or possibly even a roll forming process. The tubes 14 each include a convex shaped wall portion 14a that is shaped in accordance with the corrugated or undulating pattern of the outer sheet 12.

[0026] The outer sheet 12, the tubes 14 and the backing sheet 16 may be secured together to form a unitary assembly by various manufacturing techniques. One particularly desirable technique, however, is diffusion bonding.

Diffusion bonding is a well known, solid-state joining process that mates all the interfacing tube/panel surfaces into a single homogeneous component. The wall structure 10 in its assembled form is shown in Figure 2. A particular advantage of diffusion bonding is that no joint seams (i.e., weld seams) are present where the individual components are bonded to one another, and thus the risk of leakage from fluids flowing within the tubes 14 is dramatically reduced. Once fully assembled, side wall portions 14b of each adjacent pair of the tubes 14 are in contact with one another over substantially their full length, thus providing a highly rigid, unitary assembly.

[0027] Referring briefly to Figure 3, another benefit to the lack of any weld seams when the wall structure 10 is manufactured by diffusion bonding is that there are no joining seams of any kind present on the outer sheet 12 that faces the interior of a fusion chamber. Thus, when the wall structure 10 is formed in a generally U-shaped configuration to wrap around the side edges of a spherical blanket 18 positioned behind the wall structure, the ends of the tubes 14 may be connected to manifolds at the blanket's side or rear. As a result, all front-facing welds and tube 14 connections can be avoided. Typically, the individual sheets 12 and 14, and tubes 14, are bent into the U-shape configuration prior to diffusion bonding such that any potential geometric distortion is minimized or eliminated.

[0028] The tubes 14, the backing sheet 16 and the fusion-facing outer sheet 12 may all be fabricated from the same type of steel or they may be fabricated from different types of steel. The diffusion bonding process provides the ability to bond dissimilar metals together into a unitary assembly. In one example the wall structure 10 may be constructed from reduced-activation ferritic-martensitic (RAFM) steel, although oxygen-dispersed strengthened (ODS) steel may also be a viable alternative for one or for all of the components of the wall structure. The unitary construction of the wall structure 10 enables it to be installed as a fully pre-fabricated unit, requiring only limited welding at the rear of the blanket 18 to suitable support structure.

[0029] As noted above, the wall structure 10 is especially desirable because of its virtually non-existent risk of leakage of a cooling medium flowing

through the tubes 14. Even a slight manufacturing anomaly such as an incomplete diffusion bonding of a particular, limited area of the wall structure 10 will not lead to leaks because diffusion bonding is not being used to form the actual barrier between fluid and the fusion chamber environment. Likewise, each tube 14 is isolated from every other tube, so even in the rare instance of a failure of one tube, this would not necessarily cause failure in the entire blanket section 18 that the wall structure 10 is disposed over.

[0030] Moreover, the diffusion bonding process enables even further layers of material to be incorporated with little or no modification to the underlying wall structure 10 configuration. Thus, if at some future time, should an armor coating or plating be deemed necessary for the survival of the wall structure 10 in a given environment (e.g., within a fusion chamber as the first wall), the armor could be easily incorporated. Diffusion bonding is one of the few ways of attaching such a coating, due to the dissimilar material joint that is introduced. The four principal operations for fabricating the wall structure 10 to form a first wall of a fusion chamber may be summarized as follows: 1) fabricate and shape all parts; 2) assemble and encapsulate the assembly in a vacuum-tight shroud; 3) diffusion bond the assembly; and 4) install the assembly onto the blanket 18.

[0031] It will be appreciated that for the wall structure 10, drawing the tubes 14 to a desired cross-section is relatively straightforward, although fabricating square tubes (i.e., tubes with sharp 90 degree bends) is slightly more challenging due to potential crackling and wrinkling in the corners. To avoid this, a corner radius of at least 1 times the thickness of the tube is preferably used. Bending of the tubes 14 has similar limitations in that the bend radius is proportional to the tube diameter. Accordingly, a 3.5 to 1 radius-to-diameter ratio may be preferred to avoid wrinkling and wall-thinning in each tube 14.

[0032] To join the tubes 14 and the sheets 12 and 16 together, the diffusion bonding process involves the application of high heat and pressure, which encourages diffusion across the interface between materials. This diffusion allows two surfaces to intermingle and disappear, forming one complete volume. One method of achieving this process is by hot isostatic pressing (HIP).

In this process a thin “can” encapsulates the entire unassembled wall structure 10 assembly, and gas pressurizes the outside of the can as the temperature is simultaneously increased. Under the gas pressure, the can deforms like a bladder around the bonding part to apply isostatic pressure generally uniformly over all the surfaces of the assembly. To achieve a sufficient quality bond, all bonding surfaces must be clean, and therefore may likely require significant caustic cleaning with a suitable chemical solvent to remove any oils and or greases that may be present on the sheets 12 and 16 and the tubes 14. After the surfaces are rinsed in de-ionized water and dried with dry nitrogen gas, all air is evacuated from between the bonding surfaces to prepare for HIP.

[0033] The tube bank geometry of the flow tubes 14 may be achieved in a unique way. Instead of using a can to encapsulate the bonding surfaces, the sheets 12 and 16 may themselves act as the vacuum shroud. To accomplish this, a seam may be welded around all outer edges of the assembly comprising the components 12, 14 and 16, but leaving a gas straw attached which will later serve to de-gas the inside of the finished wall structure 10 assembly. Upon completion of the HIP operation, the welded regions at the ends and sides of the tube banks may be neatly sliced off. This leaves a wall structure 10 assembly that contains no welds whatsoever.

[0034] In summary, one particular fabrication process for diffusion bonding of the wall structure 10 may be summarized as follows: 1) roll-form the tubes 14; 2) weld, bend and heat treat the tubes 14; 3) roll-form and bend the outer corrugated sheet 12; 4) caustically clean all bonding surfaces; 5) assemble the wall structure 10; 6) weld (such as by TIG welding or other suitable welding) ends and edges of the wall structure 10; 7) post weld heat treat the assembly that will form the wall structure 10; 8) de-gas the wall structure 10 and pinch the de-gas tube closed; 9) hot isostatically press the wall structure 10 assembly; 10) cut away welded (e.g., TIG welded) areas; and 11) post HIP heat treat the wall structure 10 if desired.

[0035] Referring now to Figure 4, a wall structure 100 in accordance with another embodiment of the present disclosure is shown. The wall structure 100 may make use of an outer corrugated or undulating metal panel or sheet

102, an intermediate corrugated or undulating metal panel or sheet 104, and a backing sheet 106. The outer panel 102 in this embodiment is intended to face the center of the fusion chamber when the wall structure 100 is being used as the first wall in the fusion chamber. The outer panel 102 and the intermediate
5 panel 106 may be attached by a first plurality of welding seams 107 (i.e., continuous weld seams or spot weld seams), at those areas where surface portions of the panels 102 and 104 contact one another (i.e., the gullies 110 of the panel 102). Likewise, the backing panel 106 may be secured by a second plurality of welding seams 109 (i.e., continuous seams or spot weld seams) to
10 those areas where the gullies 112 of the intermediate sheet touch surface portions of the backing sheet 106. This construction produces a plurality of flow channels 114 and 116, with the flow channels 116 being laterally offset by about one-half the width of the channels 114. This staggered arrangement of the flow channels 114 and 116 provides the advantage that the weld seams at the gullies
15 110 are arranged directly over a center portion of the underlying flow channels 116. Thus, a cooling medium flowing in the flow channels 116 is able to sufficiently cool the weld seams 107 present in the gullies 110 of the outer panel 102, and thus to better provide uniform cooling of the entire surface of the outer panel. And similarly, the cooling medium flowing in the first plurality of flow
20 channels 114 is able to cool the second plurality of weld seams 109. Accordingly, the staggered arrangement of the pluralities of flow channels 114 and 116 are able to optimally cool all surface portions of both of the outer panel 102 and the backing sheet 106.

[0036] The multiple sheet construction of the wall structure 100 opens
25 up a wide array of possible flow designs. Each sheet 102 and 104 can be formed to have complex and/or non-linear cooling paths. The wall structure 100 would also enable coolant flow in a horizontal or vertical direction over a complexly curving surface. This situation will be present in a fusion chamber because the widths of the top and bottom blanket sections used in a fusion
30 chamber change dramatically. Since there is no inherent structural limitation to the wall structure 100, the flow through the flow channels 114 and 116 could theoretically be funneled into a narrow width at the apex of the blanket. One

example of a configuration of the wall structure 100 to accommodate this scenario is shown in Figure 5. In Figure 5 a plurality of wall structure sections 100a-100e, each constructed in accordance with wall structure 100, may be used to span a complexly shaped area that tapers down significantly from one point to another, for example the interior of a generally spherical fusion chamber. In the example of Figure 5, a plenum may be used between each adjacent pair of the wall structure sections. Thus, plenum 120 couples the tubes of wall structure section 100a in flow communication with the tubes of wall structure section 100b, plenum 122 couples wall structure sections 100b and 100c; plenum 124 couples wall structure sections 100c and 100d; and plenum 126 couples wall structure sections 100d and 100e. Thus, by including plena at desired intervals along the underlying blanket section, the number of tubes across the width of the overall wall structure assembly can decrease with the decreasing width of the underlying blanket.

[0037] When manufacturing the wall structure 100, the outer panel 102 may be fabricated via roll-forming over die-rollers. This is a convenient fabrication process because the sheet metal comes from lengthy spools; lengths as wide as the blanket sections of a fusion chamber blanket assembly are obtainable. The bend radius of the pre-corrugated sheets used to form the outer and intermediate panels 102 and 104, respectively, is also an important consideration, as too tight of a bend will tend to flatten out the corrugations.

[0038] An initial fabrication process may involve forming the panels 102 and 104 in the shape of the desired flow pattern. This can be done, for example, via well a known hydroforming process. After the panels 102 and 104 have been formed they may be joined together in spots or seams at intervals across their surfaces (e.g., in the gullies 110 and 112 of Figure 4). This may be done with a variety of standard welding techniques including resistance welding, laser welding or TIG welding. Alternatively, a solid-state bonding process may also be utilized for the same purpose, including friction-stir welding and pressure-resistance welding. These processes do not melt the base metal, and in some instances may provide an even more robust solution. However, if welding is employed, it may be possible to heat treat the finished wall structure

10 such that all welds return to a near-base metal phase prior to installing them in a fusion chamber for use.

[0039] Figure 6 shows a wall structure 200 somewhat similar to wall structure 10 of Figure 1. Wall structure 200, however, includes a plurality of tubes 202 disposed closely adjacent one another with each tube having a highly pronounced arcuate surface 204 along a first side thereof that faces toward the center of the fusion chamber. This curvature of the arcuate surface 204 serves to alleviate thermal stress buildup at the junction between the tubes 202 and a corrugated panel 206. The corrugated panel 206 is positioned over the tubes 202 on the first side. A planar backing panel 208 is positioned against the tubes 202 on a second side opposite the first side. Intermittent or continuous weld seams 210 along the troughs 212 formed between adjacent ones of the tubes 202 serve to secure the corrugated panel 206 to the tubes 202. Welds 214 on the planar backing sheet 208, for example where adjacent tubes 202 abut one another, serve to create a unitary wall structure.

[0040] Referring now to Figures 7-9, a first wall structure 300 is shown in accordance with another embodiment of the present disclosure. The first wall structure 300 in this example may be formed from at least three (but possibly more) distinct layers of material 302, 304 and 306 that are formed, such as by diffusion bonding, into a unitary, highly thermally resistant wall structure. The material layers 302 and 304 help to form undulating channel 308. The undulating channel 308 helps to enable perpendicularly arranged castellations 310 and 312 to be formed in an outer surface 314 of the structure. In this example the outer surface 314 would be facing towards the center of the fusion chamber, as indicated by arrow 316 in Figure 9. The castellations 310 and 312 help significantly to allow for thermal expansion of surface portions of the first wall structure 300 without creating "hot spots" on the outer material layer 302. Put differently, the castellations 310 and 312, along with the undulating channel 308, permit more even distribution of the thermal load experienced by the first wall structure 300 during use.

[0041] Figures 10, 11 and 12 further illustrate how a plurality of first wall components 400, 402 and 404 may be formed to meet the specific shape and/or contour of a given fusion chamber.

[0042] Figure 13 illustrates how a plurality of roll stations 500a-500e may be used to fabricate (in this example roll form) undulating material sections to provide channels having tapering cross sectional areas.

[0043] Figure 14 illustrates another first wall structure 600 in accordance with another embodiment of the present disclosure. The first wall structure 600 in this example includes a plurality of roll formed tubes 602 positioned adjacent one another, which may each be formed by stainless steel, with a corrugated cover 604 and a base sheet 606 welded thereto to form a unitary assembly. The arrows indicate high pressure that causes all parts to bond to form a unified single part.

[0044] From the foregoing, it will be appreciated that the wall structures 10 and 100-600 each form robust high resistant assemblies suitable for use in extremely high heat flux environments, and particularly within a nuclear fusion chamber. The various embodiments described herein each have specific advantages from manufacturing and or implementation standpoints. The selection of one embodiment or the other may depend on a number of factors, one being the shape and/or curvature of the area being covered by the wall structure. It is also possible that both of the wall structures 10 and 100, or 10 and 200 may be employed together to form a larger wall structure, and the benefits of each utilized as needed to meet the specific application.

[0045] While various embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the present disclosure. The examples illustrate the various embodiments and are not intended to limit the present disclosure. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.

CLAIMS

What is claimed is:

1. A high heat flux resistant metallic wall structure comprising:
5 an outer wall sheet adapted to face the high heat flux;
a plurality of tubes disposed adjacent one another, the tubes being adapted to flow a cooling medium there through;
a backing sheet; and
the outer wall sheet, the plurality of tubes and the backing sheet
10 being formed into a unitary assembly.
2. The wall structure of claim 1, wherein the outer wall sheet, the plurality of tubes and the backing sheet are formed into a unitary structure by a diffusion bonding process.
15
3. The wall structure of claim 1, wherein the outer wall sheet has a corrugated surface.
4. The wall structure of claim 3, wherein the tubes are each formed
20 with surfaces in accordance the corrugated surface of the outer wall sheet.
5. The wall structure of claim 1, wherein the unitary assembly is further configured into a generally U-shaped configuration.
- 25 6. The wall structure of claim 1, wherein the tubes are generally rectangular in cross section such that substantially a full length of the side wall portions of adjacent ones of the rectangular tubes are contact with one another.
7. The wall structure of claim 1, wherein dissimilar metals are used to
30 form the wall structure.

8. The wall structure of claim 1, wherein the outer wall sheet, the plurality of tubes and the backing sheet are formed from the same metallic material.

5 9. A high heat flux resistant metallic wall structure comprising:
a corrugated outer panel;
a corrugated intermediate panel disposed adjacent the corrugated outer
panel;
a backing sheet disposed adjacent to the corrugated intermediate panel;
10 the corrugated outer panel, the corrugated intermediate panel and the
backing sheet assembled into a unitary assembly via a plurality of weld seams;
the outer and intermediate corrugated panels cooperating to define a
plurality of first flow channels separated by a first plurality of the weld seams, to
enable a flow of a cooling medium; and
15 the intermediate corrugated panel and the backing sheet cooperating to
form a second plurality of flow channels between a second plurality of the weld
seams to enable flow of the cooling medium there through, and the second
plurality of flow channels being offset from the first plurality of flow channels such
that the first plurality of weld seams is able to be cooled by the cooling medium
20 flowing in the second plurality of flow channels.

10. The wall structure of claim 9, wherein the first plurality of flow
channels is positioned over the second plurality of welds to thus enable the
cooling medium to cool the second plurality of weld seams.

25

11. The wall structure of claim 9, wherein each of the corrugated outer
panel and the corrugated intermediate panel are roll formed to provide a
corrugated surface to each.

12. The wall structure of claim 9, further comprising:
an additional wall structure; and
a plenum for placing the additional wall structure in flow communication
with the wall structure so that the cooling medium may be circulated through
5 both the wall structure and the additional wall structure.

13. The wall structure of claim 9, wherein the corrugated outer and
intermediate panels have the same corrugated configuration.

10 14. The wall structure of claim 9, wherein at least one of the first and
second pluralities of weld seams comprise continuous weld seams.

15 15. The wall structure of claim 9, wherein at least one of the first and
second pluralities of weld seams comprise spot weld seams.

16. The wall structure of claim 9, wherein the backing sheet forms a
planar, non-corrugated sheet.

17. A high heat flux resistant metallic wall structure comprising:
- a corrugated outer panel;
 - a corrugated intermediate panel disposed adjacent the corrugated outer
5 panel;
 - a planar, non-corrugated backing sheet disposed adjacent to the corrugated intermediate panel;
 - the corrugated outer panel, the corrugated intermediate panel and the backing sheet assembled into a unitary assembly via a plurality of weld seams;
 - 10 the outer and intermediate corrugated panels having a common corrugated configuration and cooperating to define a plurality of first flow channels separated by a first plurality of the weld seams, to enable a flow of a cooling medium through the first plurality of flow channels; and
 - the intermediate corrugated panel and the backing sheet cooperating to
15 form a second plurality of flow channels between a second plurality of the weld seams to enable flow of the cooling medium through the second plurality of flow channels, and the second plurality of flow channels being offset by about one-half the width of each of said flow channel of the first plurality of flow channels such that the first plurality of weld seams is able to be cooled by the cooling
20 medium flowing in the second plurality of flow channels, and such that the cooling medium flowing in the first plurality of flow channels is able to cool the second plurality of weld seams.

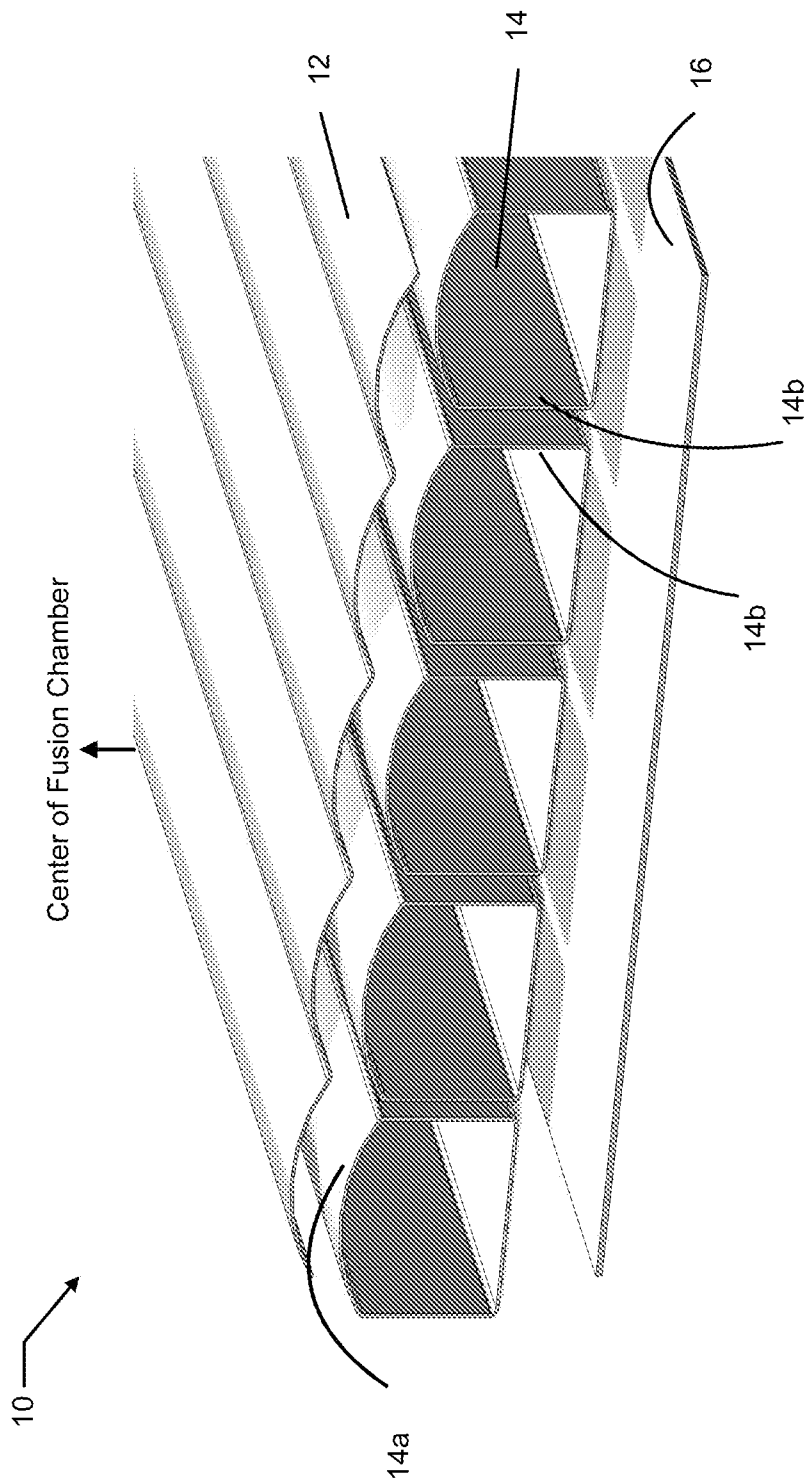


FIGURE 1

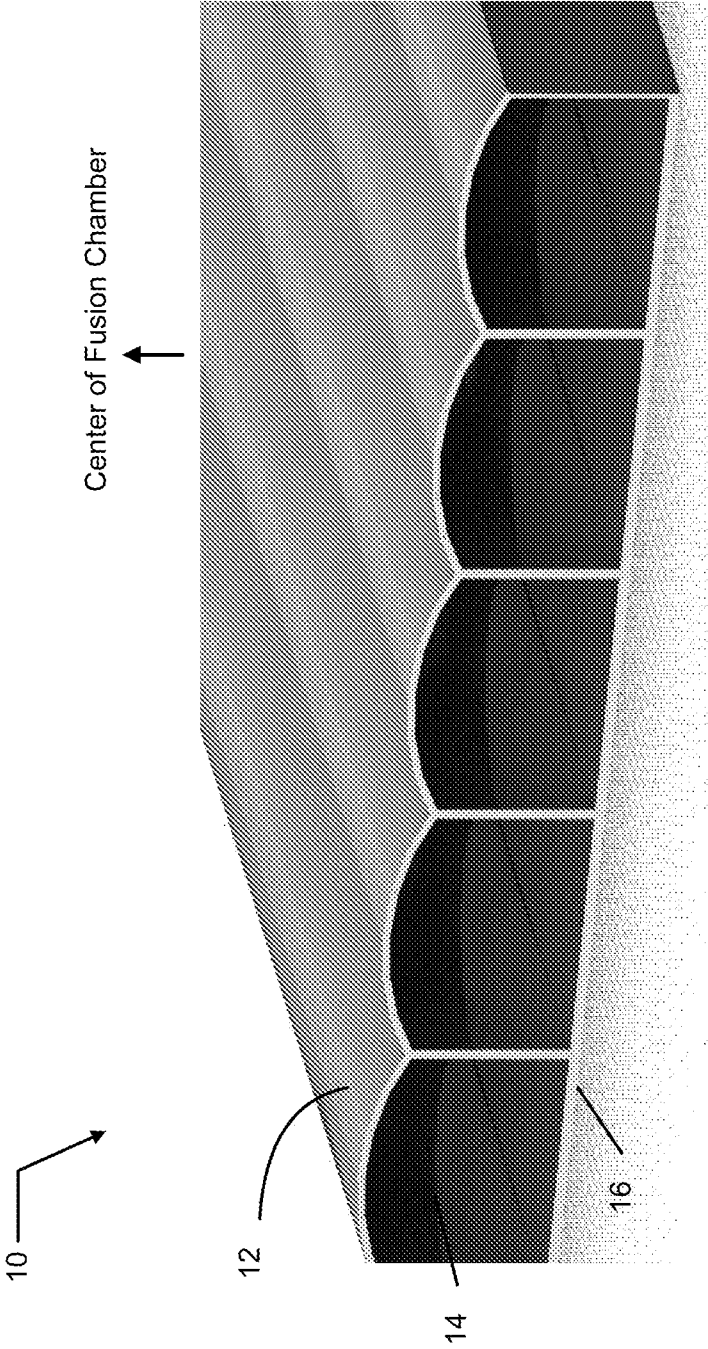
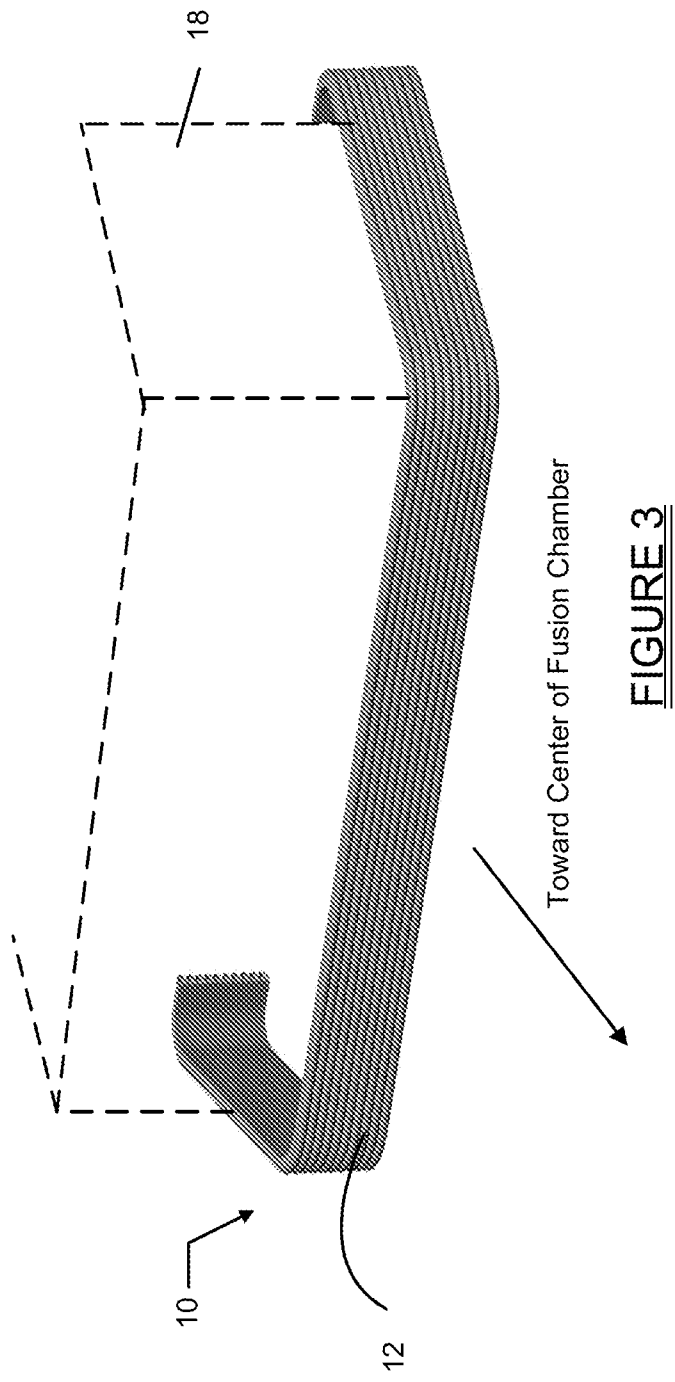


FIGURE 2



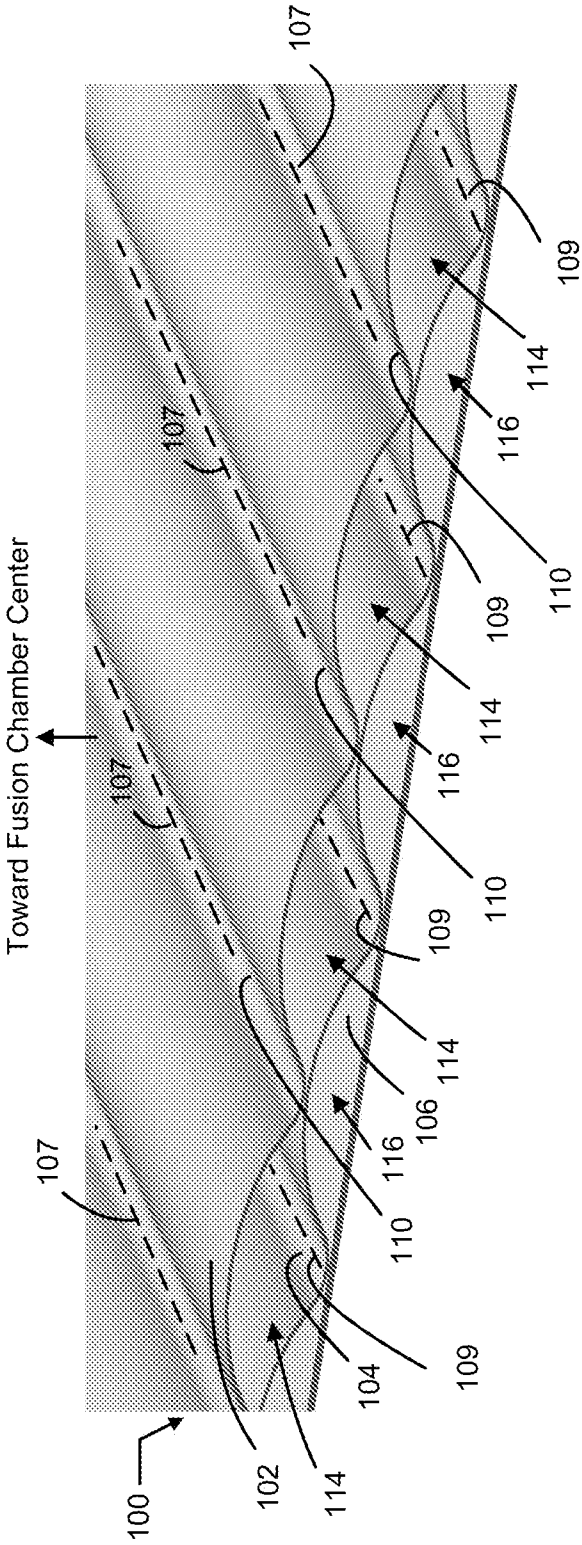


FIGURE 4

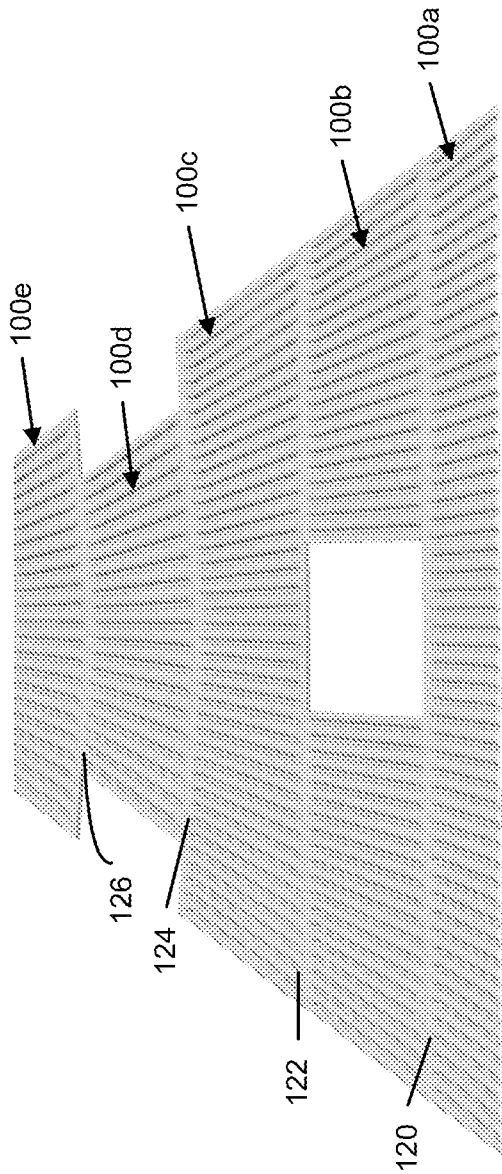


FIGURE 5

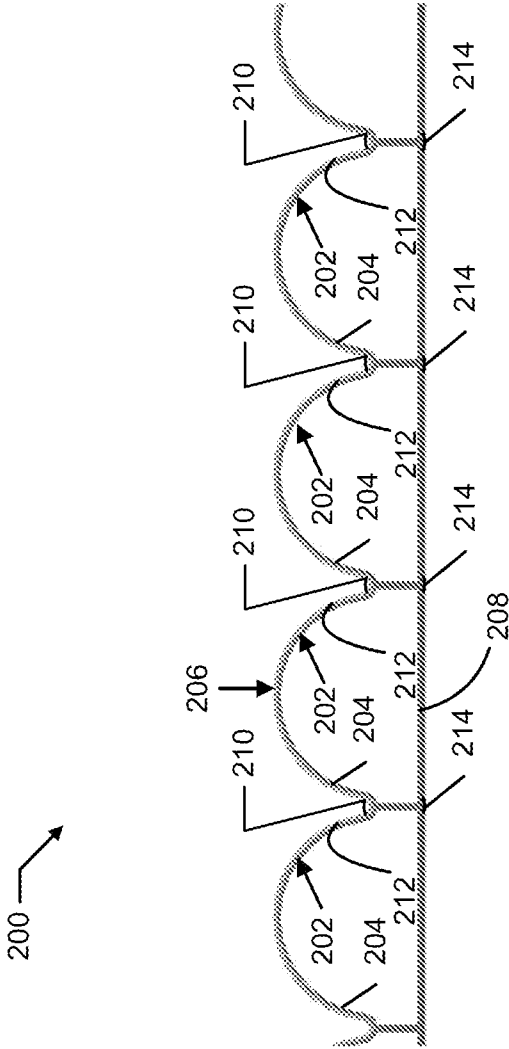
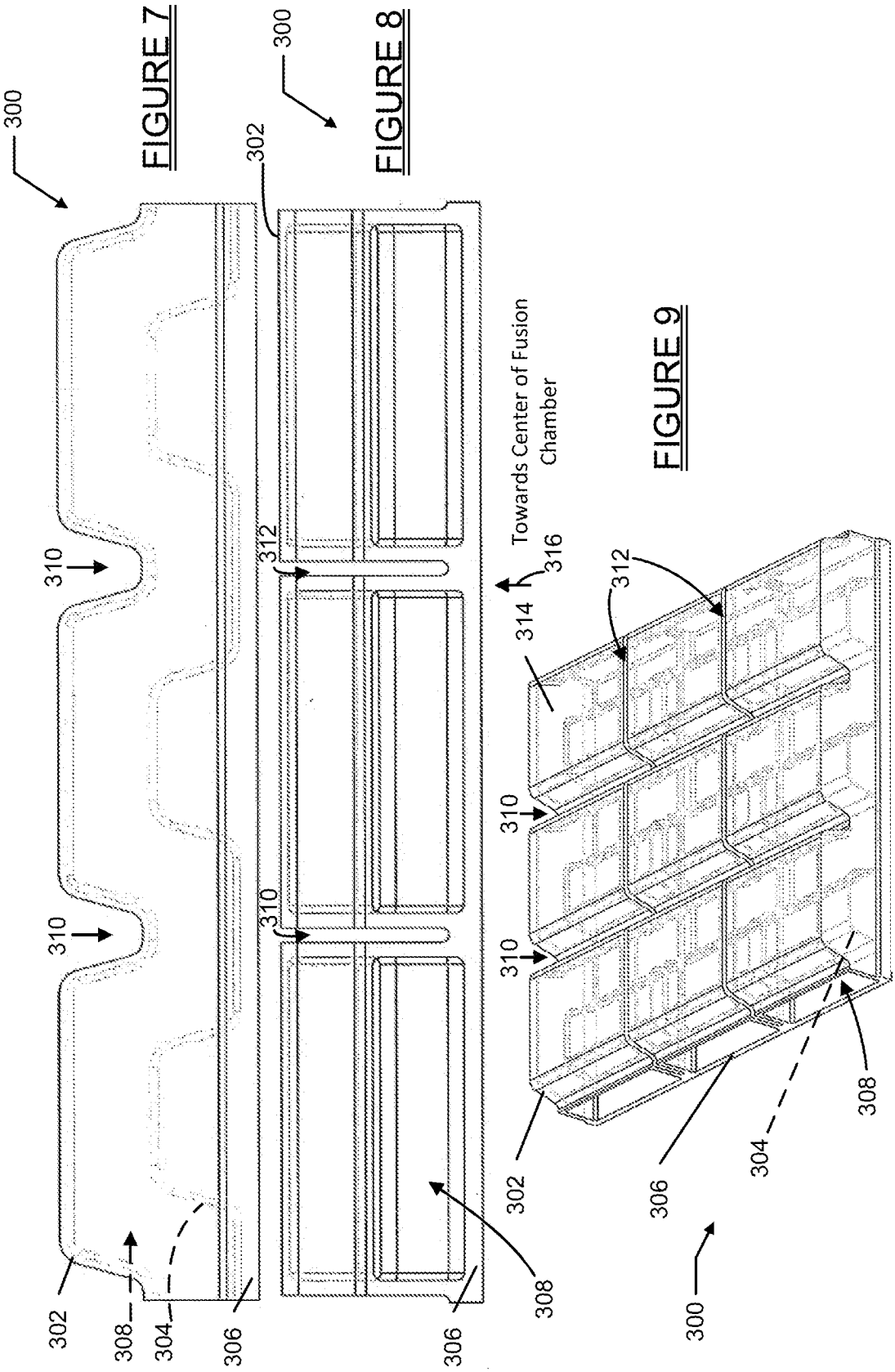
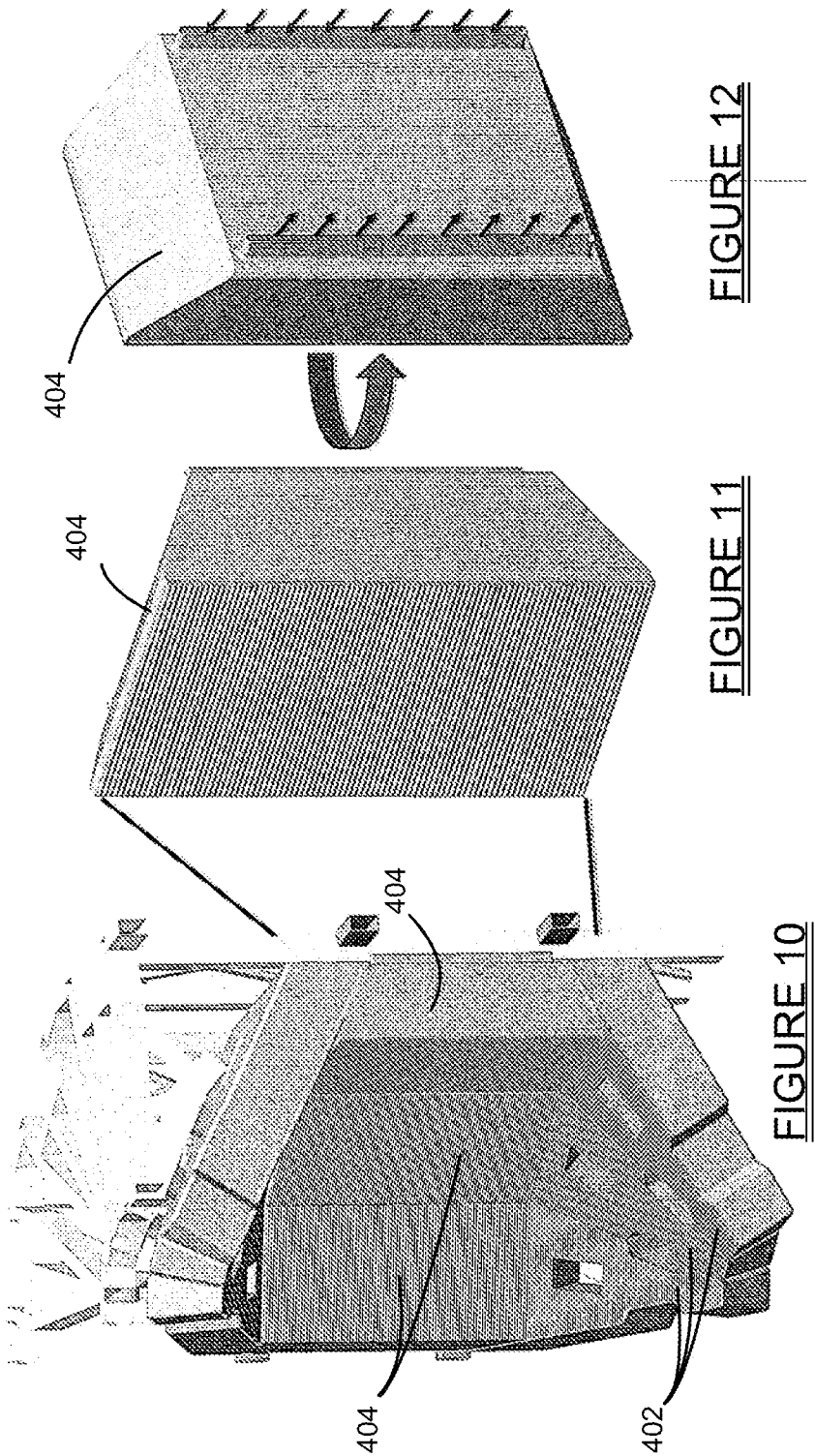


FIGURE 6





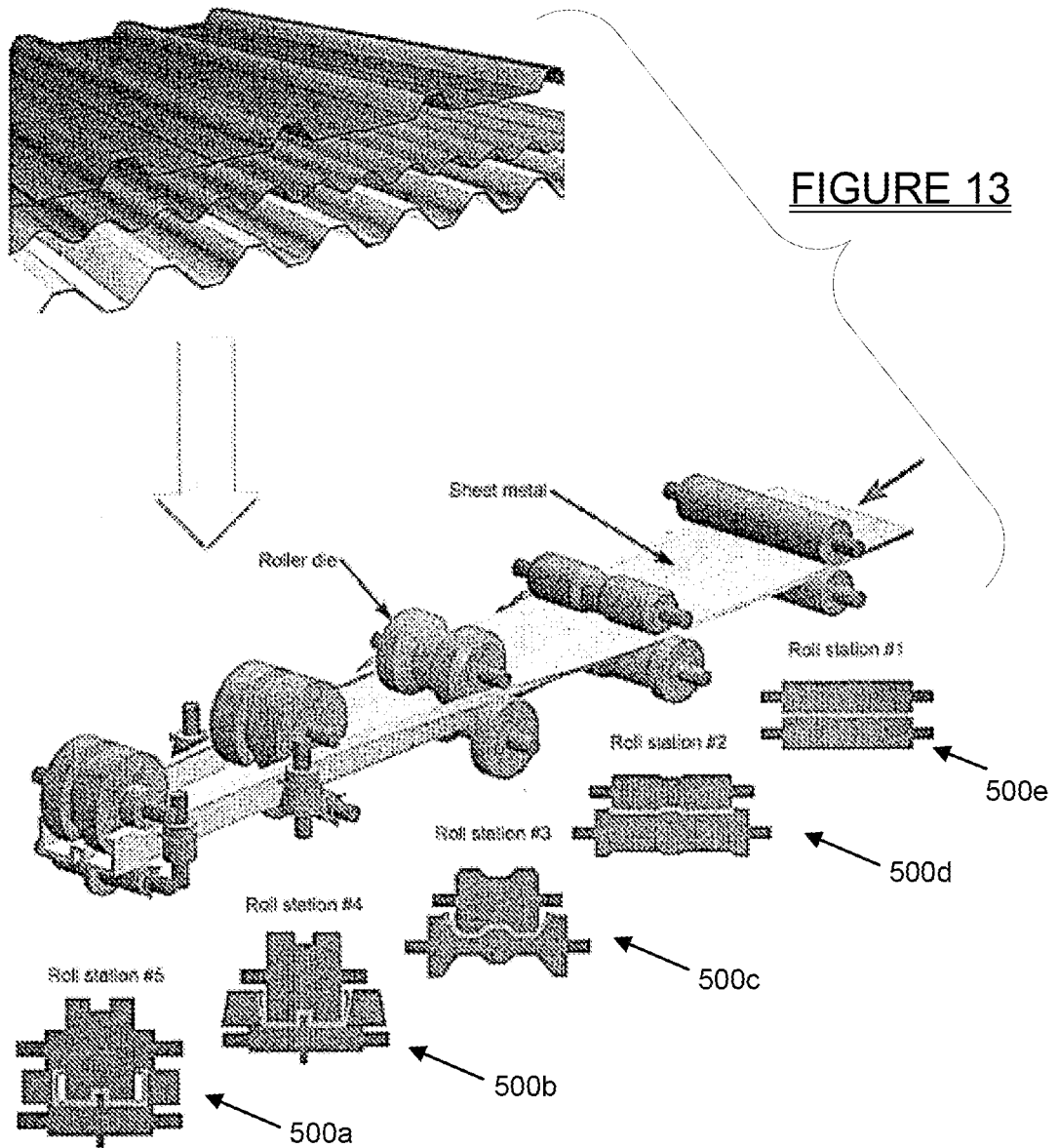
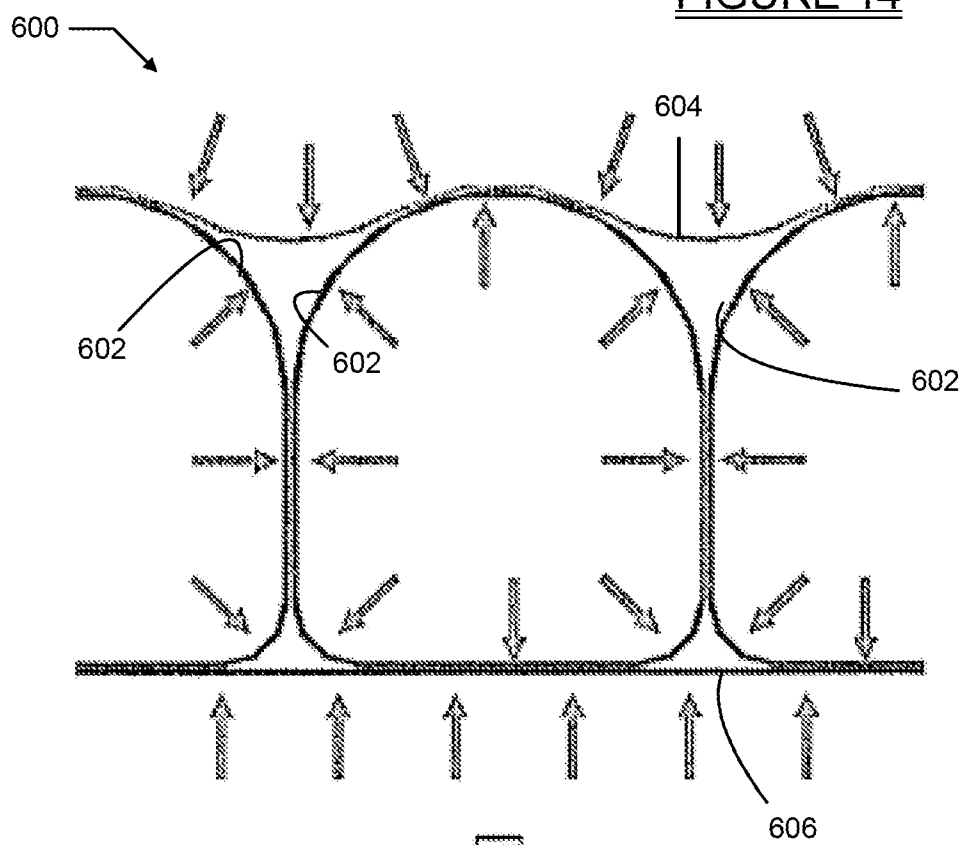


FIGURE 14



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/028477**A. CLASSIFICATION OF SUBJECT MATTER****G21B 1/11(2006.01)i, G21B 1/13(2006.01)i**

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)

G21B 1/11; G21B 1/00; F28F 3/12; G21D 5/00; B23P 15/28; F24D 3/16; F24F 5/00; G21B 1/13

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: nuclear, heat flux, layer, metal, coolant, fusion chamber, first wall, undulating, corrugate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 09-103923 A (JAPAN ATOMIC ENERGY RES. INST. et al.) 22 April 1997 See abstract, paragraphs [0001], [0012]-[0032] and figures 1-4.	1-4, 6-8
Y		5
A		9-17
Y	US 5182075 A (YOSHITAKA GOTOH et al.) 26 January 1993 See abstract, column 12, lines 9-40, claims 1-3 and figure 2.	5
A		1-4, 6-17
A	JP 2006-098009 A (TOYOX CO., LTD.) 13 April 2006 See paragraphs [0017]-[0025] and figures 1-7.	1-17
A	JP 2004-138521 A (KAWASAKI HEAVY IND., LTD.) 13 May 2004 See abstract, paragraphs [0007]-[0017] and figures 1-4.	1-17
A	KR 10-2002-0066577 A (JONG HA LEE) 19 August 2002 See abstract, claims 1-3 and figures 1-2.	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

23 July 2014 (23.07.2014)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/028477

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