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### (54) Wind turbine component having a lightweight structure

(57) A wind turbine component 10 having a lightweight structure is provided and includes a metallic matrix 20 defining a cavity 21, metallic foam 30 enclosed

within the cavity 21 and a solidification metallurgical bond 40 formed at an entire interface 41 between the metallic matrix 20 and the metallic foam 30.

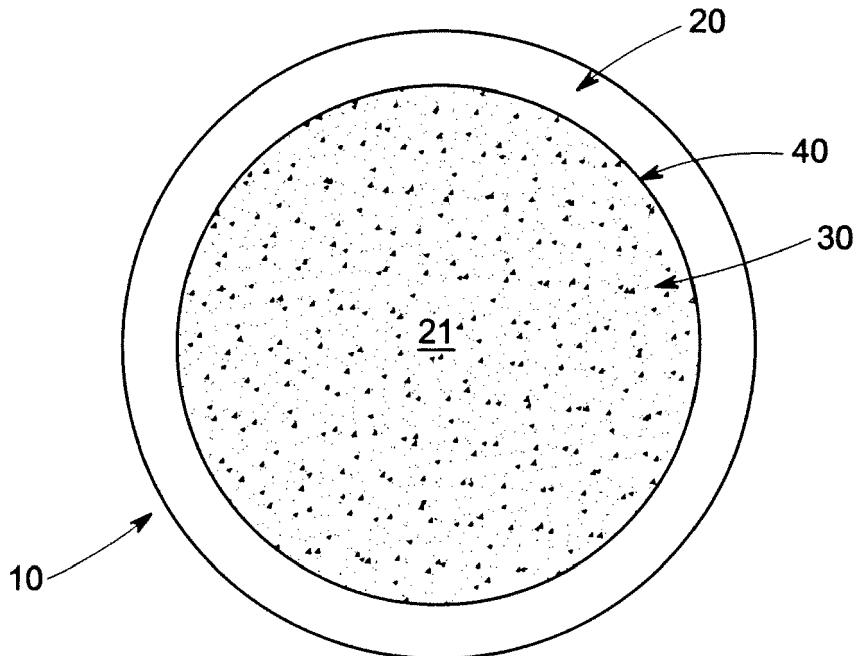


FIG. 1

## Description

**[0001]** The subject matter disclosed herein relates generally to a wind turbine component and, more particularly, to a wind turbine component having a lightweight structure.

**[0002]** Wind turbine powertrain components are often subject to large vibrational stresses. These vibrations can lead to premature failure of powertrain components and significant noise generation.

**[0003]** According to one aspect of the invention, a wind turbine component having a lightweight structure is provided and includes a metallic matrix defining a cavity, metallic foam enclosed within the cavity and a solidification metallurgical bond formed at an entire interface between the metallic matrix and the metallic foam.

**[0004]** According to another aspect of the invention, a method to form a wind turbine component configured to have a lightweight structure is provided and includes shaping a mold cavity between metallic foam and an exterior mold, filling a molten metallic matrix into the mold cavity to enclose the metallic foam and, as the molten metallic matrix cools, forming a solidification metallurgical bond at an entire interface between the metallic matrix and the metallic foam.

**[0005]** According to yet another aspect of the invention, a method to form a wind turbine component configured to have a lightweight structure is provided and includes shaping a mold cavity within a metallic matrix having an opening, filling the mold cavity with molten metallic material and a foaming agent, closing the opening such that the metallic matrix encloses the mold cavity and, as the molten metallic material cools and foams within the mold cavity, forming a solidification metallurgical bond at an entire interface between the metallic matrix and the metallic foam.

**[0006]** Various advantages and features will become more apparent from the following description taken in conjunction with the drawings.

**[0007]** The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic view of a wind turbine component configured to have a lightweight structure in accordance with embodiments;

FIG. 2 is a schematic view of a solidification metallurgical bond line;

FIG. 3 is a cross-sectional view of a wind turbine component configured to have a lightweight structure in accordance with alternate embodiments;

FIG. 4 is a cross-sectional view of a wind turbine component configured to have a lightweight structure in accordance with alternate embodiments;

FIG. 5 is an illustration of a method of forming a wind turbine component having a lightweight structure according to embodiments;

FIG. 6 is an illustration of a substantially finished wind turbine component having a lightweight structure;

FIG. 7 is an illustration of a method of forming a wind turbine component having a lightweight structure according to embodiments;

FIG. 8 is an illustration of a substantially finished wind turbine component having a lightweight structure;

FIG. 9 is an illustration of a method of forming a wind turbine component having a lightweight structure according to alternative embodiments; and

FIG. 10 is an illustration of a substantially finished wind turbine component having a lightweight structure.

**[0008]** The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

**[0009]** In accordance with various aspects, a vibration damping noise reduction lightweight structure is provided for use as a multi-ton component of various types of apparatuses. These apparatuses may include, for example, wind turbines and similar components of power generation plants. The lightweight structure may include, for example, hollow tubing and/or castings of metallic materials filled by foams of metallic materials with a solidification metallurgical bond formed at an entire interface between the metallic materials and the foams.

**[0010]** With reference now to FIG. 1, a wind turbine component configured to have a lightweight structure 10 to provide vibration damping and noise reduction is provided. The lightweight structure 10 includes a metallic matrix 20 formed to define a cavity 21, metallic foam 30

45 enclosed within the cavity 21 and a solidification metallurgical bond 40. The metallic matrix 20 may include any metal or metal alloy, such as, for example, aluminum, magnesium, iron, nickel, titanium, cobalt, copper, chromium and alloys thereof. The metallic foam 30 may similarly include any metal or metal alloy, such as, for example, aluminum, magnesium, iron, nickel, titanium, cobalt, copper, chromium and alloys thereof along with a foaming agent that eventually evolves outwardly or is dispersed evenly throughout. The metallic foam 30 may also include ceramic foam mixed into or arranged in coaxial layers with the metallic foam 30.

**[0011]** With reference to FIG. 2, the solidification metallurgical bond 40 is formed at an entire interface between

the metallic matrix 20 and the metallic foam 30 and includes an interface region 41 in which eutectic precipitates 42 or, for some materials, eutectic-type precipitates form on solidification. Additional regions 43, 44 where at least one of grain growth and partial re-crystallization occurs may also be formed in solid-state on opposite sides of the newly solidified interface region 41. The additional regions 43, 44 are respectively interposed between the interface region 41 and the main body of the metallic matrix 20 on one side and between the interface region 41 and the main body of the metallic foam 30 on the other side. The interface region 41 may be substantially wider than the additional regions 43, 44.

**[0012]** With reference to FIGS. 3 and 4, the wind turbine component configured to have the lightweight structure 10 may be provided for use as a multi-ton complex shaped component of an apparatus such as, for example, a wind turbine and/or similar components of power generation plants (i.e., wind turbine gearbox housings or bedplates). For example, as shown in FIG. 3, the lightweight structure 10 may be provided for use in a cast housing torque arm 11 of a gearbox that may be several feet in diameter and may weigh several tons. Alternatively, the lightweight structure 10 may be provided for use in a wind turbine casing 12, as shown in FIG. 4. In each example, the lightweight structure 10 is formed as an annular member within a core of the larger apparatus to at least allow the apparatus to maintain its strength and to decrease an overall weight and vibration of the apparatus.

**[0013]** In the case of the wind turbine, by replacing conventional multi-ton components with simple or complex shapes with the lightweight structure 10, the height of the wind turbine can be increased as necessary to comply with local regulations and to place the rotor blades in the wind stream as much as possible. Due to the resulting decrease in the overall weight of the wind turbine, operational noise and wind turbine vibrations may be damped. Moreover, since wind turbines configured to have lightweight components are increasingly flexible in terms of being usable in various environments and localities, the use of wind power as an alternate source of energy may increase.

**[0014]** With reference to FIGS. 5 and 6, a method to form the lightweight structure 10 is provided. The method includes shaping a mold cavity 100 between a metallic foam 101, materials of which are similar to those of the metallic foam 30 described above, and an exterior mold 102 of, for example, packed sand or permanent steel molds. The method further includes filling (i.e., mold filling) the mold cavity with 100 a molten metal to form a metallic matrix 103, materials of which are similar to those of the metallic matrix 20 described above. As the molten metallic matrix 103 cools following the filling operation, the method also includes allowing for formation of a solidification metallurgical bond 104, which is similar in terms of structure and formation processes to the solidification metallurgical bond 40 described above, at an entire interface between the metallic matrix 103 and the

metallic foam 101.

**[0015]** The shaping may include cleaning a surface of the metallic foam 101 by at least one or more of sand blasting, grit blasting, dry ice blasting, electrolytic cleaning, acid cleaning to create desired surface topography and by the removal of oxides and/or other non-metallic surface compounds. The shaping may further include pre-heating the metallic foam 101 to limit or prevent cracking or porosity upon exposure thereof to the heat of the molten metal of the metallic matrix 103. The method may also include forming a sacrificial layer 105 about a surface of the metallic foam 101 to further limit or prevent cracking or to assist with bonding. This sacrificial layer 105 will be consumed by the molten metallic materials 103 upon the filling operation or will otherwise be dispersed throughout the lightweight structure 10 such that the solidification metallurgical bond 104 can be formed at the entire interface between the metallic matrix 103 and the metallic foam 101. Still further, the method may also include defining core regions 106 in the mold cavity by, for example, inserting cores therein. These cores may be formed to, for example, survive the filling operation such that, following the filling operation, the cores can be removed with the core regions 106 left in tact.

**[0016]** Once the metallic matrix 103 has solidified and cooled by a predefined degree, the method may further include conducting a heat treatment, such as at least one of a solution heat treatment to improve the solidification metallurgical bond 104 and an age heat treatment depending on a type of materials being used for the metallic matrix 103 and the metallic foam 101.

**[0017]** With reference to FIGS. 7 and 8, the shaping described above may be conducted in accordance with a lost foam process whereby the shaping includes building an expendable foam pattern 107 about a surface of the metallic foam 101 in the mold cavity 100, coating a surface of the foam pattern 107 with, for example, a refractory coating 108 or some other similar coating and surrounding the entire expendable foam pattern 107 and the refractory coating 108 with sand and then burning out the expendable foam pattern 107 during the filling operation. The refractory coating 108 may be formed of silica, graphite or another similar material such that the refractory coating 108 permits the reacted products of the expendable foam pattern 107 to move out of the mold cavity 100 during the casting operation. With the expendable foam pattern 107 being replaced by molten metal, the metallic matrix 103 is formed around the metallic foam 101 similarly as described above. The use of such a lost foam process may permit generation of a better solidification metallurgical bond and may allow for control of bonding depth to permit formation of particular shapes and prevention of a shifting of preformed metallic foam inserts.

**[0018]** With reference to FIGS. 9 and 10, a method to form the lightweight structure 10 in accordance with alternative embodiments is provided. The method includes shaping a mold cavity 200 within a metallic matrix 201

having an opening 2010 formed therein, filling (i.e., mold filling) the mold cavity 200 with molten metallic material 202 and a foaming agent 203 via the opening 2010 and closing the opening 2010 such that the metallic matrix 201 encloses the mold cavity 200. The method further includes allowing, as the molten metallic material 202 cools and foams within the mold cavity 200, for formation of a solidification metallurgical bond 204 at an entire interface between the metallic matrix 201 and the previously molten and now foamed metallic material 202.

**[0019]** The shaping may include cleaning a surface of the metallic matrix 201 by at least one or more of sand blasting, grit blasting, dry ice blasting, electrolytic cleaning, acid cleaning to create desired surface topography and by the removal of oxides and/or other non-metallic surface compounds. The shaping may further include pre-heating the metallic matrix 201 to limit or prevent cracking or porosity upon exposure to the molten metallic material 202. The method may also include forming a sacrificial layer 205 similar to the sacrificial layer described above about a surface of the metallic matrix 201 to further limit or prevent cracking or to assist with bonding. Still further, the method may also include defining core regions 206 in the mold cavity 200 by, for example, inserting cores therein in a process similar to what is described above. The inserted cores can be removed once solidification is complete by way of a through-hole or a similar feature formed in the metallic matrix 201.

**[0020]** Once the metallic matrix 201 has cooled by a predefined degree, the method may further include conducting at least one of a solution heat treatment to improve the solidification metallurgical bond 204 and an age heat treatment.

**[0021]** In accordance with still further embodiments, the methods described above may also include controlling a distribution of the metallic material in the metallic foam 30 in accordance with known methods.

**[0022]** While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

## Claims

1. A method to form a wind turbine component (10) configured to have a lightweight structure, the method comprising:

shaping a mold cavity (21) between metallic foam (30) and an exterior mold (102); filling a molten metallic matrix (20) into the mold cavity (21) to enclose the metallic foam (30); and as the molten metallic matrix (20) cools, forming a solidification metallurgical bond (40) at an entire interface (41) between the metallic matrix (20) and the metallic foam (30).

2. The method according to claim 1, further comprising controlling a distribution of metallic material in the metallic foam (30).
3. The method according to any preceding claim, wherein the shaping comprises at least one or more of cleaning a surface of the metallic foam (30) and pre-heating the metallic foam (30).
4. The method according to any preceding claim, further comprising forming a sacrificial layer (105) about a surface of the metallic foam (30).
5. The method according to any preceding claim, further comprising defining core regions (106) in the mold cavity (21).
6. The method according to any preceding claim, further comprising conducting a heat treatment to improve the solidification metallurgical bond (40).
7. The method according to any preceding claim, wherein the shaping comprises:
  - building an expendable foam pattern (107) in the mold cavity (21);
  - coating a surface of the expendable foam pattern (107); and
  - burning out the expendable foam pattern (107) around preformed metallic foam inserts during the filling.
8. The method according to any preceding claim, further comprising forming the metallic matrix (20) and the metallic foam (30) as a multi-ton, complex shaped component with annular and angular features.
9. A method to form a wind turbine component (10) configured to have a lightweight structure, the method comprising:
  - shaping a mold cavity (21) between metallic foam (30) and an exterior mold (102);
  - building a coated expendable foam pattern (107) in the mold cavity (21);
  - filling a molten metallic matrix (20) into the mold cavity to enclose the metallic foam such that the expendable foam pattern is burned out around

preformed metallic foam inserts during the filling; and  
as the molten metallic matrix (20) cools, forming  
a solidification metallurgical bond (40) at an entire interface (41) between the metallic matrix (20) and the metallic foam (30). 5

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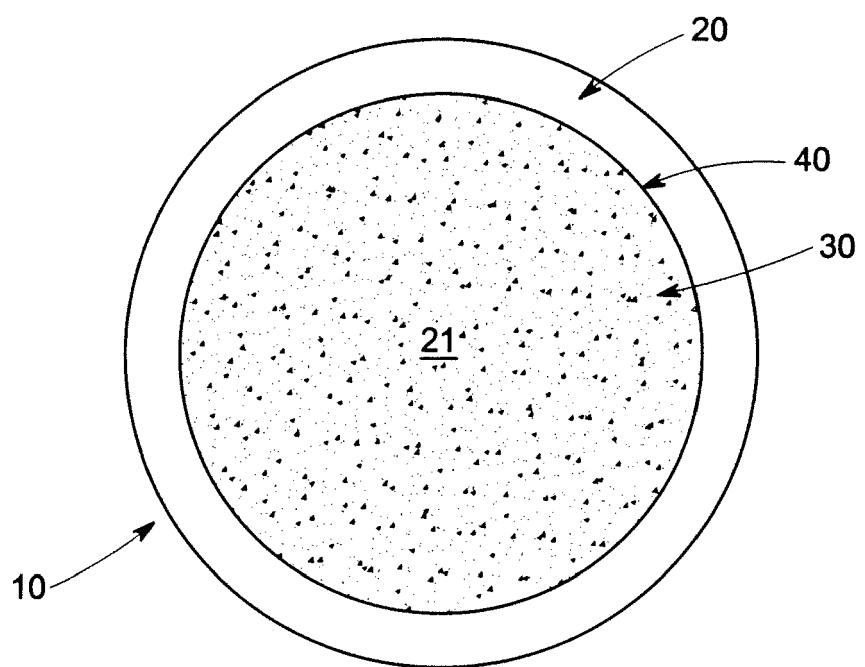


FIG. 1

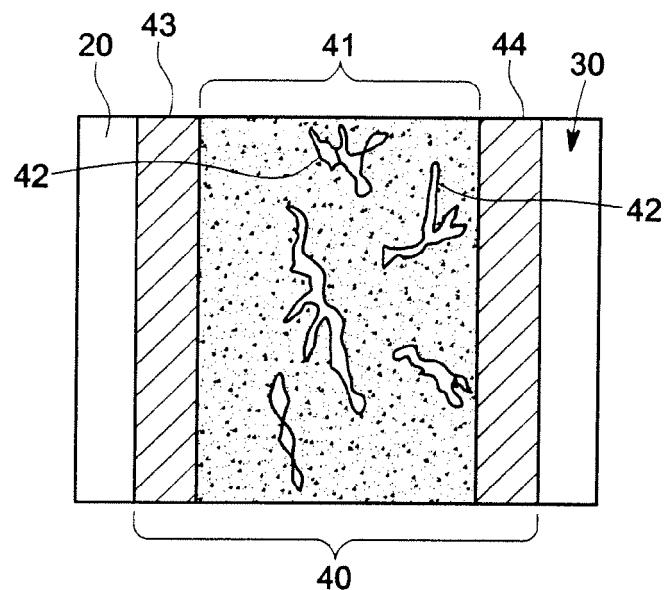


FIG. 2

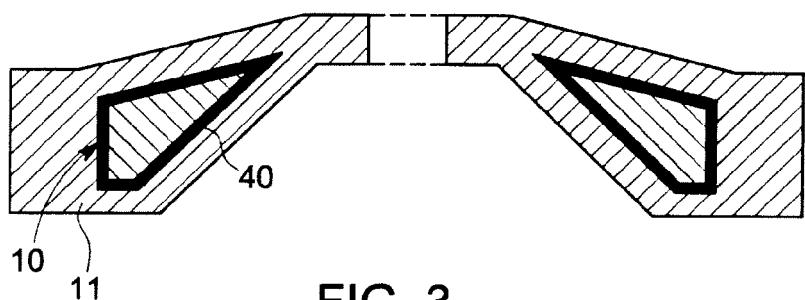


FIG. 3

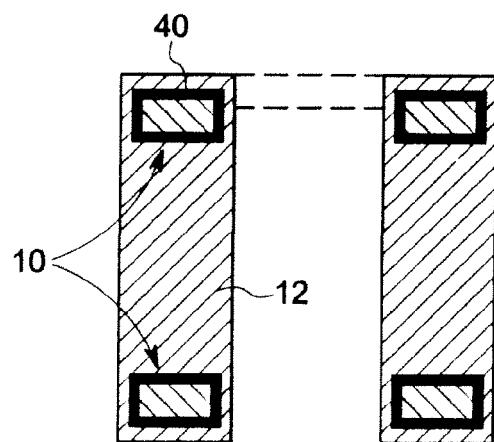


FIG. 4

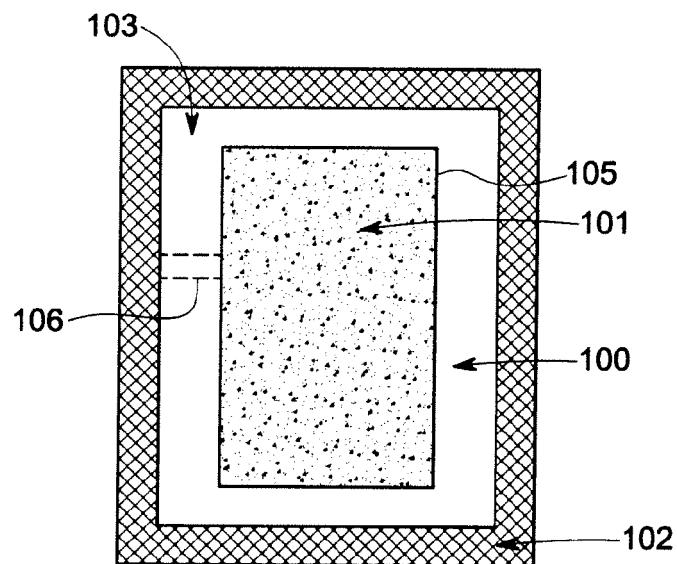


FIG. 5

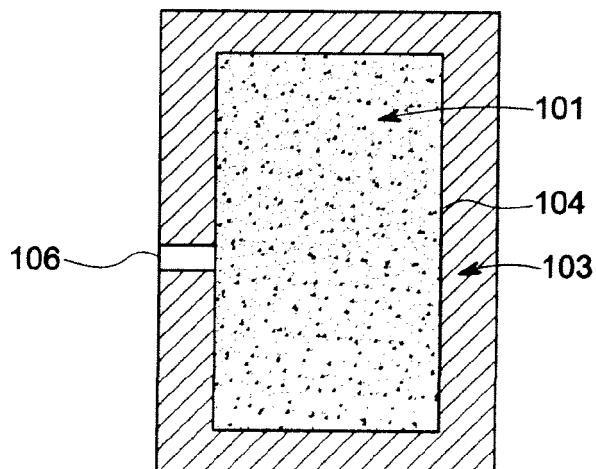


FIG. 6

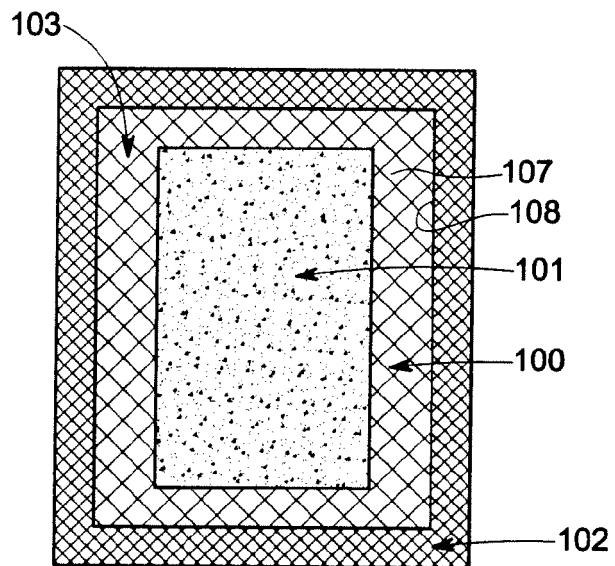


FIG. 7

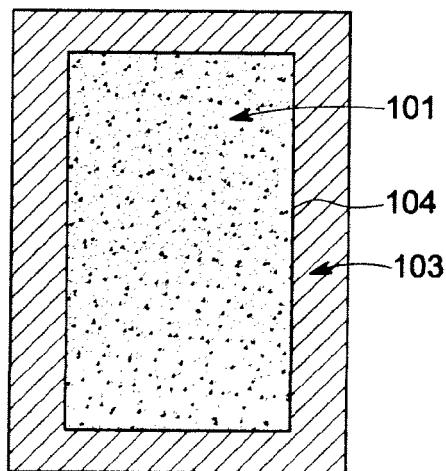


FIG. 8

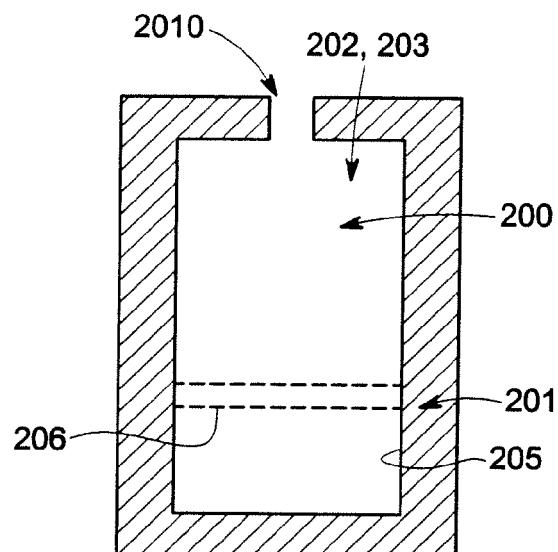


FIG. 9

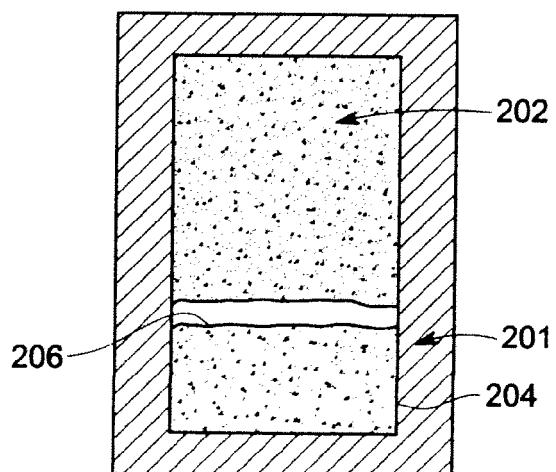


FIG. 10