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(54) **METHOD OF MAKING A COMBUSTION TURBINE COMPONENT HAVING A PLURALITY OF SURFACE COOLING FEATURES AND ASSOCIATED COMPONENTS**

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(57) **ABSTRACT**

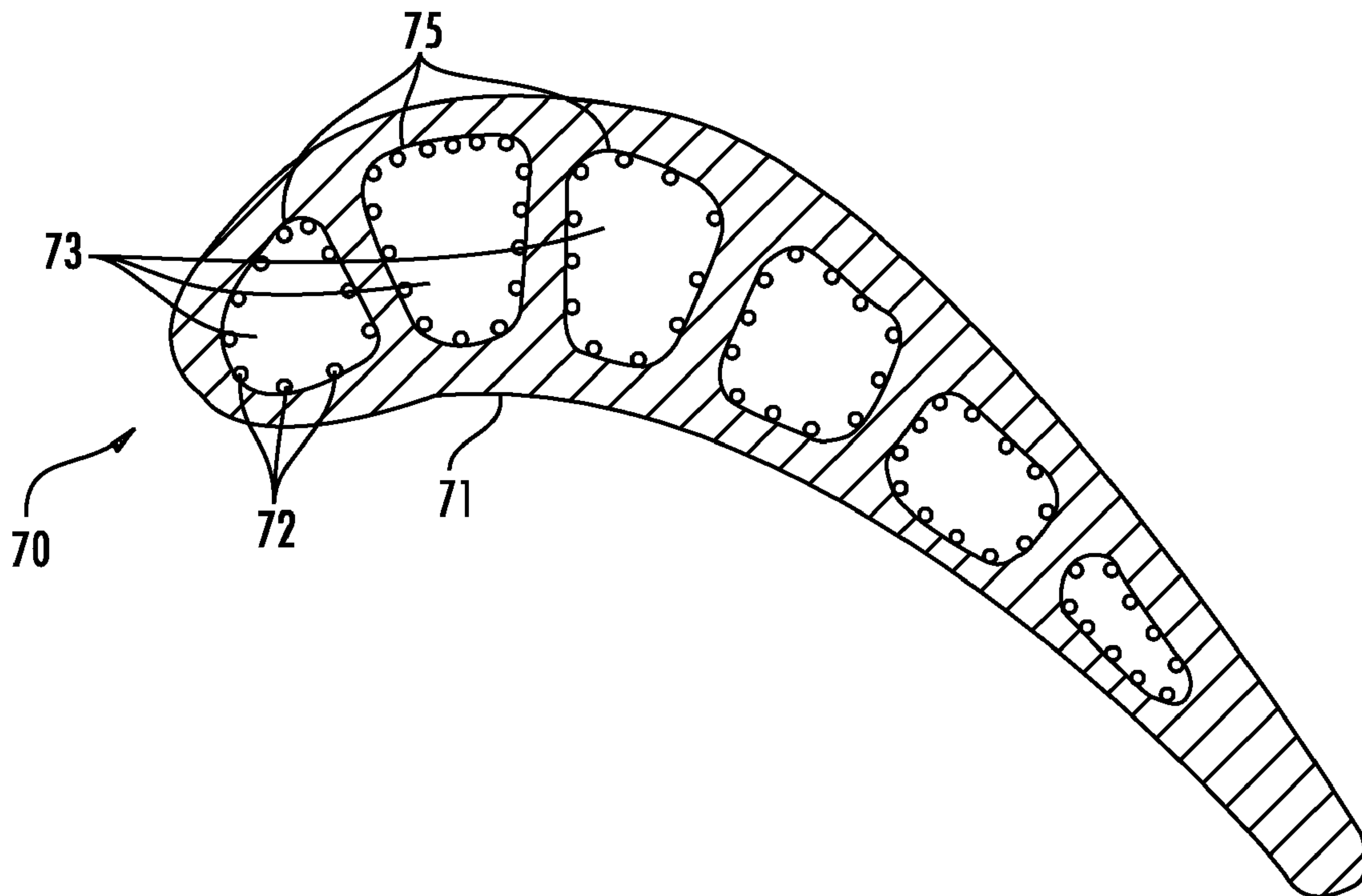
A method of making a combustion turbine component includes forming a metallic body by direct metal fabrication (DMF) to have at least one surface portion defining a first plurality of surface cooling features each having a first dimension and at least one second surface cooling feature on at least one of the first plurality of surface cooling features and having a second dimension less than said first dimension and less than 200  $\mu\text{m}$ . Forming the metallic body by DMF may include forming a plurality of metallic combustion turbine subcomponent greenbodies by DMF and assembling the plurality of metallic combustion turbine subcomponent greenbodies together to form a metallic greenbody assembly. The metallic greenbody assembly may be sintered to thereby form the metallic body.

(21) Appl. No.: **12/507,503**

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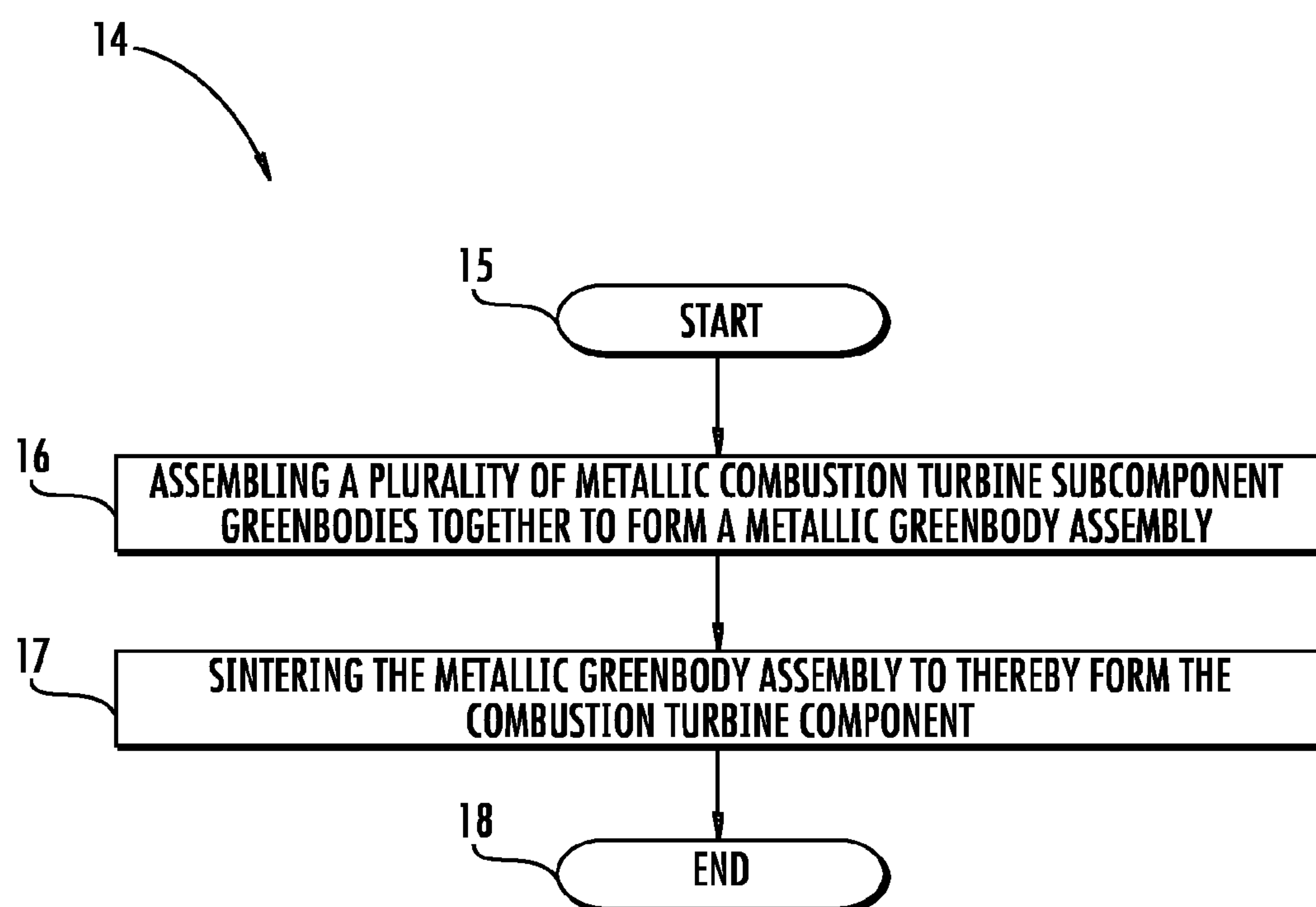


FIG. 1

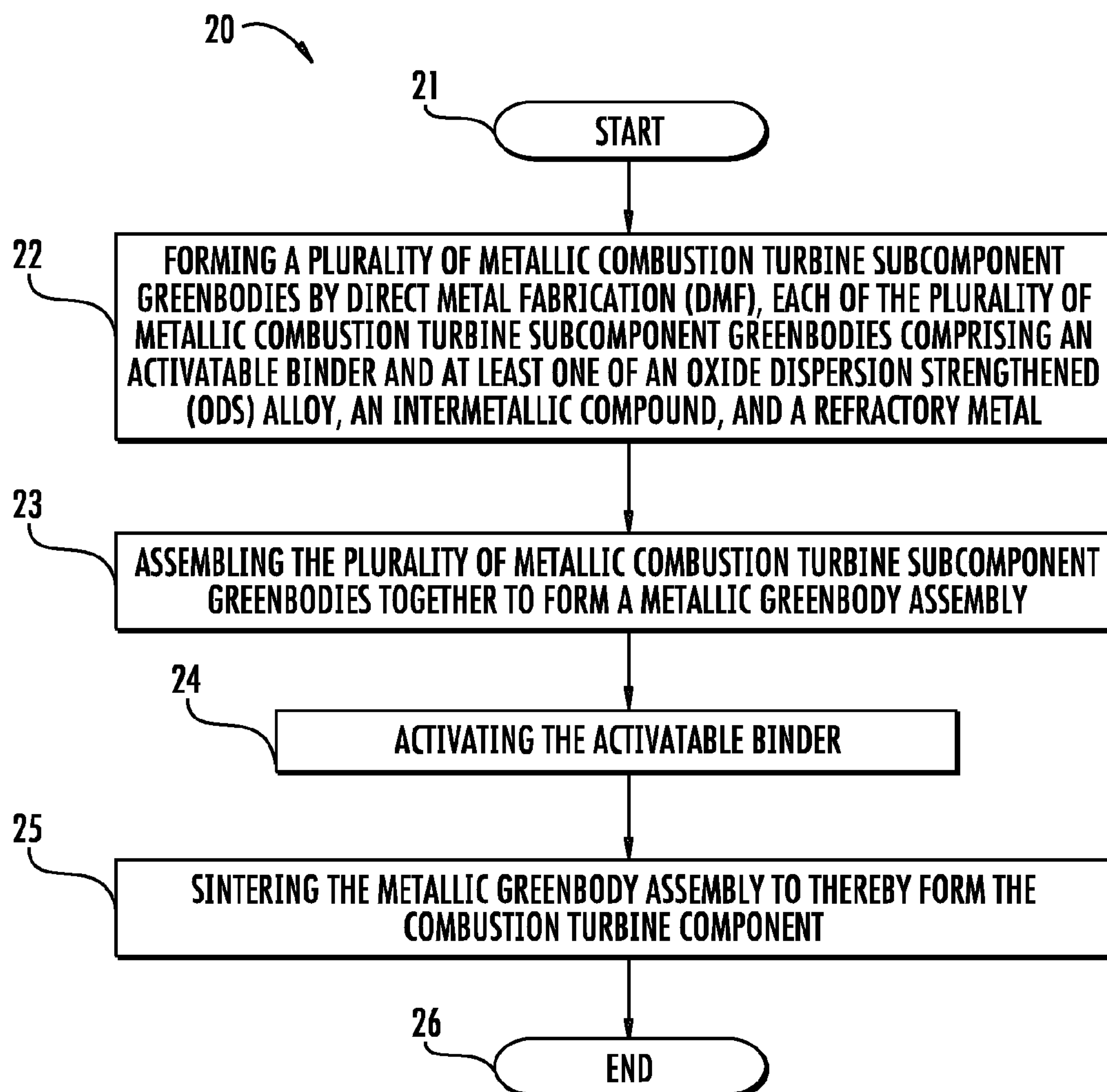


FIG. 2

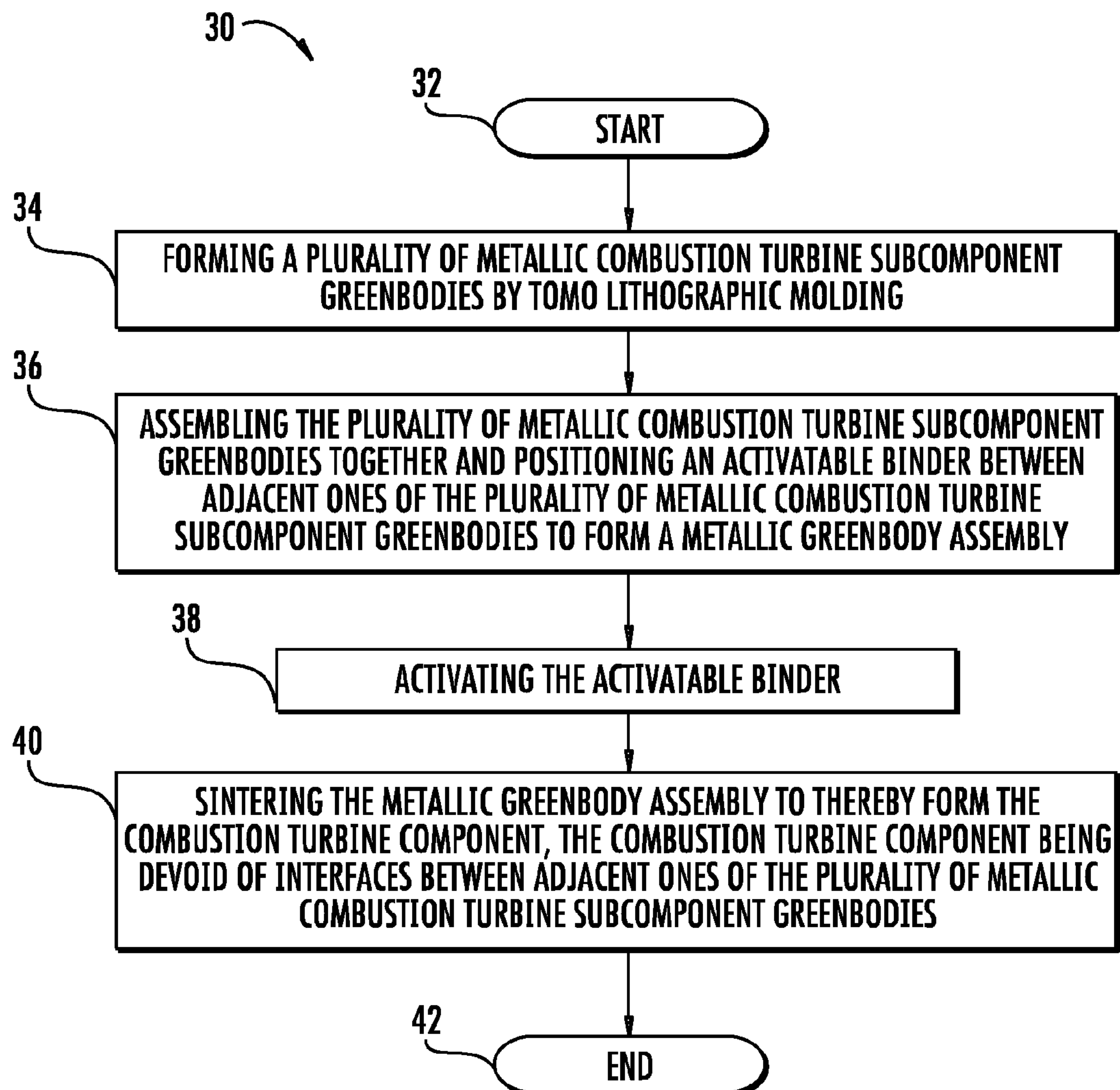


FIG. 3

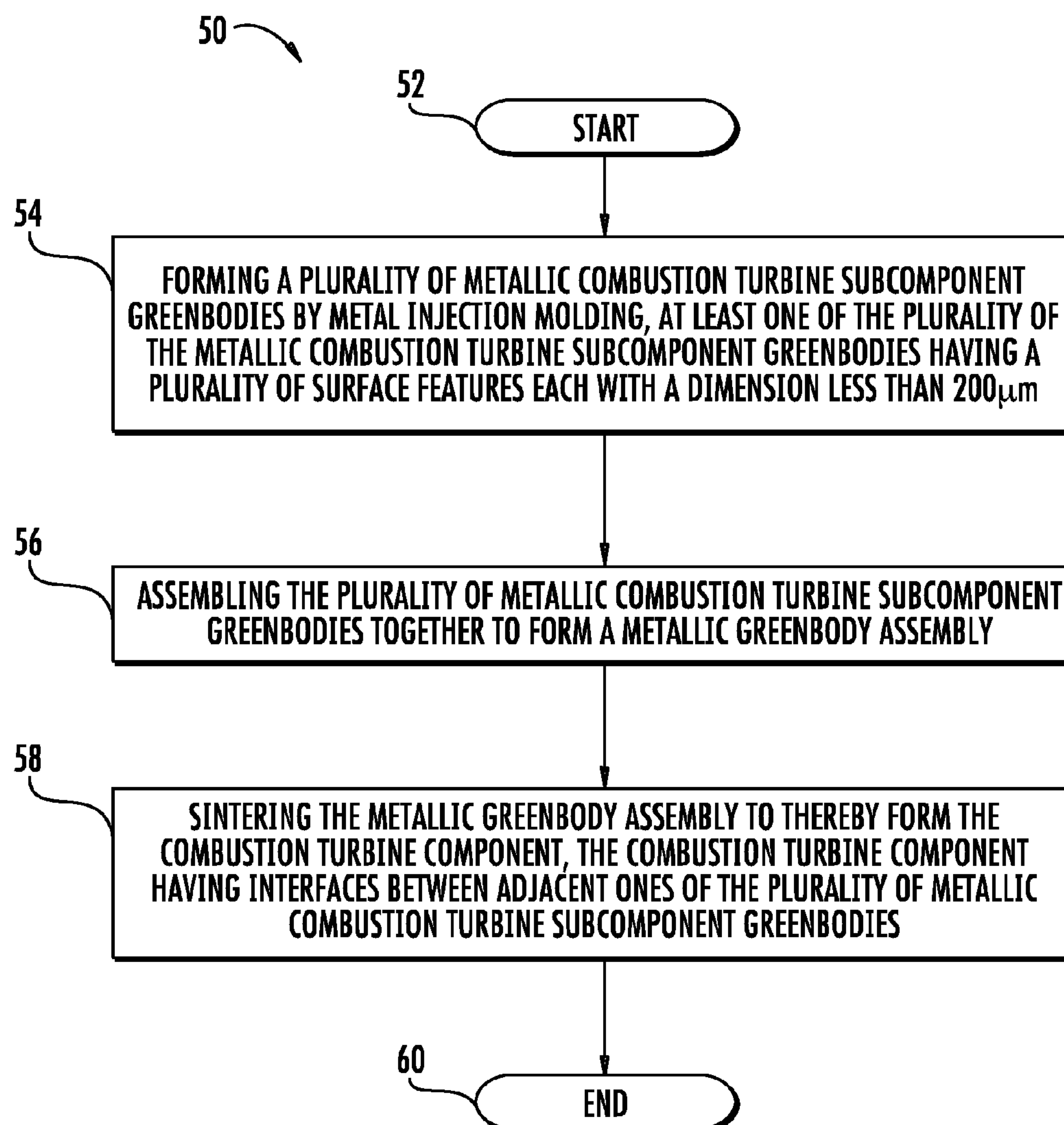


FIG. 4

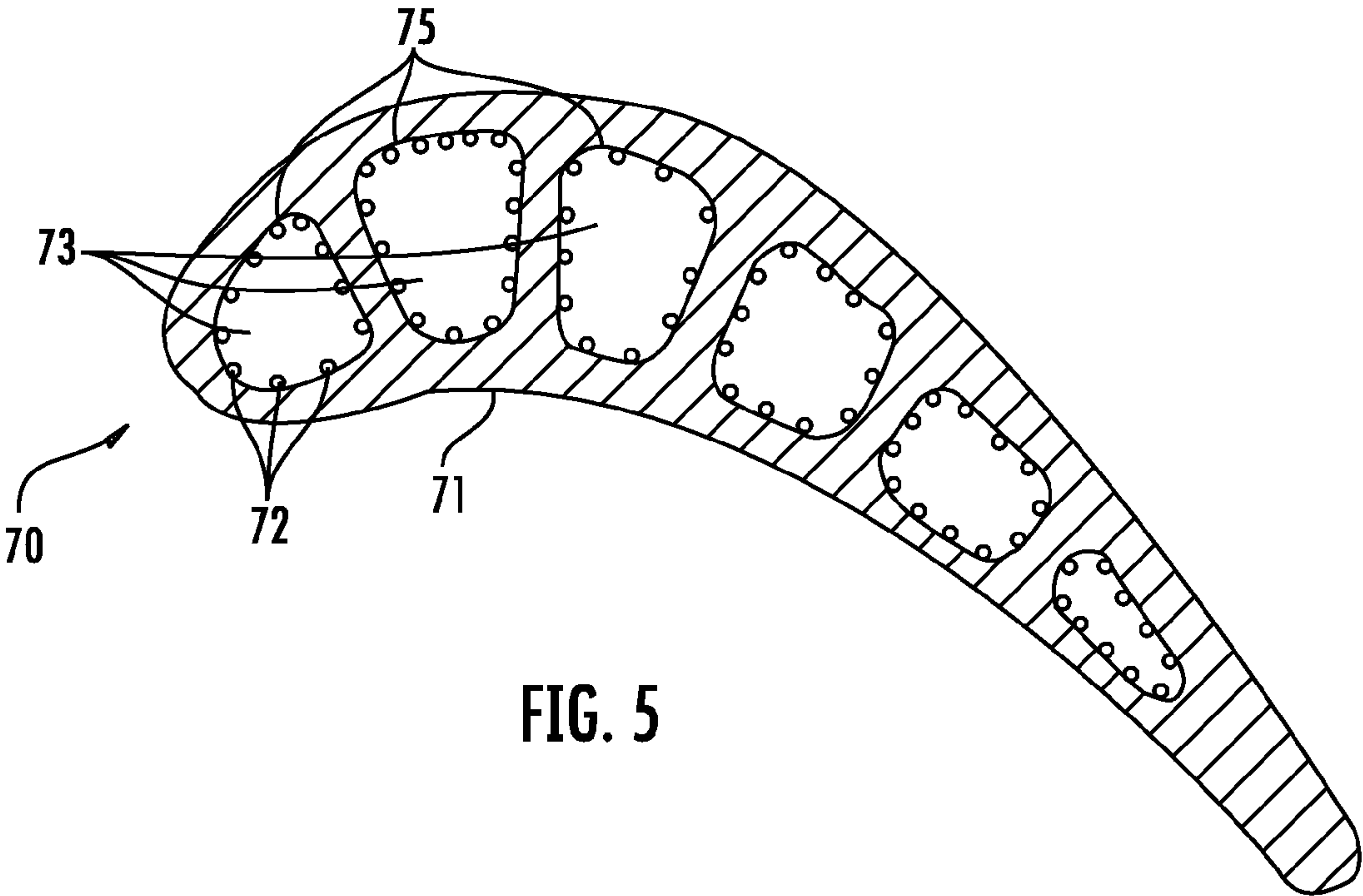


FIG. 5

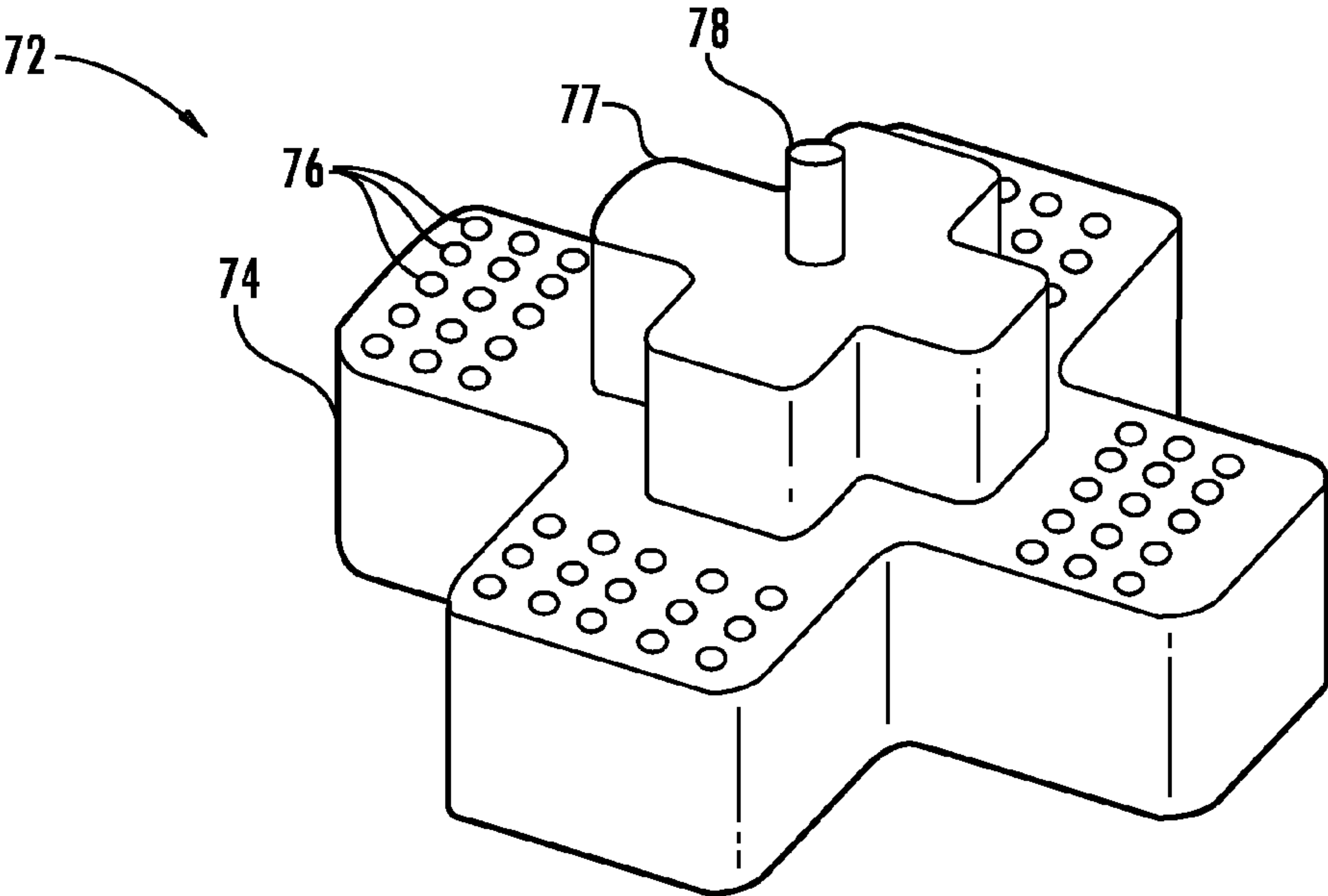


FIG. 6

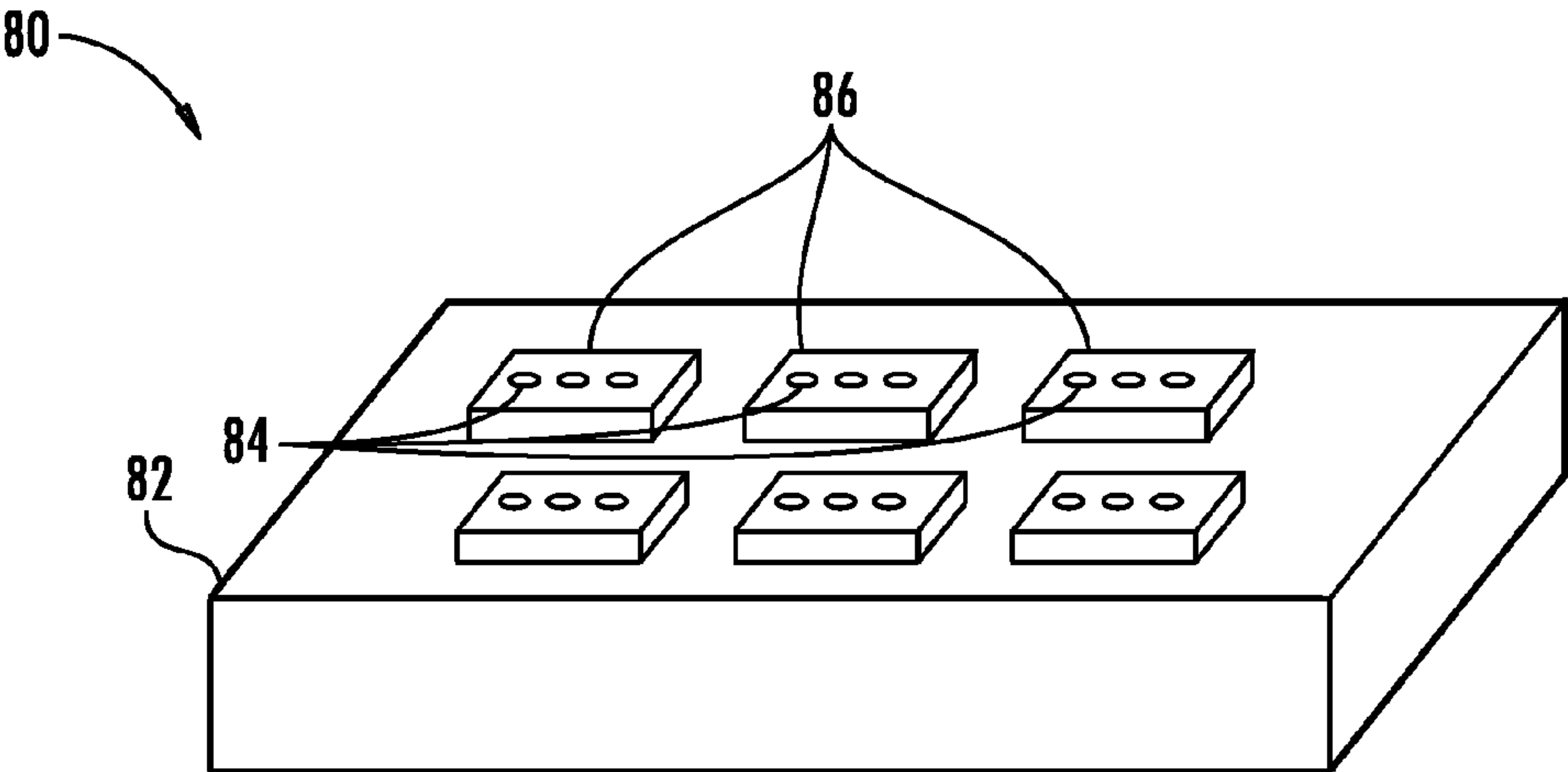


FIG. 7



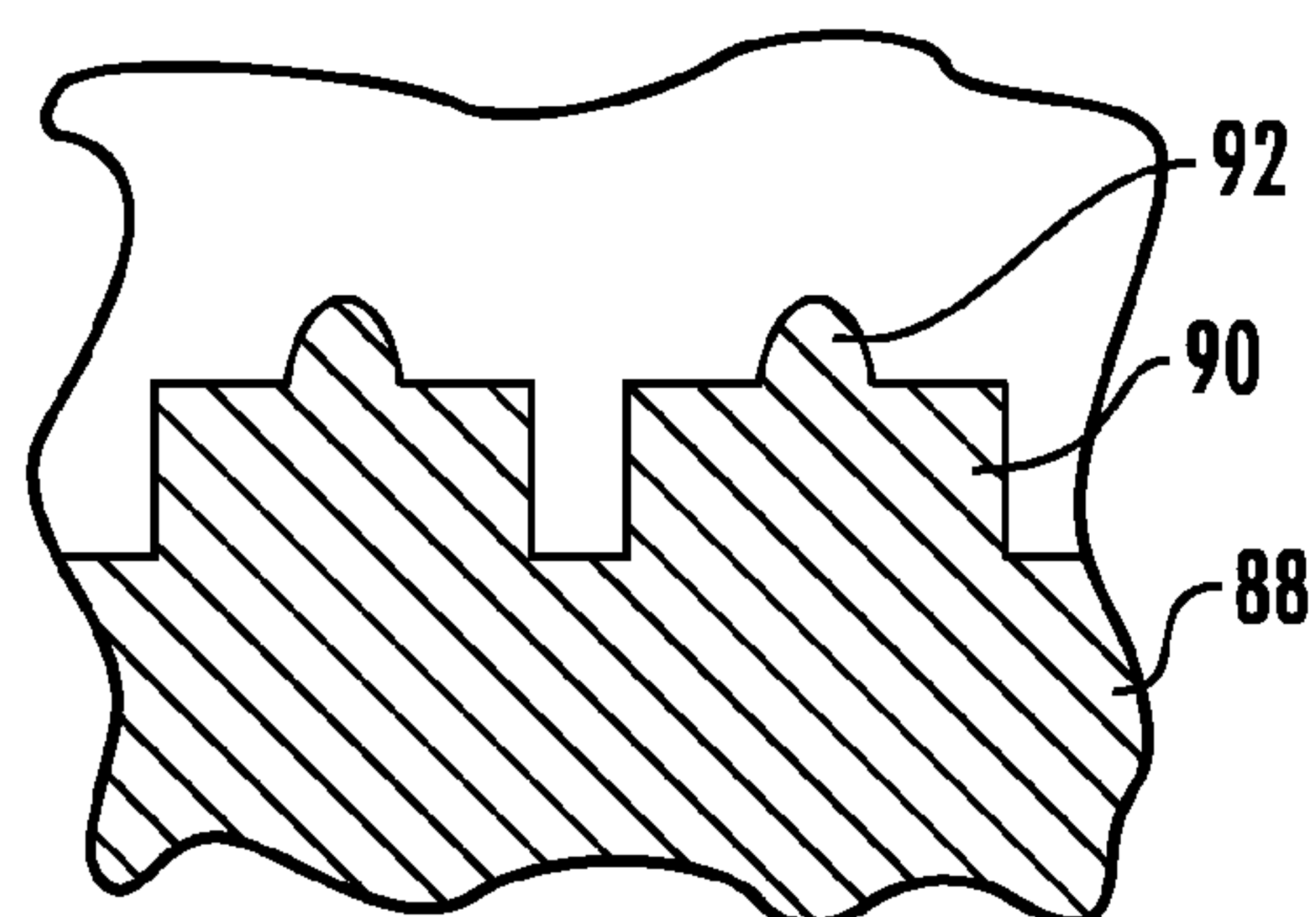


FIG. 8

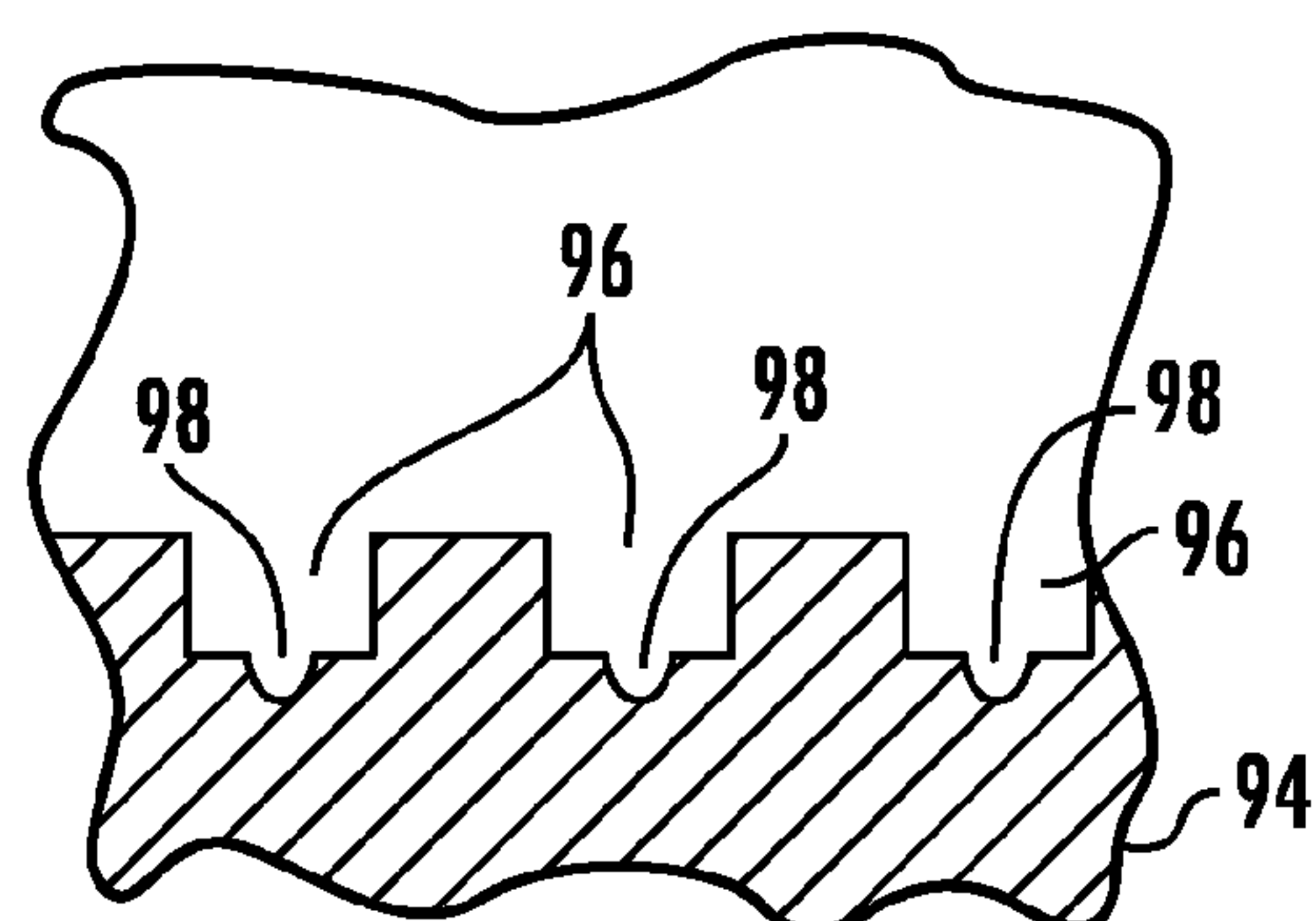


FIG. 9

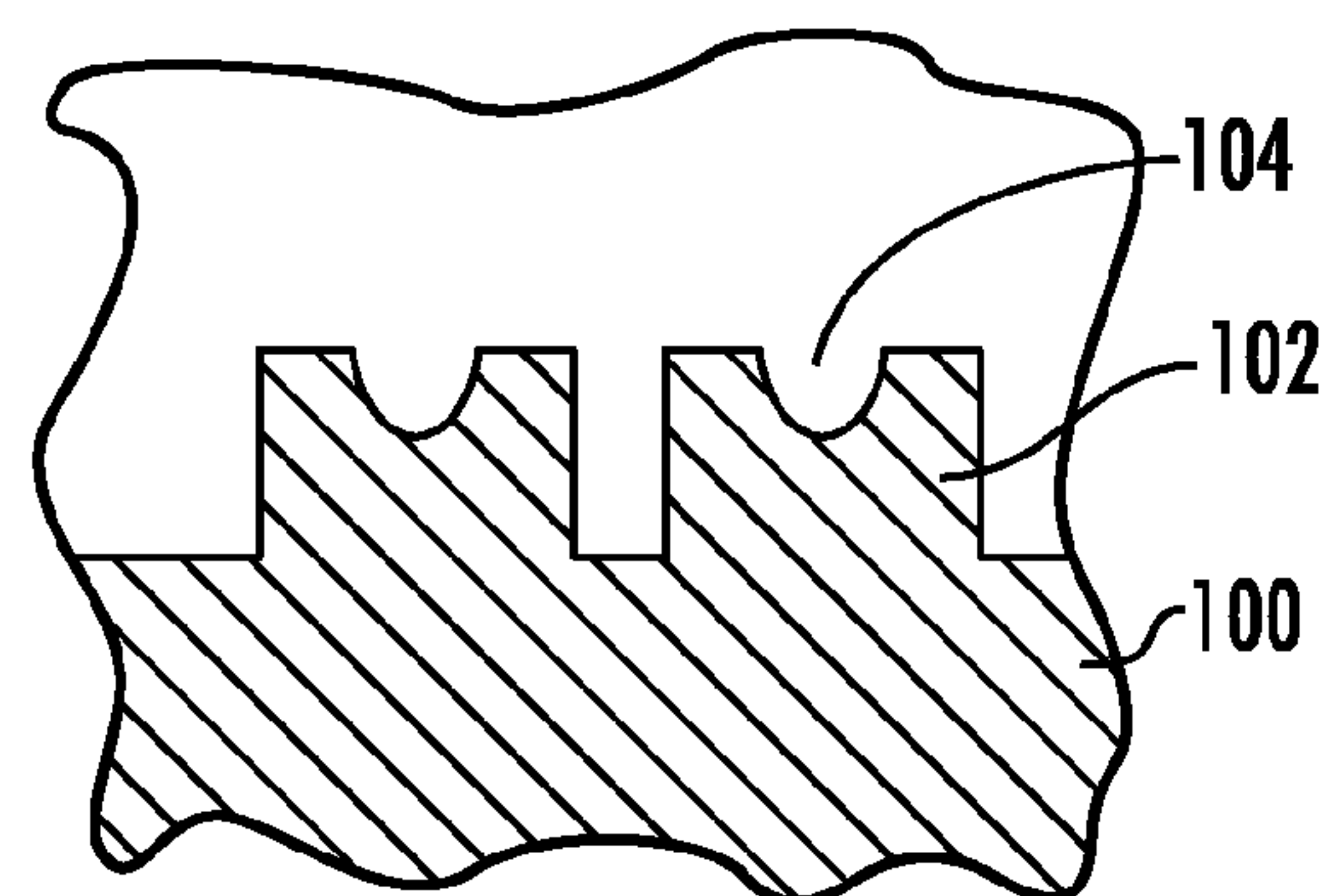


FIG. 10

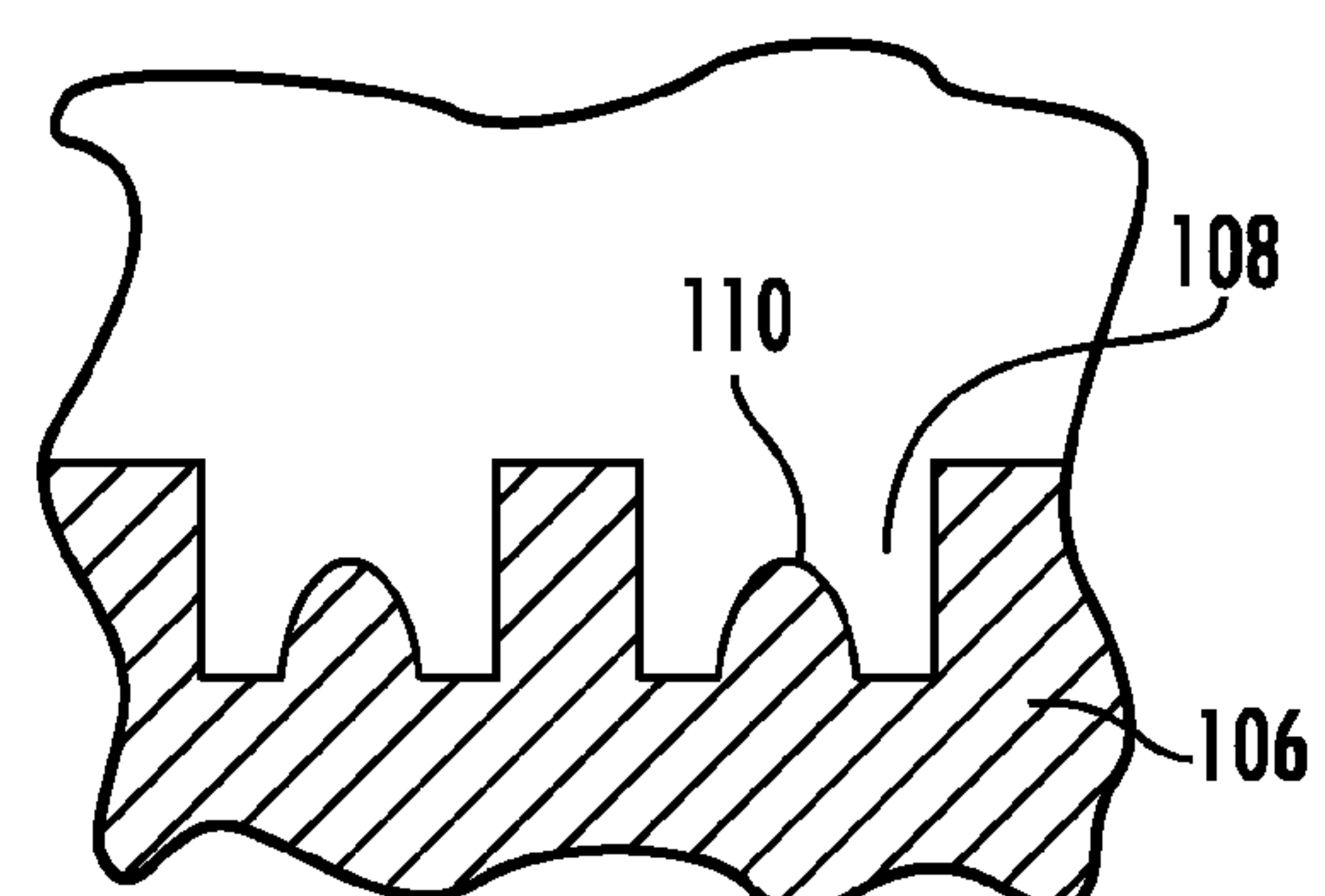


FIG. 11



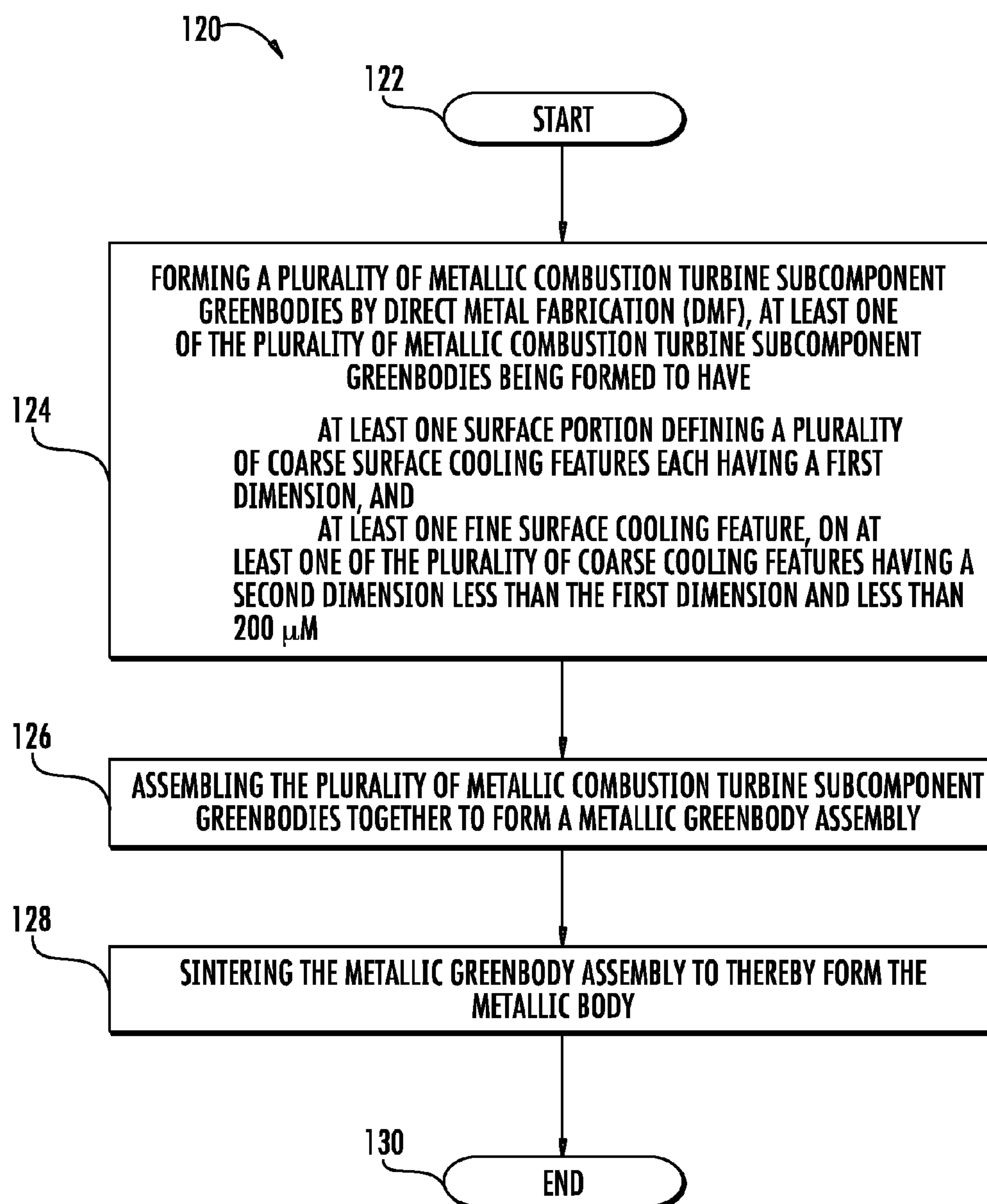


FIG. 12

# METHOD OF MAKING A COMBUSTION TURBINE COMPONENT HAVING A PLURALITY OF SURFACE COOLING FEATURES AND ASSOCIATED COMPONENTS

## GOVERNMENT CONTRACT

[0001] The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract No. DE-FC26-05NT42644 awarded by the Department of Energy.

## FIELD OF THE INVENTION

[0002] The present invention relates to the field of metallurgy, and, more particularly, to combustion turbine components having surface cooling features and associated methods.

## BACKGROUND OF THE INVENTION

[0003] A combustion turbine typically includes, in a serial flow relationship, a compressor section to compress the entering airflow, a combustion section in which a mixture of fuel and the compressed air is burned to generate a propulsive gas flow, and a turbine section that is rotated by the propulsive gas flow. After passing through the turbine section, the propulsive gas flow exits the engine through a diffuser section. In ground based combustion turbines used for electricity generation, power is normally extracted from the rotating shaft to drive an electrical power generator.

[0004] A component of such a combustion turbine may advantageously be precisely formed and may take a variety of complicated shapes. Some current methods of combustion turbine component formation include casting and forging.

[0005] Casting is a manufacturing process by which a liquid metal is poured into a mold, typically ceramic, which contains a hollow cavity of the desired shape to be formed. The liquid metal is allowed to solidify and the solid combustion turbine component casting is then ejected or broken out of the mold to complete the process. There may, however, be limitations on the size of the combustion turbine components that may be formed by casting. Likewise, there may be limitations on the size of surface features of the combustion turbine components that may be formed (e.g. it may not be possible to form surface features having dimensions below a certain size).

[0006] Forging is the term for shaping metal by using localized compressive forces. A combustion turbine component formed by forging may be relatively strong and may have a fine grain structure. However, due to the fine grain structure, a forged combustion turbine component generally exhibits relatively low resistance to creep and may thus be unsuitable for use in certain applications. Subsequent heat treatment can promote grain growth, however, and it may be easier to control grain size in a forging than a casting. In addition, the formation of small surface features on such a combustion turbine component during the forging process may be difficult. Since forgings are generally solid shapes and cooling passages are later machined into the forging, it may be difficult to machine fine scale internal features on an internal surface of a cooling passage of a forging.

[0007] As discussed above, due to process limitations and cost concerns, forming an entire combustion turbine compo-

nent of a desired shape and having desired surface features by the above processes may be difficult or costly. Thus, attempts at forming combustion turbine subcomponents and joining the subcomponents together to form a whole combustion turbine component have been made.

[0008] Some efforts have focused on welding. U.S. Pat. No. 7,337,940 to Subramanian et al., for example, discloses a method of manufacturing a combustion turbine component by friction stir welding a plurality of combustion turbine subcomponents together. The combustion turbine subcomponents are formed by conventional processes, such as casting or forging. However, some features may not be easily or cost effectively formed by casting or forging processes. In addition, some combustion turbine subcomponents may be constructed from materials that are not easily friction stir welded.

[0009] Other efforts at joining combustion turbine subcomponents together to form a combustion turbine component have instead focused on brazing. U.S. Pat. No. 6,434,946 to Shaw et al. discloses a method of making a combustion turbine component by bonding a brazing alloy to the surfaces of two combustion turbine subcomponents to be joined together and assembling the two combustion turbine subcomponents. The assembly is then heated to a brazing temperature to form a braze joint between the combustion turbine subcomponents, thereby forming the combustion turbine component. However, a braze joint may be undesirable in some situations and may not provide as strong a bond as desired.

[0010] In addition, the continuing effort to design and build more powerful and efficient combustion turbines has led to a desire for a component thereof to have enhanced high performance capabilities, such as heat transfer. Indeed, a component's ability to transfer heat away from itself is particularly important due to the high operating temperatures of combustion turbines.

[0011] Newton's Law of Cooling states that the rate of heat loss of a body is proportional to both the difference in temperatures between the body itself and its environment and the surface area of the body. Therefore, one way to enhance the cooling capabilities of a combustion turbine component is to increase its surface area.

[0012] U.S. Pat. Pub. 2008/0000611 to Bunker et al., for example, discloses a method of forming a casting mold that will be used to cast a combustion turbine component having a variety of surface cooling features, such as hemispheres, that increase the surface area of the combustion turbine component. The increased surface area provides the combustion turbine component with enhanced cooling capabilities. However, a combustion turbine component formed by casting and having an increased surface area may not be desirable in some applications. Furthermore, certain arrangements of surface cooling features may not be easily formed by casting techniques.

[0013] U.S. Pat. No. 6,503,574 to Skelly et al. discloses a method for making a combustion turbine component having cooling grooves defined therein. A combustion turbine component substrate is formed by single crystal casting techniques and then a bond coating is formed on the combustion turbine component substrate. A pattern of three-dimensional recessed grooves is etched in the bond coating by photolithography and then a thermal barrier coating is formed on the bond coating. However, recessed grooves may not provide the desired cooling capabilities in some applications.

[0014] Therefore, different methods of joining combustion turbine subcomponents together to form a combustion tur-



bine component may be desirable. In addition, a combustion turbine component having increased surface area that is formed by joining a plurality of combustion turbine subcomponents together may also be desirable.

#### SUMMARY OF THE INVENTION

**[0015]** In view of the foregoing background, it is therefore an object of the present invention to provide a combustion turbine component having a plurality of surface cooling features together with methods of making such a combustion turbine component.

**[0016]** This and other objects, features, and advantages in accordance with the present invention are provided by a method of making a combustion turbine component comprising forming a metallic combustion turbine component body by direct metal fabrication (DMF). The metallic combustion turbine component body may be formed to have at least one surface portion defining a plurality of coarse surface cooling features each having a first dimension, and at least one fine surface cooling feature on at least one of the plurality of coarse surface cooling features and having a second dimension less than the first dimension and less than 200  $\mu\text{m}$ . The cooling features increase the surface area of the combustion turbine component and thereby enhance its ability to transfer heat away from itself, improving high temperature performance.

**[0017]** DMF advantageously allows for a greater variety of shapes to be formed than casting or forging. In addition, DMF allows the formation of smaller surface features than may be possible with conventional casting or forging processes.

**[0018]** The at least one fine surface cooling feature may comprise a projection, such as a convex projection. The at least one fine surface cooling feature may comprise a recess, such as a concave recess.

**[0019]** The DMF may comprise tomo lithographic molding. Additionally or alternatively the DMF may comprise metal injection molding.

**[0020]** Forming the metallic combustion turbine component body by DMF may include forming a plurality of metallic combustion turbine subcomponent greenbodies by DMF, each of the plurality of metallic combustion turbine subcomponent greenbodies comprising an activatable binder. The plurality of metallic combustion turbine subcomponent greenbodies may be assembled together to form a metallic greenbody assembly. The activatable binder may be activated. The metallic greenbody assembly may be sintered to thereby form the metallic body.

**[0021]** The first dimension may be greater than 500  $\mu\text{m}$ . At least one of the plurality of coarse surface cooling features may comprise a projection or a recess, for example.

**[0022]** The metallic combustion turbine component body may comprise at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal. Such materials may impart the combustion turbine component with various desirable properties.

**[0023]** Another aspect is directed to a combustion turbine component comprising a metallic body having at least one surface portion defining a plurality of coarse cooling features each having a dimension greater than 500  $\mu\text{m}$ . A plurality of

fine cooling features, each having a dimension less than 200  $\mu\text{m}$ , is on at least one of the plurality of coarse cooling features.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0024]** FIG. 1 is a flowchart for a method of forming a combustion turbine component in accordance with the present invention.

**[0025]** FIG. 2 is a more detailed flowchart for the method of forming a combustion turbine component in accordance with the present invention.

**[0026]** FIG. 3 is another more detailed flowchart for the method of forming a combustion turbine component in accordance with the present invention.

**[0027]** FIG. 4 is a yet another flowchart for the method of forming a combustion turbine component in accordance with the present invention.

**[0028]** FIG. 5 is a cross sectional view of combustion turbine component having a plurality of surface cooling features in accordance with the present invention.

**[0029]** FIG. 6 is a greatly enlarged perspective view of the one of the surface cooling features of the combustion turbine component of FIG. 5.

**[0030]** FIG. 7 is a greatly enlarged perspective view of an alternative embodiment of a surface cooling feature for a combustion turbine component in accordance with the present invention.

**[0031]** FIG. 8 is a greatly enlarged schematic cross sectional view of yet another surface cooling feature for a combustion turbine component in accordance with the present invention.

**[0032]** FIG. 9 is a greatly enlarged schematic cross sectional view of still another surface cooling feature for a combustion turbine component in accordance with the present invention.

**[0033]** FIG. 10 is a greatly enlarged schematic cross sectional view of another surface cooling feature for a combustion turbine component in accordance with the present invention.

**[0034]** FIG. 11 is a greatly enlarged cross schematic sectional view of still another surface cooling feature for a combustion turbine component in accordance with the present invention.

**[0035]** FIG. 12 is flowchart of a method of forming a combustion turbine component having a plurality of surface cooling features in accordance with the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0036]** The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

**[0037]** Referring initially to the flowchart 14 of FIG. 1, a first embodiment of a method of making a combustion turbine component is now described. After the start (Block 15), at Block 16 a plurality of metallic combustion turbine subcom-



ponent greenbodies are assembled together to form a metallic greenbody assembly. The metallic greenbody assembly has a shape closely resembling that of the final combustion turbine component, but has a greater porosity, a lesser density, and a larger size. The plurality of metallic combustion turbine subcomponent greenbodies may be assembled by conventional methods known to those of skill in the art.

**[0038]** Those of skill in the art will understand that a metallic combustion turbine subcomponent greenbody is an unsintered metallic combustion turbine subcomponent that lacks strength and has both a low density and high porosity compared to a sintered metallic body.

**[0039]** At Block 17, the metallic greenbody assembly is sintered to thereby form the combustion turbine component. During sintering, the metallic greenbody assembly may shrink in all directions by up to 20%, thereby increasing in density. In addition, the porosity of the metallic greenbody assembly is reduced and the strength of the metallic greenbody assembly is increased.

**[0040]** The sintering may be solid state sintering or liquid state sintering. During solid state sintering, the metallic greenbody assembly is heated to a temperature below the melting point of its constituents and held at that temperature until its particles adhere to each other. During liquid state sintering, the metallic greenbody assembly is heated until at least one but not all of its constituents melt and reach a liquid state.

**[0041]** The metallic greenbody assembly may be placed under pressure during the sintering. In this case, the sintering may comprise hot isostatic pressing (HIP). HIP subjects a component to high gas pressure in a containment vessel. The pressurizing gas is preferably argon, although other inert gasses may be used as will be appreciated by those of skill in the art. The pressurizing gas is preferably applied between 100 and 310 MPa (15,000 p.s.i. and 45,000 p.s.i.) at a temperature of 480° C. to 2000° C., although other pressures and other temperatures may be used as well. As the containment vessel is heated during the HIP, the pressure inside increases. The pressure is isostatic because it is applied to the metallic greenbody assembly from all directions evenly. The pressure and heat during HIP helps to reduce internal voids in the metallic greenbody assembly through a combination of plastic deformation, creep, and diffusion bonding, thus increasing the density of the metallic greenbody assembly. Alternatively, the sintering may be performed without the metallic greenbody assembly being placed under pressure. Block 18 indicates the end of the method.

**[0042]** After sintering, a bond coating may be formed on the combustion turbine component and a thermal barrier coating may be formed on the bond coating. Any number of exemplary bond coatings and thermal barrier coatings known to those of skill in the art may be used. In addition, the thermal barrier coating may be formed directly on the combustion turbine component, without an intervening bond coating. Additionally or alternatively, a wear resistant layer may be formed on the combustion turbine component.

**[0043]** Those of skill in the art will understand that, in some embodiments, after sintering the combustion turbine component may be placed into a casting mold and that additional metallic layers may therefore be formed around the combustion turbine component, encasing it.

**[0044]** In addition, it should be understood that a plurality of metallic combustion turbine subcomponent greenbodies may be assembled to form a metallic greenbody assembly and

that the metallic greenbody assembly may be sintered to form a combustion turbine subcomponent assembly. Multiple combustion turbine subcomponent assemblies may be formed in this fashion and then joined together by conventional methods, such as welding or brazing, to form the combustion turbine component. The multiple combustion turbine subcomponent assemblies may also be placed into a casting mold and additional layers may be formed therearound to form a combustion turbine component.

**[0045]** Referring now to the flowchart 20 of FIG. 2, a more detailed method of making a combustion turbine component is now described. After the start (Block 21) at Block 22 a plurality of metallic combustion turbine subcomponent greenbodies are formed by direct metal fabrication (DMF).

**[0046]** Direct metal fabrication processes include (1) layered powder build-up processes, such as selective laser sintering (SLS), (2) processes using light energy to chemically change a material, such as stereolithography (SLA), (3) deposition techniques that selectively deposit either particles or thin laminates, such as solid ground curing (SGC), laminated object manufacturing (LOM), fused deposition modeling (FDM), and ballistic particle manufacturing (BPM), and (4) powder metallurgy processes that tightly compact a metal powder into a mold or die, such as metal injection molding (MIM) or tomo lithographic molding. SLS, for example, uses a high powered laser to fuse the particles of a metal powder into a mass representing a desired three dimensional object, one layer at a time.

**[0047]** The plurality of metallic combustion turbine subcomponent greenbodies may be formed by any of the above DMF processes, or by other processes known to those of skill in the art. In addition, each of the plurality of metallic combustion turbine subcomponent greenbodies may be formed by the same DMF process, or each may be formed by different DMF processes. For example, it may be advantageous for some of the metallic combustion turbine subcomponent greenbodies to be formed by SLA while others are formed by MIM.

**[0048]** Each of the plurality of metallic combustion turbine subcomponent greenbodies in this embodiment may comprise an activatable binder and at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal. Each of the plurality of metallic combustion turbine subcomponent greenbodies may also comprise a Nickel based superalloy and, optionally, at least one rare earth element. The activatable binder may comprise a polymer or plastic binder, a metallic mix including a melting point depressor, or another suitable binder known to those of skill in the art. Intermetallic compounds are solid phases containing two or more metallic elements, optionally having one or more non-metallic elements. Intermetallic phases form due to strong bonding between unlike metal atoms, this results in an ordered crystal structure, whereby the various atomic species occupy specific sublattice sites. Intermetallic compounds may also include interstitial compounds such as carbides and nitrides. Such intermetallic compounds offer advantageous properties like high temperature resistance and hardness. Refractory metals include tungsten, molybdenum, niobium, tantalum, and rhenium, and are extraordinarily resistant to heat and wear. The methods described herein allow the formation of combustion turbine components from the above materials, whereas conventional methods such as casting and forging may not. It should be



noted that the plurality of metallic combustion turbine subcomponent greenbodies may be metallic and not contain any ceramic.

[0049] At Block 23, the plurality of metallic combustion turbine subcomponent greenbodies are assembled together to form a metallic greenbody assembly. At Block 24, the activatable binder is activated. The activatable binder may be activated by heating the greenbody assembly, or may be activated by other suitable methods. After activation, the activatable binder may optionally be cured through the use of a chemical agent, ultraviolet radiation, bombardment with an electron beam, or further heating. Furthermore, the activatable binder may optionally be removed from the greenbody assembly by a pre-sintering heat treating at a temperature of 400° C. to 600° C., or at other suitable temperatures, or through the use of chemical agents. This pre-sintering heat treating, in some embodiments, may increase the density, decrease the porosity, and shrink the greenbody assembly.

[0050] At Block 25, the metallic greenbody assembly is sintered to thereby form the combustion turbine component. Block 26 indicates the end of the method.

[0051] With reference to the flowchart 30 of FIG. 3, an alternative embodiment of a method of making a combustion turbine component is now described. After the start (Block 32), at Block 34, a plurality of metallic combustion turbine subcomponent greenbodies is formed by tomo lithographic molding. Tomo lithographic molding involves the production of a master tool which is then used either directly as a mold or die, or alternatively used to produce a secondary consumable mold. To create the master tool, a series of layers are fabricated with lithographic techniques. The layers are micro-machined to add additional features and details, and are then laminated together by brazing or epoxy bonding to form the master tool. The master tool may then be used as a mold or die for processes such as microcasting, microinjection molding, metal injection molding, and powder injection molding.

[0052] It should be understood that the term tomo lithographic molding as used hereinafter is to mean the use of a master tool formed by tomo lithographic molding in conjunction with a suitable process to form metallic combustion turbine subcomponent greenbodies therefrom.

[0053] At Block 36, the plurality of metallic combustion turbine subcomponent greenbodies is assembled together and an activatable binder is positioned between adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies to form a metallic greenbody assembly. The activatable binder may be formed from the same material as the plurality of metallic combustion turbine subcomponent greenbodies that has been mixed with a suitable binding agent, such as a polymer or plastic binder or a melting point depressor, such as boron. Alternatively, the activatable binder may be a metallic mix together with a melting point depressor.

[0054] If the activatable binder includes a melting point depressor, the sintering may be liquid state sintering and the plurality of metallic combustion turbine subcomponent greenbodies may bond together by transient liquid phase (TLP) bonding. If the plurality of metallic combustion turbine subcomponent greenbodies is to be bonded together by TLP bonding, the activatable binder between each of the plurality of metallic combustion turbine subcomponent greenbodies is considered to be a TLP forming layer. The metallic greenbody assembly and thus the TLP forming layer are then heat treated at a temperature higher than the melting point of the TLP

forming layer, but lower than the melting point of the other constituents of the metallic greenbody assembly. Accordingly, the TLP forming layer melts during the sintering.

[0055] As the temperature remains constant, the melting point depressor diffuses from the TLP forming layer into each of the plurality of metallic combustion turbine subcomponent greenbodies, and molecules from each of the plurality of metallic combustion turbine subcomponent greenbodies diffuse into the TLP layer. As a result of this diffusion, the melting point of TLP layer increases beyond the temperature of the heat treatment and the TLP layer, now close in composition to the plurality of metallic combustion turbine subcomponent greenbodies, resolidifies. The resulting bonded region between each of the plurality of metallic combustion turbine subcomponent greenbodies is thin and of a high strength.

[0056] Those of skill in the art will appreciate that the activatable binder may be positioned between certain adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies but not between other adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies.

[0057] At Block 38, the activatable binder is activated. At Block 40, the metallic greenbody assembly is sintered to thereby form the combustion turbine component. The combustion turbine component is devoid of an interface between adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies after sintering. This lack of interfaces may provide the combustion turbine component with increased strength and the metallurgical properties throughout may be consistent. Block 42 indicates the end of the method.

[0058] Another embodiment of a method of making a combustion turbine component is now described with reference to the flowchart 50 of FIG. 4. After the start (Block 52), at Block 54 a plurality of metallic combustion turbine subcomponent greenbodies is formed by metal injection molding. Metal injection molding involves injecting a metallic powder and a suitable binder into a mold, in some situations with conventional plastic injection molding machines and processes. The mold used with the metal injection molding may be formed by tomo lithographic molding or may be formed from other methods.

[0059] At least one of the plurality of metallic combustion turbine subcomponent greenbodies is formed to have at least one internal cooling passage. This internal cooling passage is formed to have a plurality of internal surface features, each with a dimension less than 200  $\mu\text{m}$ . As will be explained in detail below, this plurality of internal surface features increases the internal surface area of the cooling passages of the combustion turbine component and therefore enhances its ability to transfer heat away from itself. As will also be explained in detail below, each of the plurality of internal surface features may take a variety of shapes and may be either a projection or a recess.

[0060] Of course, those of skill in the art will recognize that, in some applications, one of the metallic combustion turbine subcomponent greenbodies need not have internal cooling passages. In such applications, the surface features described herein may be external cooling features.

[0061] At Block 56, the plurality of metallic combustion turbine subcomponent greenbodies is assembled together to form a metallic greenbody assembly. At Block 58, the metallic greenbody assembly is sintered to thereby form the combustion turbine component. In this embodiment, the combus-



tion turbine component has interfaces between adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies. Block 60 indicates the end of the method. Those of skill in the art will appreciate that, in some applications, there may be an interface between certain adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies after sintering and no interface between other adjacent ones of the plurality of metallic combustion turbine subcomponent greenbodies after sintering.

[0062] With reference to FIGS. 5-6, a combustion turbine component 70 having a plurality of internal surface cooling features 72 is now described. The combustion turbine component 70 comprises a metallic body 71 to define at least a substrate for the combustion turbine component, the metallic body having a plurality of internal cooling passages 73. The internal cooling passages 73 each have an internal surface portion 75.

[0063] The internal surface portion 75 defines a plurality of coarse surface cooling features 74, each having a dimension greater than 500  $\mu\text{m}$ . As perhaps best shown in FIG. 6, one of the plurality of coarse surface cooling features 74 illustratively comprises a three-tiered projection.

[0064] A plurality of fine surface cooling features 76 is on at least one of plurality of coarse surface cooling features 74, each having a dimension less than 200  $\mu\text{m}$ . As also shown in FIG. 6, the plurality of fine surface cooling features 76 illustratively comprises convex or hemispherical projections, and may be on the order of 50  $\mu\text{m}$ , for example.

[0065] The surface cooling features described herein increase the surface area of the internal surface portion 75 of the combustion turbine component 70, thereby enhancing its ability to transfer heat away from itself and cool itself and into a cooling fluid flowing therethrough. This enhanced heat transfer may allow for the size of the cooling passageways 73 to be decreased compared to those of conventional combustion turbine components. Furthermore, this enhanced heat transfer may allow for an amount of cooling fluid used to cool the combustion turbine component 70 to be reduced.

[0066] A first additional surface cooling feature 77 comprising an "x" shaped projection is illustratively on the coarse surface cooling feature 74 and has a dimension greater than 200  $\mu\text{m}$ . It should be understood that, although one first additional cooling feature 77 is shown, there may instead be a plurality of first additional surface cooling features on at least one of the plurality of coarse surface cooling features 74 and that ones of this plurality of first additional surface cooling features may be of sizes both greater than and less than 200  $\mu\text{m}$ .

[0067] A second additional surface cooling feature 78 comprising a circular-base pin and having a dimension less than 200  $\mu\text{m}$  is illustratively on the first additional surface cooling feature 77.

[0068] Those of skill in the art will recognize that there may be any number of stacked pluralities of surface cooling features (e.g. there may be a third plurality of additional surface cooling features on the second plurality of additional surface cooling features, and so on and so forth)

[0069] Each of the plurality of coarse surface cooling features 74, plurality of fine surface cooling features 76, first additional plurality of surface cooling features 77, and second additional plurality of surface cooling features 78 may be projections of other suitable shapes, including but not limited to square-base pins, circular-base pins, square-base pyramids, circular base cones, tapered pins, polygonal-based

pyramids, conical frustums, pyramidal frustums, convex cones, serpentine ribs, hemispheres, and combinations thereof. Each of the plurality of coarse surface cooling features 74, plurality of fine surface cooling features 76, first additional plurality of surface cooling features 77, and second additional plurality of surface cooling features 78 may also be recesses of various shapes, including but not limited to concave cones, dimples, concave hemispheres, serpentine ribs, square shaped recesses, circular shaped pin recesses, and combinations thereof. Each of the plurality of coarse surface cooling features 74, plurality of fine surface cooling features 76, first additional plurality of surface cooling features 77, and second additional plurality of surface cooling features 78 may have the same shape, or each may have a different shape. For example, one of the plurality of fine surface cooling features 76 may be a convex hemispherical projection while another of the plurality of fine surface cooling features may be a concave square shaped recess.

[0070] The metallic combustion turbine component body 70 may comprise at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal. Advantages of construction from these materials are explained above. In addition, the metallic body 71 may comprise a plurality of metallic combustion turbine subcomponent bodies bonded together, or a plurality of metallic combustion turbine subcomponent greenbodies bonded together, by methods described in detail above.

[0071] An alternative embodiment of the surface cooling features in accordance with the present invention will now be described with reference to FIG. 7. One of a plurality of coarse surface cooling features 82 comprising a rectangular projection has a dimension greater than 500  $\mu\text{m}$ , and a plurality of fine surface cooling features 86 comprising rectangular projections and having at least one dimension less than 200  $\mu\text{m}$  is illustratively thereon. A first plurality of additional surface cooling features 84 comprising convex hemispheres and having at least one dimension less than 200  $\mu\text{m}$ , such as less than 50  $\mu\text{m}$ , is on the plurality of fine surface cooling features 86.

[0072] Various embodiments of the such surface cooling features in accordance with the present invention will now be described with reference to FIGS. 8-11. Referring first to FIG. 8, an internal surface portion of a cooling passage of an combustion turbine component 88 defines a plurality of coarse surface cooling features 90 comprising rectangular projections having a dimension, in this instance the width, that is greater than 500  $\mu\text{m}$ . A plurality of fine surface cooling features 92 comprising hemispherical projections and having a dimension, in this instance a diameter, that is less than 200  $\mu\text{m}$  is on the plurality of coarse surface cooling features 90.

[0073] Referring now to FIG. 9, an internal surface portion of a cooling passage of a combustion turbine component 94 defines a plurality of coarse surface cooling features 96 comprising rectangular recesses having a dimension greater than 500  $\mu\text{m}$ . A plurality of fine surface cooling features 98 comprising concave hemispherical recesses having a dimension less than 200  $\mu\text{m}$  is defined in the plurality of coarse surface cooling features 96.

[0074] Illustrated in FIG. 10 is an internal surface portion of a cooling passage of an combustion turbine component 100 defining a plurality of coarse surface cooling features 102 comprising rectangular projections having a dimension greater than 500  $\mu\text{m}$ . A plurality of fine surface cooling features 104 comprising concave hemispherical recesses having



a dimension less than 200  $\mu\text{m}$  is defined in the plurality of coarse surface cooling features **102**.

**[0075]** Now referring to FIG. **11**, an internal surface portion of a cooling passage of a combustion turbine component **106** defines a plurality of coarse surface cooling features **108** comprising rectangular recesses having a dimension greater than 500  $\mu\text{m}$ . A plurality of fine surface cooling features **110** comprising convex hemispheres and having a dimension less than 200  $\mu\text{m}$  is on the plurality of coarse surface cooling features **108**.

**[0076]** A method of making a combustion turbine component having a plurality of surface cooling features is now described. The method includes forming a metallic combustion turbine component body by direct metal fabrication (DMF). The metallic combustion turbine component body is formed to have at least one surface portion defining a plurality of coarse surface cooling features each having a first dimension. The metallic combustion turbine component body is also formed to have at least one fine cooling feature on at least one of the first plurality of surface cooling features and having a second dimension less than 200  $\mu\text{m}$ .

**[0077]** The first dimension may be greater than 500  $\mu\text{m}$ . There may be a plurality of fine surface cooling features on one of the plurality of coarse surface cooling features, or there may be a plurality of fine surface cooling features on each of the plurality of coarse surface cooling features.

**[0078]** The at least one fine surface cooling feature may comprise a projection or a convex projection. Alternatively, the at least one fine surface cooling feature may comprise a recess or a concave recess. If there are a plurality of fine surface cooling features, each of the plurality of fine surface cooling features may comprise the same shape, or may comprise different shapes (e.g. one of the plurality of fine surface cooling features may comprise a convex projection while another of the plurality of fine surface cooling features may comprise a concave recess).

**[0079]** One of the plurality of coarse surface cooling features may comprise a projection or a convex projection. In addition, one of the plurality of coarse surface cooling features may comprise a recess or a concave recess. Each of the plurality of coarse cooling features may be the same shape or each may be a different shape.

**[0080]** Additional details of the plurality of coarse surface cooling features and the at least one fine surface cooling feature may be found above. The DMF may comprise tomo lithographic molding or metal injection molding, details of which may also be found above.

**[0081]** The metallic body may comprise at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal. Advantageous properties of these materials are discussed above. The metallic body may additionally or alternatively comprise a nickel based superalloy and, optionally, at least one rare earth element.

**[0082]** With reference to the flowchart **120** of FIG. **12**, a more detailed method of forming a combustion turbine component having surface cooling features is now described. After the start (Block **122**), at Block **124** a plurality of metallic combustion turbine subcomponent greenbodies are formed by direct metal fabrication (DMF). At least one of the plurality of metallic combustion turbine subcomponent greenbodies is formed to have at least one surface portion defining a plurality of coarse surface cooling features each having a first dimension. In addition, the at least one of the plurality of metallic combustion turbine subcomponent greenbodies is

formed to have at least one fine surface cooling feature on at least one of the plurality of coarse surface cooling features and having a dimension less than the first dimension and less than 200  $\mu\text{m}$ .

**[0083]** The plurality of metallic combustion turbine subcomponent greenbodies may comprise an activatable binder. The activatable binder may be activated prior to sintering.

**[0084]** At Block **126**, the plurality of metallic combustion turbine subcomponent greenbodies are assembled together to form a metallic greenbody assembly. At Block **128**, the metallic greenbody assembly is sintered to thereby form the metallic body. Block **130** indicates the end of the method. Further details of assembling and sintering may be found above.

**[0085]** Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A method of making a combustion turbine component comprising:
  - forming a metallic body by direct metal fabrication (DMF) to have
    - at least one surface portion defining a plurality of coarse surface cooling features each having a first dimension, and
    - at least one fine surface cooling feature on at least one of the plurality of coarse surface cooling features and having a second dimension less than said first dimension and less than 200  $\mu\text{m}$ .
2. The method of claim 1 wherein the at least one fine surface cooling feature comprises a projection.
3. The method of claim 1 wherein the at least one fine surface cooling feature comprises a convex projection.
4. The method of claim 1 wherein the at least one fine surface cooling feature comprises a recess.
5. The method of claim 1 wherein the at least one fine surface cooling feature comprises a concave recess.
6. The method of claim 1 wherein the DMF comprises tomo lithographic molding.
7. The method of claim 1 wherein the DMF comprises metal injection molding.
8. The method of claim 1 wherein forming the metallic body by DMF comprises:
  - forming a plurality of metallic combustion turbine subcomponent greenbodies by DMF, each of the plurality of metallic combustion turbine subcomponent greenbodies comprising an activatable binder;
  - assembling the plurality of metallic combustion turbine subcomponent greenbodies together to form a metallic greenbody assembly;
  - activating the activatable binder; and
  - sintering the metallic greenbody assembly to thereby form the metallic body.
9. The method of claim 1 wherein the first dimension is greater than 500  $\mu\text{m}$ .
10. The method of claim 1 wherein at least one of the plurality of coarse surface cooling features comprises a projection.



**11.** The method of claim **1** wherein at least one of the plurality of coarse surface cooling features comprises a recess.

**12.** The method of claim **1** wherein the metallic combustion turbine component body comprises at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal.

**13.** A method of making a combustion turbine component comprising:

forming a plurality of metallic combustion turbine subcomponent greenbodies by DMF, at least one of the plurality of metallic combustion turbine subcomponent greenbodies being formed to have  
at least one surface portion defining a plurality of coarse surface cooling features each having a first dimension greater than 500  $\mu\text{m}$ , and  
at least one fine surface cooling feature on at least one of the plurality of coarse surface cooling features and having a second dimension less than 200  $\mu\text{m}$ ;

assembling the plurality of metallic combustion turbine subcomponent greenbodies together to form a metallic greenbody assembly; and

sintering the metallic greenbody assembly to thereby form the combustion turbine component.

**14.** The method of claim **13** wherein the plurality of metallic combustion turbine subcomponent greenbodies comprises an activatable binder; and further comprising activating the activatable binder prior to sintering.

**15.** The method of claim **13** wherein the at least one fine surface cooling feature comprises a projection.

**16.** The method of claim **13** wherein the at least one fine surface cooling feature comprises a convex projection.

**17.** The method of claim **13** wherein the at least one fine surface cooling feature comprises a recess.

**18.** The method of claim **13** wherein the at least one fine surface cooling feature comprises a concave recess.

**19.** The method of claim **13** wherein the DMF comprises tomo lithographic molding.

**20.** The method of claim **13** wherein the DMF comprises metal injection molding.

**21.** The method of claim **13** wherein at least one of the plurality of coarse surface cooling features comprises a projection.

**22.** The method of claim **13** wherein at least one of the plurality of coarse surface cooling features comprises a recess.

**23.** The method of claim **13** wherein at least one of the plurality of metallic combustion turbine subcomponent greenbodies comprises at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal.

**24.** A combustion turbine component comprising:

a metallic body to define at least a substrate for the combustion turbine component, said metallic body having  
at least one surface portion defining a plurality of coarse cooling features each having a first dimension, and  
at least one fine cooling feature on at least one of said plurality of coarse cooling features each having a second dimension less than the first dimension and less than 200  $\mu\text{m}$ .

**25.** The combustion turbine component of claim **24** wherein the first dimension is greater than 500  $\mu\text{m}$ .

**26.** The combustion turbine component of claim **24** wherein the at least one fine surface cooling feature comprises a projection.

**27.** The combustion turbine component of claim **24** wherein the at least one fine surface cooling feature comprises a convex projection.

**28.** The combustion turbine component of claim **24** wherein the at least one fine surface cooling feature comprises a recess.

**29.** The combustion turbine component of claim **24** wherein the at least one fine surface cooling feature comprises a concave recess.

**30.** The combustion turbine component of claim **24** wherein at least one of the plurality of coarse surface cooling features comprises a projection.

**31.** The combustion turbine component of claim **24** wherein at least one of the plurality of coarse surface cooling features comprises a recess.

**32.** The combustion turbine component of claim **24** wherein the metallic combustion turbine component body comprises at least one of an oxide dispersion strengthened (ODS) alloy, an intermetallic compound, and a refractory metal.

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