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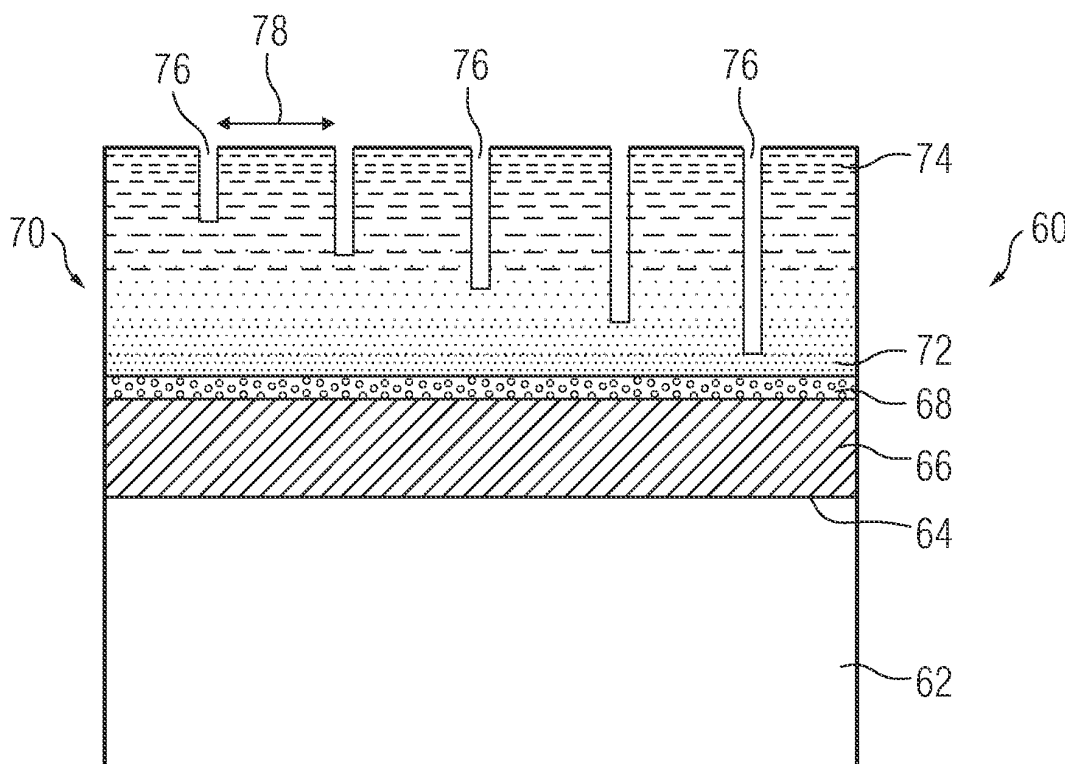
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(54) **A method for forming thermal barrier coating and device with the thermal barrier coating**

(57) A method for forming a thermal barrier coating (60) for a device having a substrate (62) is provided. The method includes depositing a bond coat layer (66) onto

the substrate (62), depositing an insulating layer (70) onto the bond coat layer (66), characterized in that the insulating layer (70) is deposited by selective laser melting.

FIG 3



Description

[0001] The present invention relates to a thermal barrier coating for a device, such as, a component of a gas turbine.

[0002] Thermal Barrier Coatings (TBC) have been readily employed on first and second rows of turbine blades and vanes as well as on combustor chamber components exposed to the hot gas path of industrial gas turbines (IGT). Typically, yttria stabilized zirconia TBCs are extensively applied to the hot sections and provide protection against thermo-mechanical shock, high temperature oxidation and hot corrosion degradation. While the primary driver to implement TBCs has been initially the life time extension of the coated components, advanced IGTs utilize TBCs more and more to allow for increases in efficiency and power output of a gas turbine. One measure to improve efficiency and power output is to reduce the cooling air consumption of the components in the hot gas path, i.e. by allowing those components to be operated at higher temperatures. The push to higher firing temperatures and reduced cooling flows generates an on-going demand for advanced TBCs with higher temperature stability and better thermal insulation to achieve long term efficiency and performance goals of advanced industrial gas turbines.

[0003] The TBC comprises a two-layer system: an outer insulating ceramic layer and an underlying oxidation-resistant metallic layer or a bond coat deposited directly onto the surface of the metallic component. The bond coat provides the physical and chemical bond between the ceramic coating and a substrate of the device and serves as an oxidation and corrosion resistance by forming a slow growing adherent protective Alumina scale. The top ceramic layer provides benefits in performance, efficiency and durability through a) increased engine operating temperature; b) extended metallic component lifetime when subjected to elevated temperature and stress; and c) reduced cooling requirements for the metallic components. Depending on the ceramic layer thickness and through thickness heat flux, substrate temperatures can be reduced by several hundred degrees. The development and acceptance of TBCs are closely linked to processing technology: in this connection, ceramic top-coats are presently deposited using air plasma spray (APS) or electron beam-physical vapour deposition (EB-PVD) processes. Although both coatings have the same chemical composition, their microstructures are fundamentally different from each other and so are their thermal insulation properties and performance.

[0004] Currently, double or multi layered TBC coatings are used with a bond coat compatible TBC sub-layer, which is generally a yttria stabilized zirconia (YSZ). YSZ provides chemical and mechanical compatibility with the bond coat and with one or more high temperature stable TBC top layers improving temperature stability.

[0005] However, currently used TBC deposition techniques such as APS and EB-PVD reduce the choice of

chemical composition for the layers of the TBC and microstructures causing a limitation for an achievable temperature capability.

[0006] It is therefore an object of the present invention to provide a thermal barrier coating which offers a flexibility regarding the choice of chemical composition of materials to form the layers of the thermal barrier coating.

[0007] The object is achieved by providing a method for forming a thermal barrier coating for a device according to claim 1 and providing a device with the thermal barrier coating according to claim 9.

[0008] By using selective laser melting technique to deposit an insulating layer of the thermal barrier coating, a flexibility of depositing a wide variety of materials with different chemical composition as the insulating layer of the thermal barrier coating is achieved.

[0009] The device includes a component of a gas turbine. Components of gas turbine such as a blade, a vane or combustor chamber components are exposed to hot gas path. To protect such components from thermal stress, a thermal barrier coating is applied to the components of the gas turbine.

[0010] In one embodiment, engravings are formed by selectively depositing the insulating layer onto the bond coat layer. The engravings reduce intrinsic thermal stress on the thermal barrier coating.

[0011] In one embodiment, the engravings are linear to allow reduction in thermal stress and have a minimal impact on aerodynamic efficiency.

[0012] The engravings are oriented along the insulating layer such that in a working position of the component the engravings are aligned with streamlines of a working gas flow over the thermal barrier coating. This arrangement reduces the gas impact on portion of the insulating layer adjacent to the engravings and also helps in keeping the engravings free of debris that may accumulate in a cross-flow environment.

[0013] The depth of the engravings orthogonal to a surface of the insulating layer is substantially equal to the depth of the insulating layer thereby preventing exposure of bond coat layer to the environment. Further, a partial depth of the engravings which is less than the depth of the insulating layer not only relieves stress in the coating, but also serves as crack terminator for a crack developing between the bond coat layer and the insulating layer of thermal barrier coating.

[0014] The insulating layer has a decreasing proportion of a first ceramic material to a second ceramic material along a thickness of the insulating layer. By such an arrangement a gradient interface design is achieved in the insulating layer, which advantageously reduces a tendency of vertical-to-horizontal crack deflection and increases fracture resistance with respect to delamination cracks.

[0015] The insulating layer includes a plurality of layers having different composition of the first ceramic material and the second ceramic material. The plurality of layers prevent development of crack in the insulating layer, fur-

ther, each layer has a variation in adherence to the bond coat as well as capability to withstand high temperatures depending on the composition of the layer. In addition, the plurality of layers with different composition of the first ceramic material and the second ceramic material ensures achieving a gradient interface design in the insulating layer.

[0016] In one embodiment, the engravings are present to a depth substantially equal to a depth of the insulating layer of the thermal barrier coating. The engravings allow the insulating layer to withstand a large temperature gradient across its thickness without failure, since the expansion or contraction of the material can be at least partially relieved by changes in the size of the engravings.

[0017] According to one embodiment, the first ceramic material comprises yttria stabilized zirconia which provides adherence to bond coat.

[0018] According to another embodiment, the second ceramic material comprises pyrochlores, perovskites, tungsten bronze or magnetoplumbite structures. These materials have low thermal conductivity and provide excellent thermal insulation.

[0019] The above-mentioned and other features of the invention will now be addressed with reference to the accompanying drawings of the present invention. The illustrated embodiments are intended to illustrate, but not limit the invention. The drawings contain the following figures, in which like numbers refer to like parts, throughout the description and drawings.

FIG. 1 is a schematic diagram of a gas turbine;

FIG. 2 is a partial cross-sectional view of a turbine component coated with an exemplary multi-layer thermal barrier coating; and

FIG. 3 is a schematic diagram of a partial cross-sectional view of the turbine component depicting thermal barrier coating with engravings.

[0020] Embodiments of the present invention relate to thermal barrier coating for a device and more particularly to a method for forming the thermal barrier coating to be coated on a device, such as, but not limited to a component of a gas turbine. As previously noted, thermal barrier coatings are employed to protect components of the gas turbine, such as a blade, a vane or combustor components that are exposed to a hot gas path. Although, the present invention is described with reference to a gas turbine, the invention may also be used for turbomachines such as a turbofan and the like. It may be noted that the exemplary method of forming the thermal barrier coating, as well as the thermal barrier coating can be applied to any device or article that is subjected to a high temperature environment due to exposure to hot gases.

[0021] FIG. 1 is a schematic diagram of a gas turbine 10 depicting internal components. The gas turbine 10 includes a rotor 13 which is mounted such that it can

rotate along an axis of rotation 12, has a shaft 11 and is also referred to as a turbine rotor.

[0022] The gas turbine 10 includes an intake housing 14, a compressor 15, an annular combustion chamber 20 with a plurality of coaxially arranged burners 17; a turbine 18 and exhaust-gas housing 19 follow one another along the rotor 13.

[0023] The annular combustion chamber 20 is in communication with an annular hot-gas passage 21, where, by way of example, four successive turbine stages 22 form the turbine 18.

[0024] It may be noted that each turbine stage 22 is formed, for example, from two blade or vane rings. As seen in the direction of flow of a working medium 23, in the hot gas passage 21 a row of guide vanes 25 is followed by a row 35 formed from rotor blades 30. The guide vanes 40 are secured to an inner housing 48 of a stator 53, whereas the rotor blades 30 of the row 35 are fitted to the rotor 13 for example by means of a turbine disk 43.

[0025] A generator not shown in FIG. 1 is coupled to the rotor 13. During the operation of the gas turbine 10, the compressor 15 sucks in air 45 through the intake housing 14 and compresses it. The compressed air provided at the turbine-side end of the compressor 15 is passed to the burners 17, where it is mixed with a fuel. The mix is then burnt in the combustion chamber 20, forming the working medium 23. From there, the working medium 23 flows along the hot-gas passage 21 past the guide vanes 40 and the rotor blades 30. The working medium 23 is expanded at the rotor blades 30, transferring its momentum, so that the rotor blades 30 drive the rotor 13 and the latter in turn drives the generator coupled to it.

[0026] In addition, while the gas turbine 10 is in operation, the components which are exposed to the hot working medium 23 are subjected to thermal stresses. The guide vanes 40 and the rotor blades 30 of the first turbine stage 22, as seen in the direction of flow of the working medium 23, together with the heat shield bricks which line the annular combustion chamber 20, are subject to the highest thermal stresses. These components are typically cooled by a coolant, such as oil.

[0027] As will be appreciated, the components of the gas turbine 10 are made from a material such as superalloys which are iron-based, nickel-based or cobalt-based. More particularly, the turbine vane or blade 40, 30 and components of the combustion chamber 20 are made from the superalloys mentioned hereinabove.

[0028] The components such as the blade or the vane and the combustion chamber of the gas turbine are exposed to thermal, mechanical and chemical stresses during the operation of the gas turbine. To protect the components a coating is generally applied on the various components to protect against corrosion or oxidation. The coating will be described in greater detail with reference to FIG. 2.

[0029] FIG. 2 shows a partial cross sectional view of a component of the gas turbine 10 of FIG. 1, coated with

an exemplary thermal barrier coating 60, in accordance with aspects of the present technique.

[0030] The components of the gas turbine include a substrate 62 having a surface 64 which is exposed to a high temperature environment. The thermal barrier coating 60 is deposited over the surface 64 of the substrate 62. The substrate 62 is a metallic substrate made up of the superalloy as mentioned with reference to FIG. 1.

[0031] More particularly, a bond coat layer 66 is applied onto the substrate 62. In accordance with aspects of the present technique, a metallic bond coat layer 66 such as for example, formed from MCrAlX alloy is applied onto the substrate 62, wherein M is at least one element selected from the group consisting of iron (Fe), cobalt (Co), nickel (Ni), X is an active element and may include yttrium (Y) and/or silicon (Si) and/or at least one of the rare earth elements or hafnium (Hf).

[0032] In accordance with aspects of the present technique, the bond coat layer 66 may be applied using a thermal spray process, such as a high velocity oxy-fuel (HVOF) process, low pressure plasma spray process, atmospheric plasma spray process, air plasma spray process and the like.

[0033] An insulating layer 70 is applied onto the bond coat layer 66. More particularly, the bond coat layer 66 is present between the surface 64 of the substrate 62 and the insulating layer 70.

[0034] The insulating layer 70 may include a first ceramic material and a second ceramic material, wherein the second ceramic material has a higher temperature capability than the first ceramic material.

[0035] In accordance with aspects of the present technique, the insulating layer 70 is deposited using selective laser melting (SLM) process. Selective laser melting is a method of producing metal and ceramic parts. Unlike normal methods of part manufacture, casting, machining and the like, SLM grows components using a layered manufacturing. Layered manufacturing takes a computer-generated design and builds it in a series of layers from the parts bottom to the top. SLM does this by selectively melting layers of metal powder to the shape of the cross section of the part being manufactured using high-powered lasers.

[0036] SLM is used to deposit a plurality of layers in the insulating layer 70. The plurality of layers have different composition of the first ceramic material and the second ceramic material.

[0037] In one embodiment, the insulating layer 70 is deposited using the SLM process such that the insulating layer 70 has a decreasing proportion of the first ceramic material to the second ceramic material along a thickness of the insulating layer 70 from the bond coat layer 66.

[0038] In one embodiment, a powder having variable composition of the first ceramic material and the second ceramic material is deposited over the bond coat layer 66 using SLM to obtain a first layer, again, the powder with a different composition of the first ceramic material and the second ceramic material is deposited to form a

second layer. Similarly, other layers having different compositions of the first ceramic material and the second ceramic material may be deposited using selective laser melting to obtain a gradient interface design for the insulating layer 70.

[0039] As an example, powder having a 100% amount of the first ceramic material is deposited over the surface of the substrate using SLM to obtain a first layer; powder having 67% of the first ceramic material and 33% of the second ceramic material is deposited to obtain a second layer; with 33% of the first ceramic material and 67% of the second ceramic material to obtain a third layer and the fourth layer is obtained by using SLM on powder having 100% of the second ceramic material.

[0040] It may be noted that to achieve the gradient interface, the plurality of layers may include three layers having different composition of the first ceramic material and the second ceramic material.

[0041] The number of layers is increased if the surface temperature to which the component is subjected is increased; however, increasing the number of layers increases material cost as well as processing cost. Therefore, the number of layers is chosen so that it provides an optimum solution between temperature capability and material cost incurred.

[0042] In one embodiment, powder form of first ceramic material and the second ceramic material may be kept in separate powder feeders and co-deposited over the bond coat layer using SLM. The composition of the first ceramic material and the second ceramic material may be changed in-situ to obtain the gradient interface. The insulating layer 70 is formed by spraying the powder of both the first and the second ceramic material simultaneously according to the desired composition and then applying SLM to melt the powder with the desired composition to obtain a layer. This technique will help in achieving a gradient transition between the plurality of layers of the thermal barrier coating 60.

[0043] In accordance with aspects of the present technique, the first ceramic material is generally formed from partially stabilized zirconia, such as, but not limited to yttria stabilized zirconia.

[0044] The second ceramic material may include pyrochlores, perovskites, tungsten bronze or magnetoplumbite structures, such as gadolinium hafnate ($\text{Gd}_2\text{Hf}_2\text{O}_7$), gadolinium zirconate ($\text{Gd}_2\text{Zr}_2\text{O}_7$), barium neodymium titanate and so forth which typically have a porous structure.

[0045] In one embodiment, the second ceramic material has a higher temperature capability than the first ceramic material.

[0046] In another embodiment, the second ceramic material may have a lower thermal conductivity than the first ceramic material for a given density.

[0047] The thermal barrier coating includes a thermally grown oxide layer 68 also referred to as an alumina scale, which is formed naturally on the bond coat layer. The thermally grown oxide layer 68 protects aluminium in the

bond coat layer 66 from further oxidation thereby extending the life of the thermal barrier coating 60.

[0048] As previously noted, the insulating layer 70 of the thermal barrier coating may include a plurality of layers, such as a top layer 74 and a bottom layer 72. As depicted in FIG. 2, the top layer 74 is distal to the bond coat layer 66 and the bottom layer 72 is proximal to the bond coat layer 66.

[0049] In one embodiment, the bottom layer 72 which is formed from the first ceramic material such as yttria stabilized zirconia may be deposited using the air plasma spray process or a thermal spray process. The top layer 74 is deposited using selective laser melting. This enables the top layer 74 to be formed from materials having different chemical compositions.

[0050] FIG. 3 shows a partial cross-sectional view of the turbine component depicting thermal barrier coating 60 with engravings 76. The engravings 76 are formed on the insulating layer 70 by selectively applying the SLM on the insulating layer 70. More particularly, engravings 76 are formed when a beam of laser is switched off, this does not melt the powder which includes the first ceramic material and the second ceramic material, and hence an engraving 76 is formed in a region which is not melted by the laser. This selective melting of powder is used to form engravings 76 in the insulated layer 70.

[0051] The engravings may be linear. More particularly, the engravings 76 may be in the form of grooves having a depth substantially equal to a depth of the insulating layer 70. The engravings 76 may have several structures such as, but not limited to a V-shaped structure or a U-shaped structure.

[0052] The engravings 76 are formed in a pattern such that the engravings 76 are oriented along the insulating layer 70 such that in a working position of the component the engravings 76 are aligned with streamlines of a working gas flow over the thermal barrier coating. As an example, since the working gas or fluid flows parallel to a longitudinal axis of the engravings 76, the fluid dynamic impact on a portion adjacent to the engravings 76 is reduced. Furthermore, the arrangement of engravings 76 prevents accumulation of debris that might otherwise possibly accumulate in a cross-flow environment.

[0053] In addition, continuous engravings may also be formed on the blade 30 or the vane 40 of the gas turbine 10 of FIG. 1, in a direction corresponding to the direction of the fluid stream over the blade 30 or the vane 40, i.e. from the leading edge toward the trailing edge. In one embodiment, such engravings 76 are formed proximate the leading edge only, i.e. along the highest temperature regions of the blade 30 or the vane 40. Engravings 76 may also be formed on the thermal barrier coating 60 of the blade or the vane in a direction parallel to the air flow from the leading edge to the trailing edge of the blade 30 or the vane 40. These embodiments are provided by way of illustration and are not meant to limit the present invention, which may include engravings 76 with or without ridges (not shown), and engravings parallel to, perpen-

dicular to and/or otherwise oblique to a direction of a fluid stream.

[0054] With continuing reference to FIG. 3, engravings 76 may have different depths, for example, extending to the depth of the top layer 74, to about 50% of the thickness of the insulating layer 70. It may be noted that the depth of the engravings 76 is less than 100% the depth of the insulating layer 70; this prevents penetrating the underlying bond coat layer 66 and also prevents exposure of the substrate 62 to the high temperature environment.

[0055] In one embodiment, the depth of the engravings 76 may be from about 50% to about 67% of the depth of the insulating layer 70, these partial depths not only relieve stress in the coating 60, but they also serve as crack terminators for a crack developing between the bond coat layer 66 and the insulating layer 70 of the thermal barrier coating 60.

[0056] As previously noted, engravings 76 are formed with spacing 78 there between. The spacing 78 between adjacent engravings may be from about 500 to about 1000 microns.

[0057] Selective laser melting allows the thermal barrier coating 60 to achieve variety of geometrical shapes such as engravings 76 described hereinabove, that help in reducing stress and increasing the durability of the coating thus protecting the components of the gas turbine from thermal and chemical stresses.

Claims

1. A method for forming a thermal barrier coating (60) for a device having a substrate, the method comprising:

- depositing a bond coat layer (66) onto the substrate (62),
- depositing an insulating layer (70) onto the bond coat layer (66),

characterized in that the insulating layer (70) is deposited by selective laser melting.

2. The method according to claim 1, **characterized in that** the device is a component (20, 30, 40) of a turbomachine.

3. The method according to claim 1 or 2, **characterized in that** the insulating layer (70) is deposited selectively onto the bond coat layer (66) such that engravings (76) are formed in the insulating layer (70).

4. The method according to claim 3, **characterised in that** the engravings (76) are linear.

5. The method according to claims 3 and 4,

characterized in that the engravings (76) are oriented along the insulating layer (70) such that in a working position of the device the engravings (76) are aligned with streamlines of a working gas flow over the thermal barrier coating (60).

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6. The method according to any of the claims 3 to 5, **characterized in that** the engravings (76) have a depth orthogonal to a surface of the insulating layer (70) substantially equal to a depth of the insulating layer (70) of the thermal barrier coating (60). 10
7. The method according to any of the claims 1 to 5, **characterized in that** the insulating layer (70) has a decreasing proportion of a first ceramic material to a second ceramic material along a thickness of the insulating layer (70). 15
8. The method according to claim 7, **characterized in that** the insulating layer (70) comprises a plurality of layers having different composition of the first ceramic material and the second ceramic material. 20
9. A device with a thermal barrier coating (60), comprising: 25
 - a substrate (62);
 - a bond coat layer (66) deposited onto the substrate (62); 30
 - an insulating layer (70) deposited onto the bond coat layer (66),

characterized in that the insulating layer (70) is deposited using the method of selective laser melting. 35
10. The device according to claim 9, **characterized in that** the insulating layer (70) of the thermal barrier coating (60) comprises engravings (76) for reducing thermal intrinsic stress. 40
11. The device according to claim 9 or 10, **characterized in that** the insulating layer (70) comprises a plurality of layers having different composition of a first ceramic material and a second ceramic material. 45
12. The device according to claim 11, **characterized in that** the first ceramic material comprises yttria stabilized zirconia. 50
13. The device according to claim 11 or 12, **characterized in that** the second ceramic material comprises a crystal lattice structure of a monazite, pyrochlore, perovskite, tungsten bronze or magnetoplumbite structure. 55
14. The device according to any of the claims 11 to 13,

characterized in that the plurality of layers comprises a top layer (74) distal to the bond coat layer (66), formed from the second ceramic material and a bottom layer (72) proximal to the bond coat layer (66), formed from the first ceramic material.

15. The device according to any of the claims 9 to 14, **characterized in that** the thermal barrier coating is formed according to a method according to any of the claims 1 to 8.

FIG 1

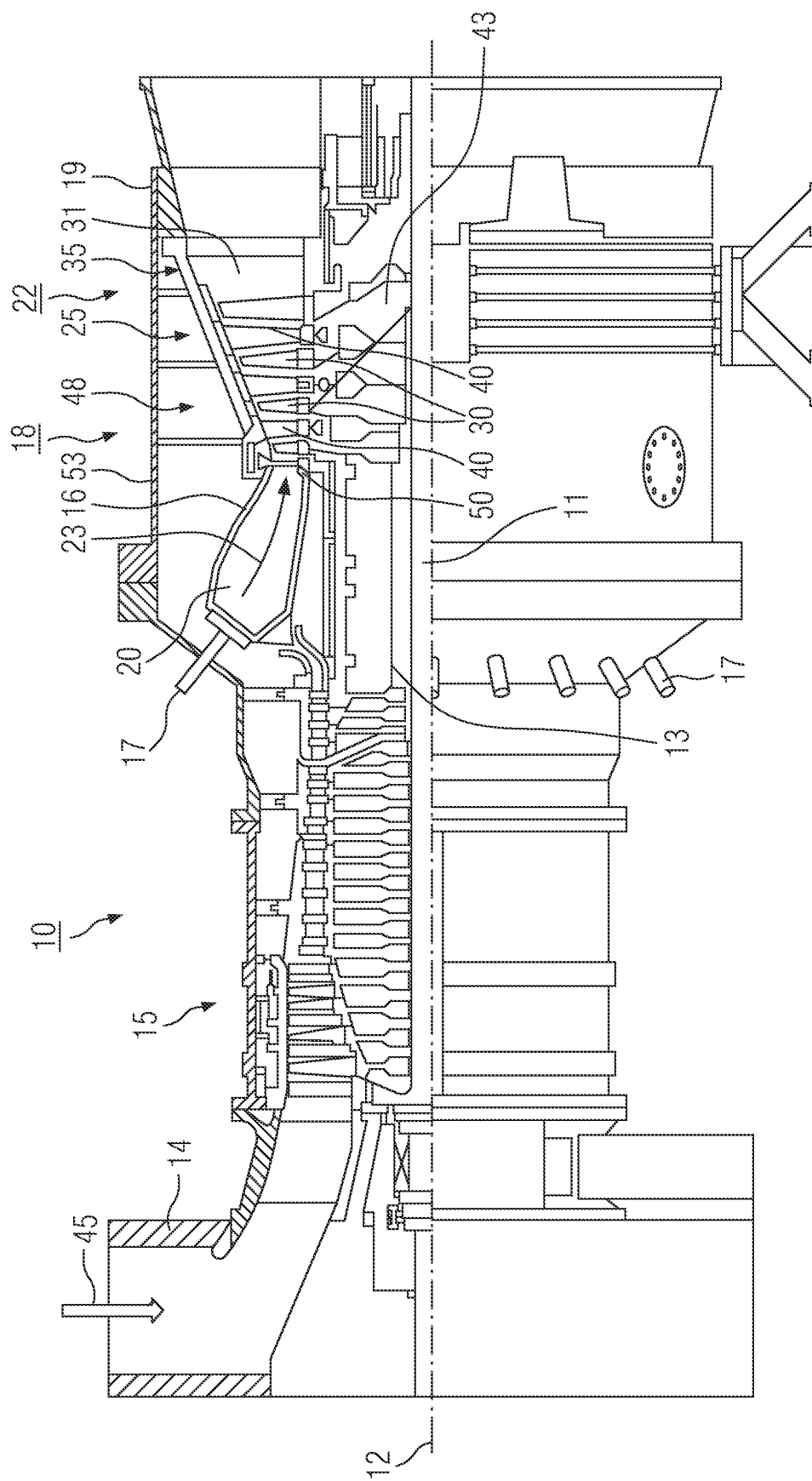


FIG 2

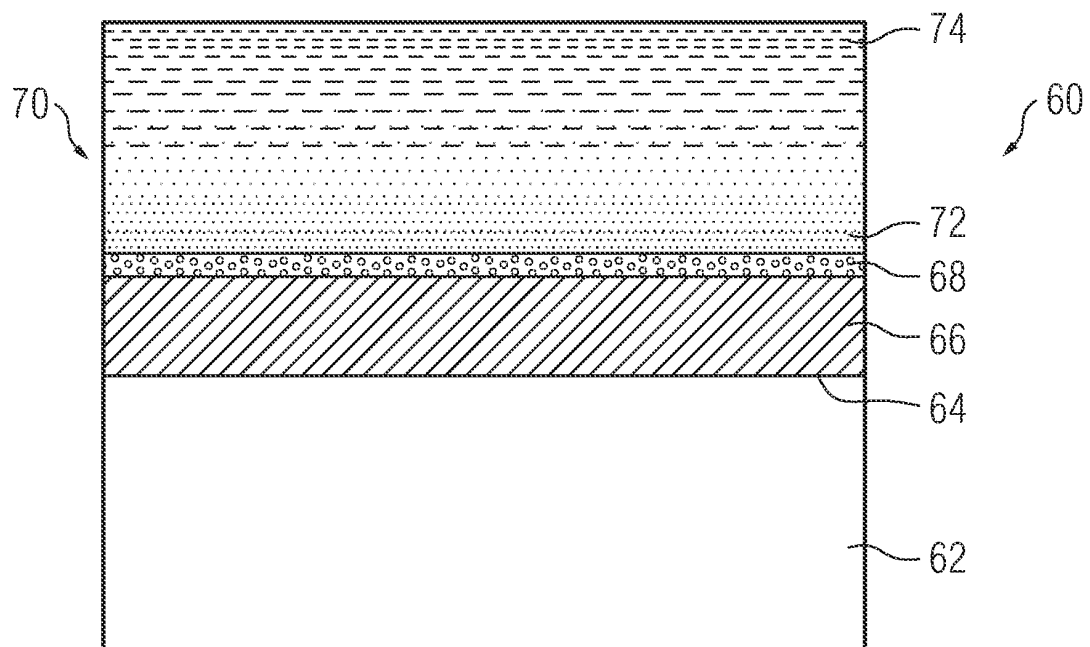
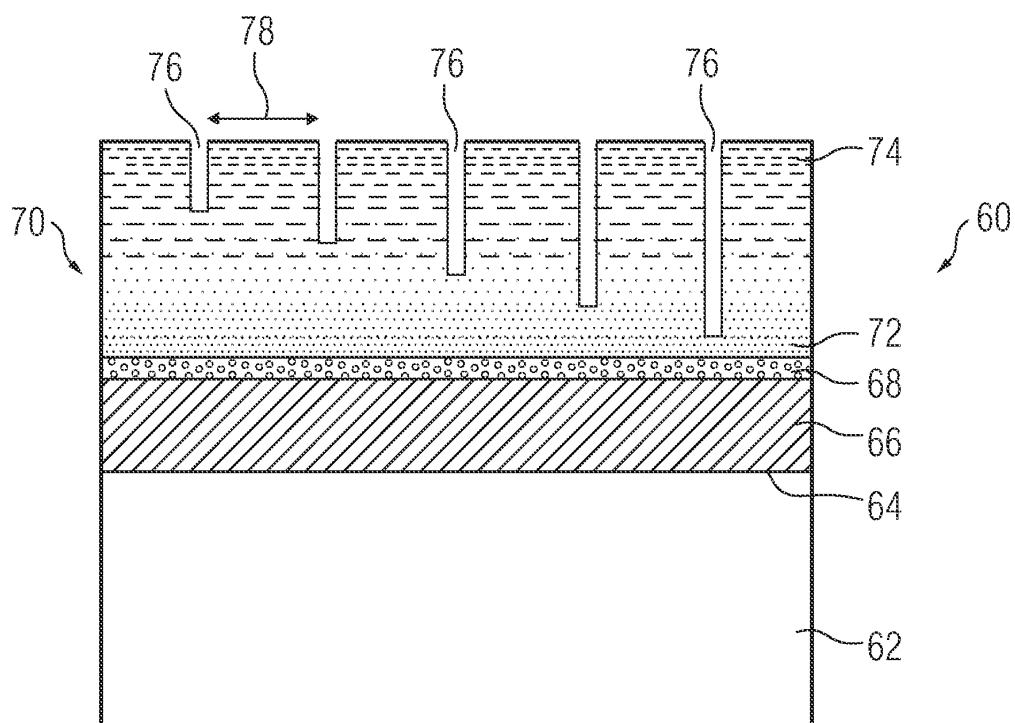


FIG 3





EUROPEAN SEARCH REPORT

Application Number
EP 10 17 7333

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 22 December 2010	Examiner Ovejero, Elena
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EUROPEAN SEARCH REPORT

Application Number
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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 10 17 7333

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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