US 20110097188A1

(19) United States
(12) Patent Application Publication
Bunker
(10) Pub. No.: US 2011/0097188 A1
(43) Pub. Date: Apr. 28, 2011

(54) STRUCTURE AND METHOD FOR IMPROVING FILM COOLING USING SHALLOW TRENCH WITH HOLES ORIENTED ALONG LENGTH OF TRENCH

(75) Inventor: **Ronald Scott Bunker**, Niskayuna, NY (US)

(73) Assignee: **GENERAL ELECTRIC COMPANY**, SCHENECTADY, NY (US)

(21) Appl. No.: **12/604,460**

(22) Filed: **Oct. 23, 2009**

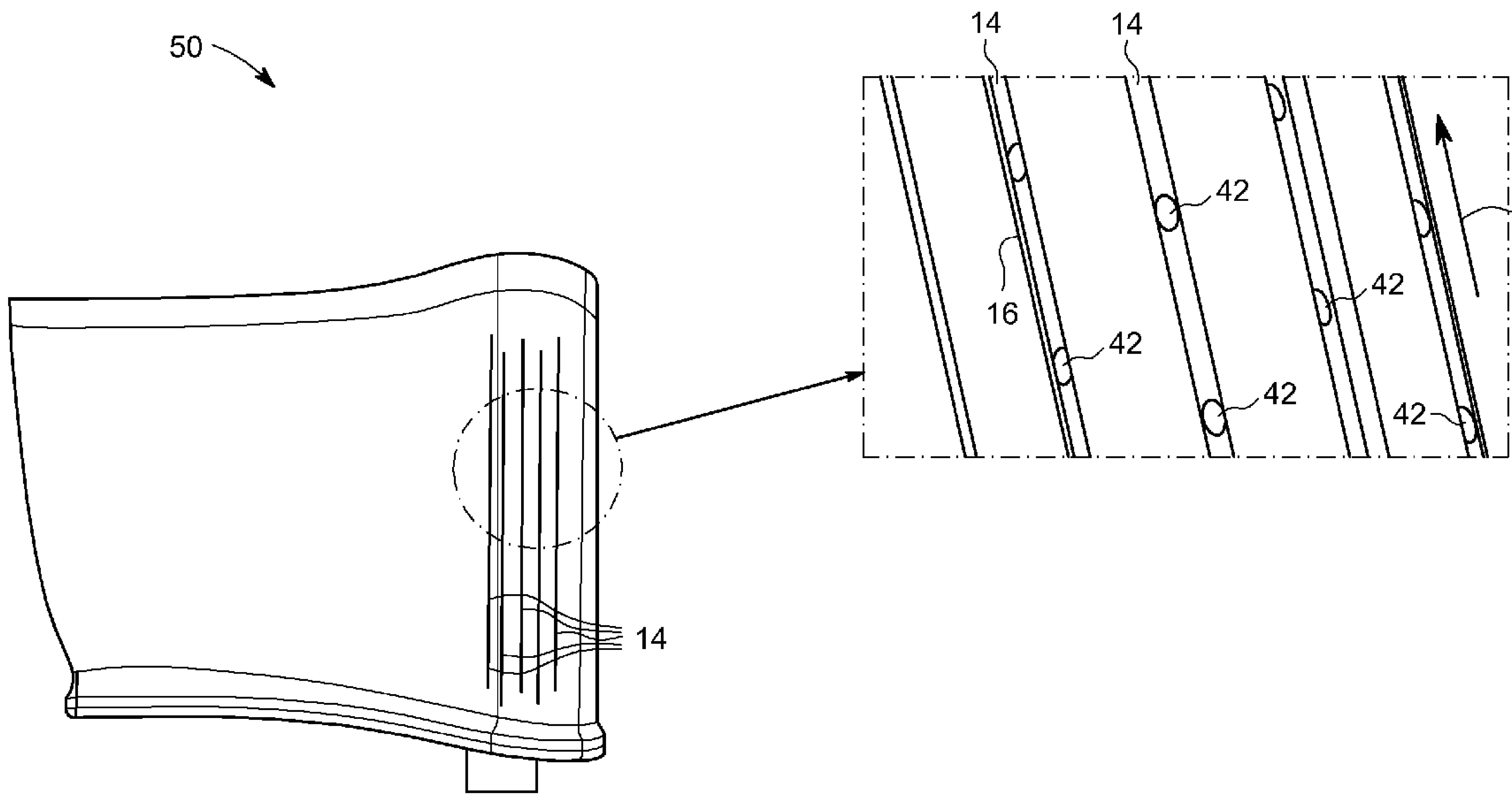
**Publication Classification**

(51) **Int. Cl.**
***F01D 25/12*** (2006.01)
***F01D 5/18*** (2006.01)

(52) **U.S. Cl.** ................. **415/1**; 416/97 R; 415/115; 416/1

(57) **ABSTRACT**

A turbine airfoil includes a plurality of shallow trenches. Each trench includes a plurality of film holes disposed within and located along the lengthwise direction of the trench and angled through an airfoil substrate in the lengthwise direction of the trench.



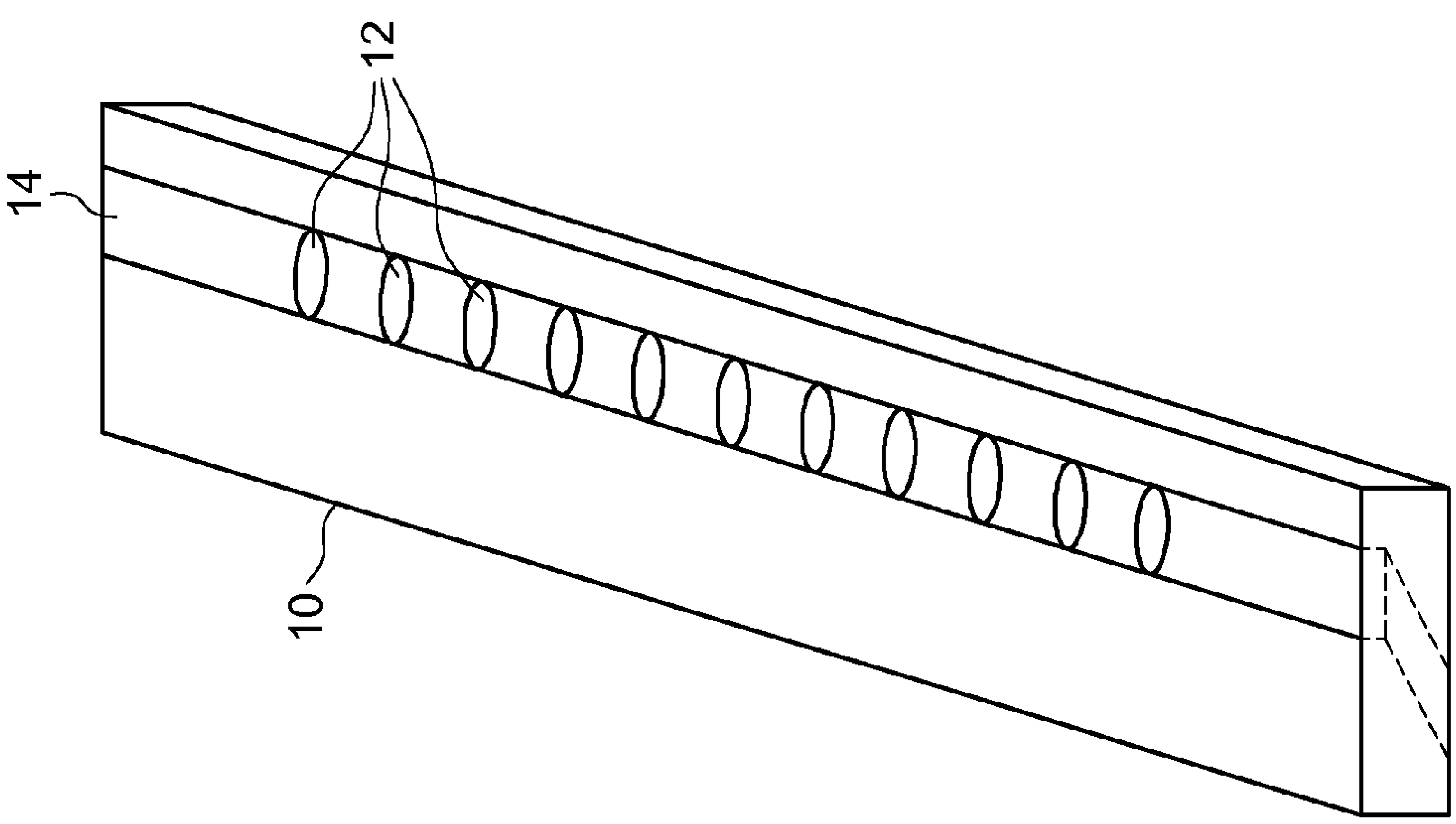



FIG. 1

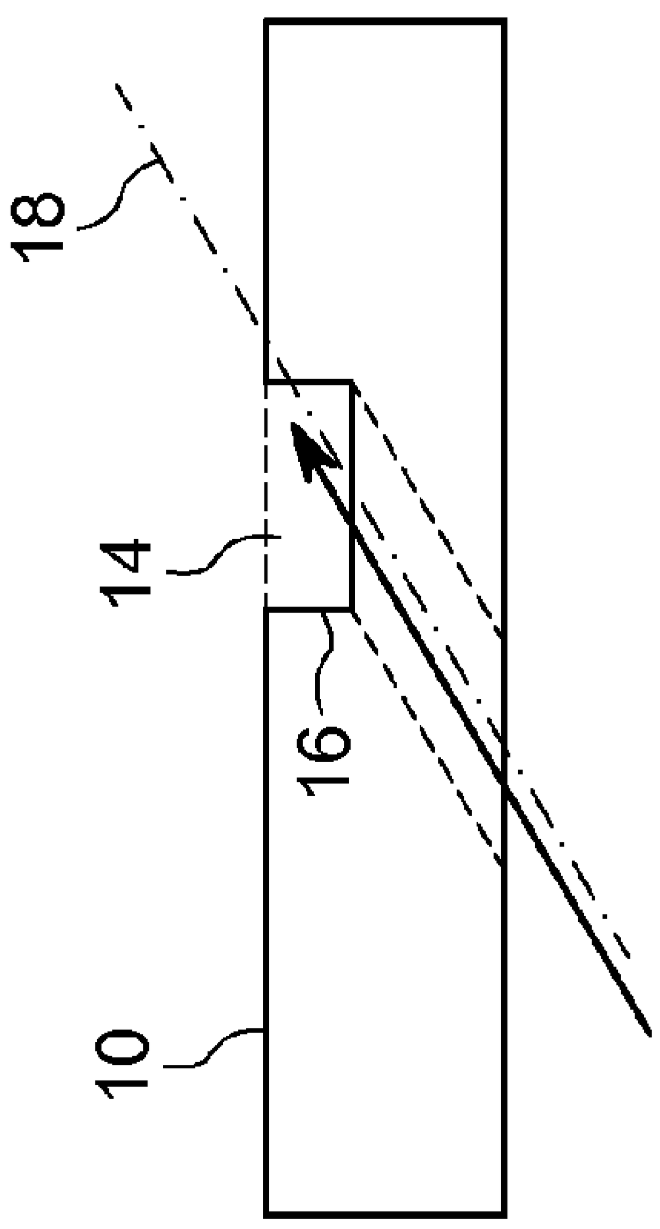



FIG. 2

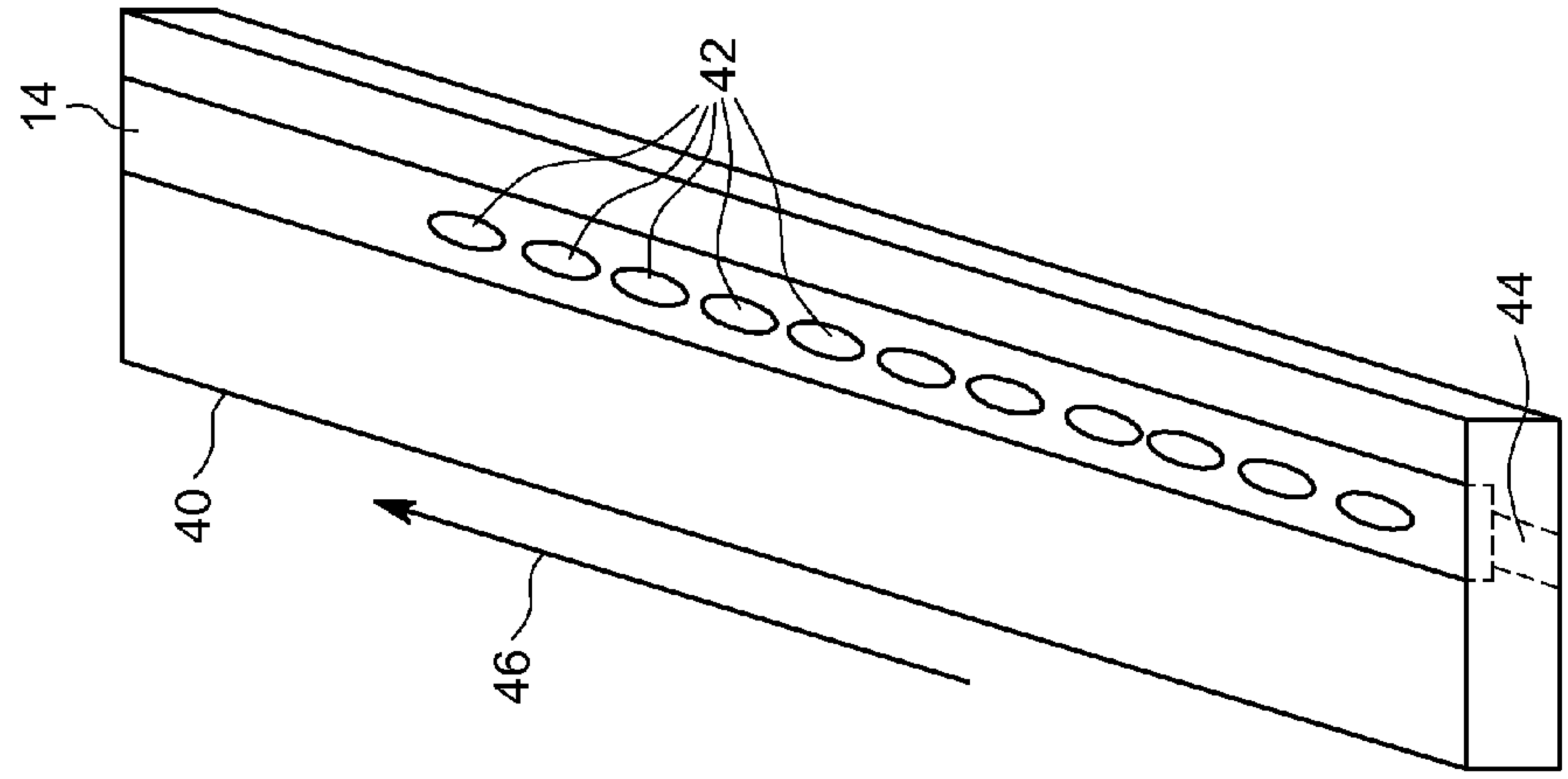



FIG. 4

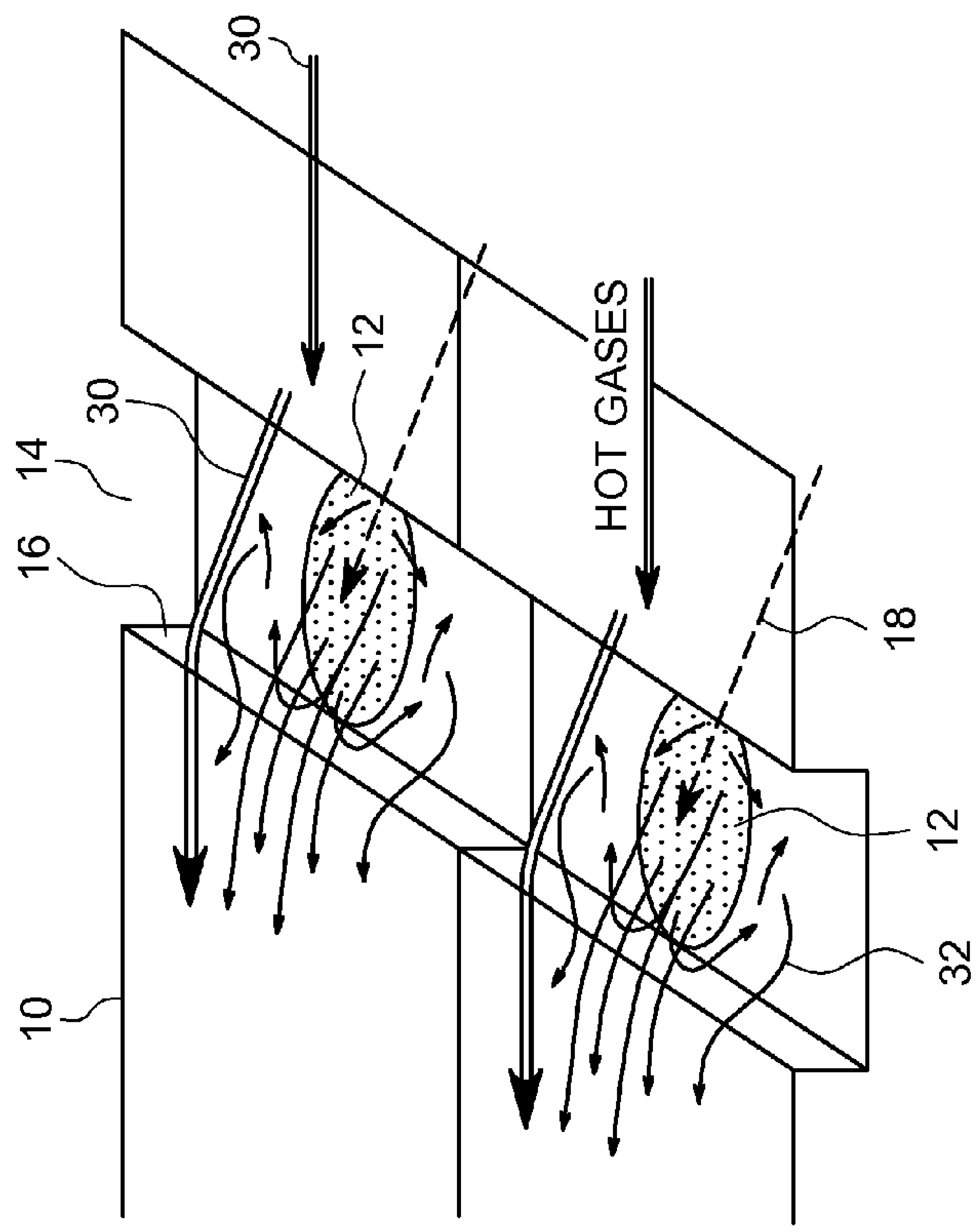



FIG. 3

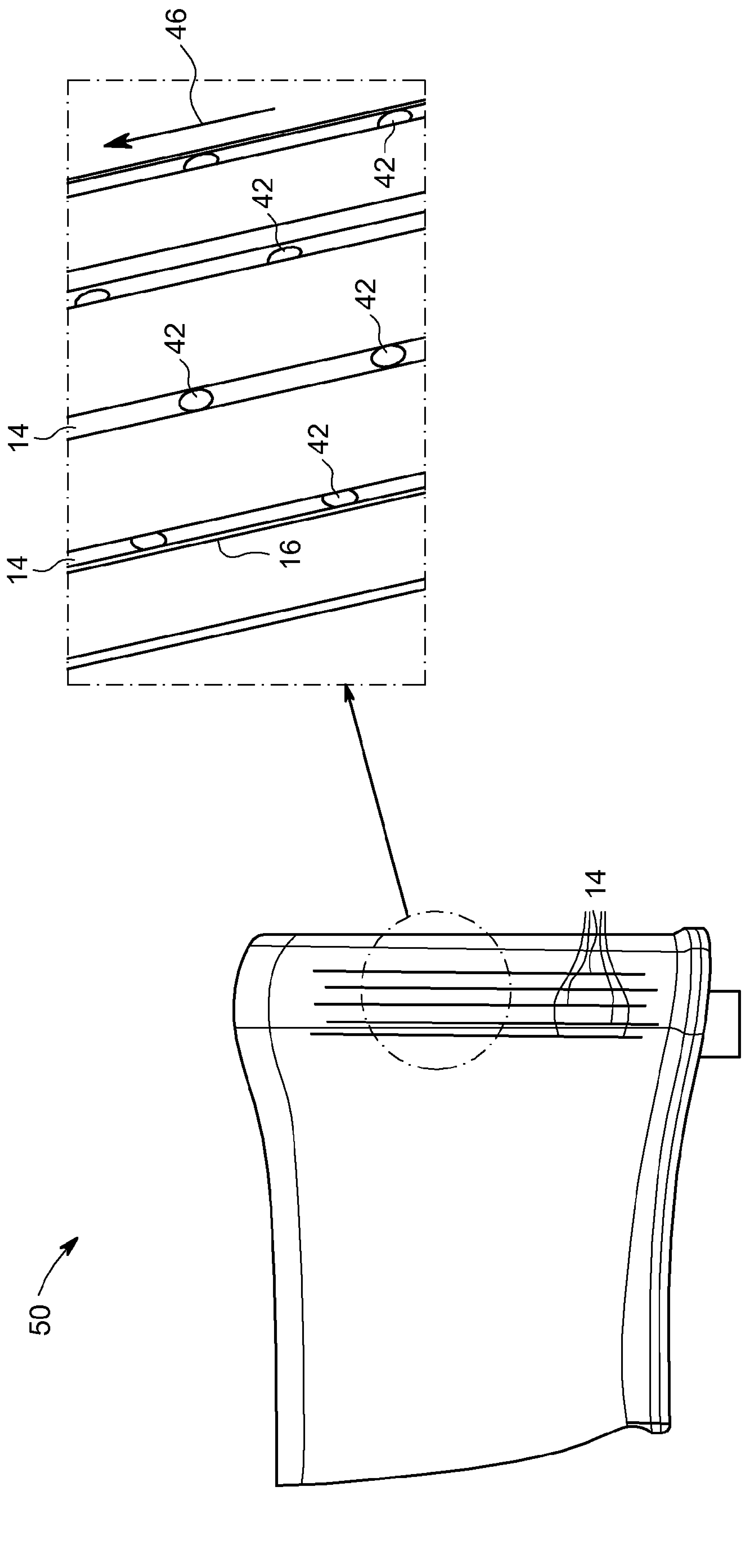



FIG. 5

FIG. 6

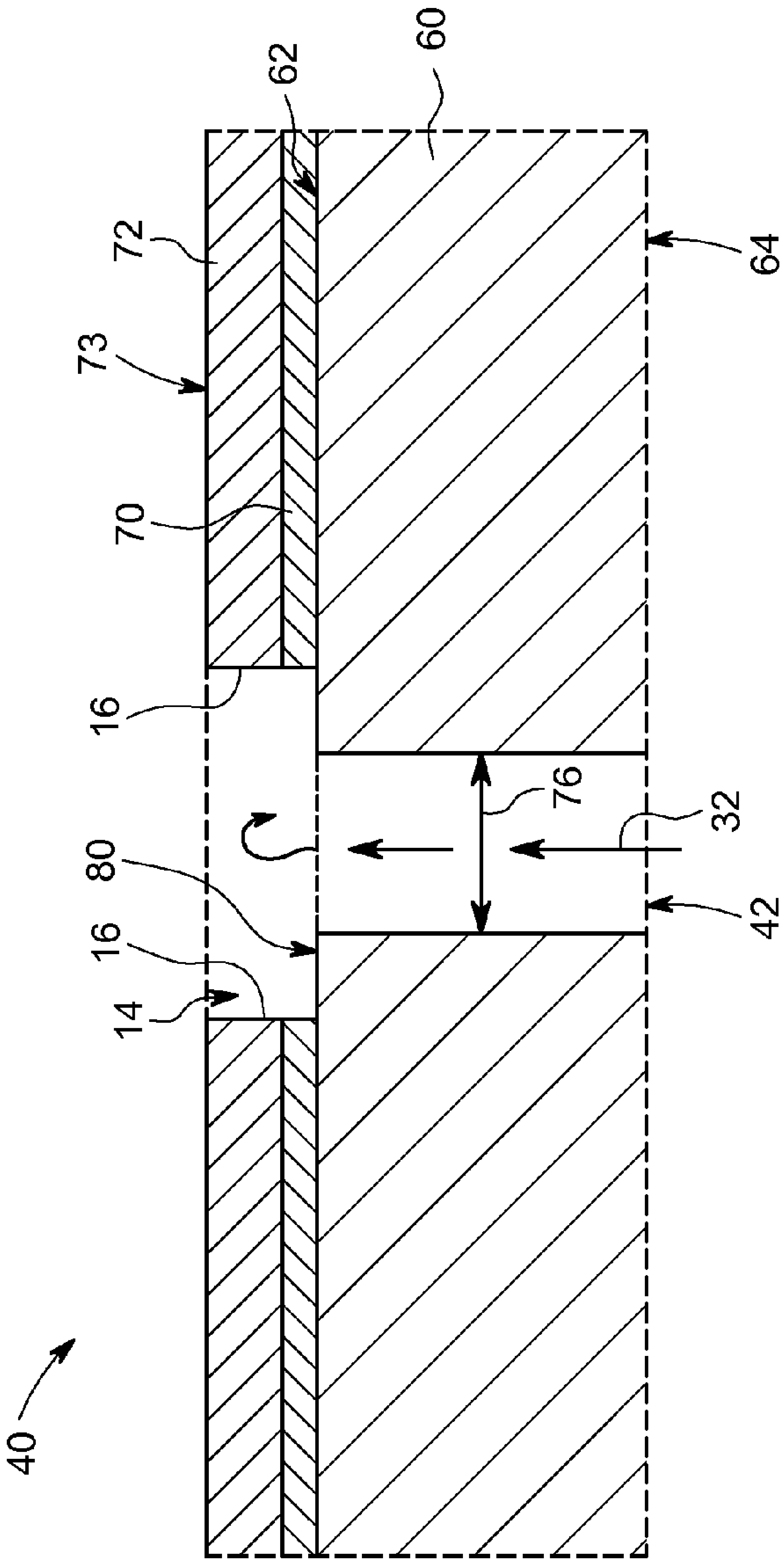
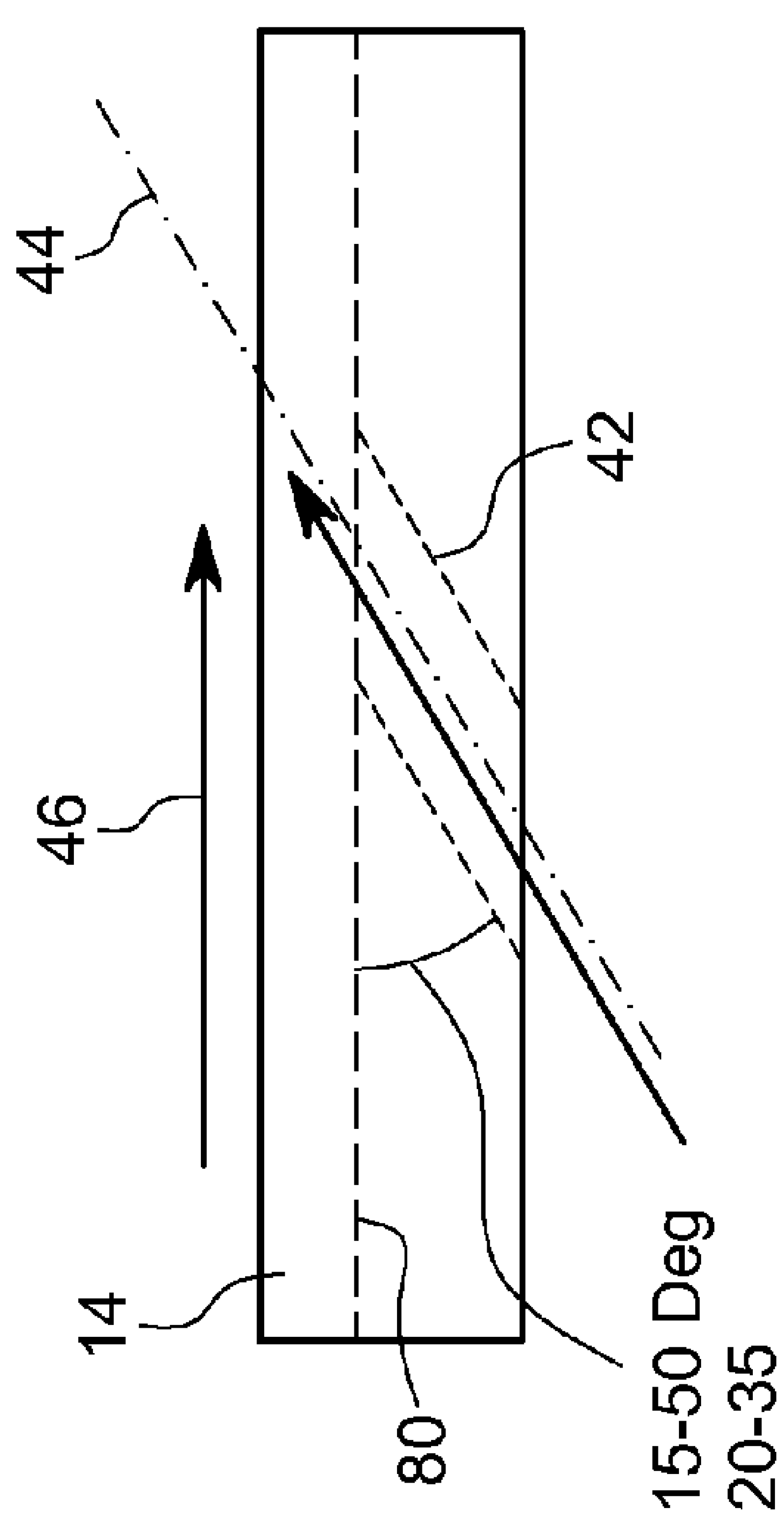



FIG. 7



# STRUCTURE AND METHOD FOR IMPROVING FILM COOLING USING SHALLOW TRENCH WITH HOLES ORIENTED ALONG LENGTH OF TRENCH

## BACKGROUND

**[0001]** The invention relates generally to film-cooled parts and more particularly to a method of film cooling common locations on virtually all cooled turbine airfoils.

**[0002]** Gas turbines and other high-temperature equipment use film cooling extensively for effective protection of the hot gas path components, such as turbine blades. Film cooling refers to a technique for cooling a part in which cool air is discharged through a plurality of small holes in the external walls of the part to provide a relatively thin, cool layer or barrier along the external surface of the part and prevent or reduce direct contact with hot gasses.

**[0003]** Common locations employed to cool turbine airfoils include, among others, the airfoil leading edge showerhead film and film holes on forward endwall regions. One common cooling technique utilizes rows of axially round holes inside a shallow trench in which the axis of each hole is oriented substantially transverse to the lengthwise direction of the trench. The use of a shallow trench increases spreading of the film cooling, making the film cooling less susceptible to freestream turbulence effects, and also tolerant to effects due to deposits on the surface.

**[0004]** These known turbine airfoil film cooling techniques using shallow trenches improve film cooling effectiveness over prior film cooling techniques that employ film holes in the absence of shallow trenches. It would be advantageous to provide a next generation of turbine airfoil film cooling that improves film cooling effectiveness beyond that achievable using known turbine airfoil film cooling techniques that employ shallow trenches.

## BRIEF DESCRIPTION

**[0005]** Briefly, in accordance with one embodiment, a turbine airfoil is configured with at least one shallow trench, each trench comprising a plurality of film holes disposed therein and located along the lengthwise direction of the corresponding trench and angled through a corresponding airfoil substrate substantially in the lengthwise direction of the corresponding trench.

**[0006]** According to another embodiment, a method of film cooling a turbine airfoil comprises:

**[0007]** configuring a turbine airfoil with at least one shallow trench having a lengthwise direction in a desired location; and

**[0008]** providing a plurality of film cooling holes within each trench, each film cooling hole having a central axis oriented substantially in the lengthwise direction of the corresponding trench such that film jets emanating from the plurality of film cooling holes issue into the corresponding trench substantially parallel to the lengthwise direction of the corresponding trench.

**[0009]** According to yet another embodiment, a film-cooled aerodynamic component comprises at least one shallow trench having a length and a width, each trench comprising a plurality of film holes disposed therein along the lengthwise direction of the trench, each film hole angled through the aerodynamic component substantially in the lengthwise direction of the corresponding trench.

## DRAWINGS

**[0010]** These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

**[0011]** FIG. **1** is a perspective view illustrating a plurality of film-cooling holes inside a shallow trench known in the art;

**[0012]** FIG. **2** illustrates the angular relationship between the shallow trench walls and the central axis of a film-cooling hole depicted in FIG. **1** depicting in further detail;

**[0013]** FIG. **3** is a perspective view illustrating film-cooling flow due to lateral flow blockage for the film-cooling holes shown in FIG. **1**;

**[0014]** FIG. **4** is a perspective view illustrating a plurality of film-cooling holes inside a shallow trench in which each hole includes a central axis oriented in the lengthwise direction of the trench according to one embodiment;

**[0015]** FIG. **5** illustrates a plurality of film-cooling holes inside corresponding shall trenches applied to a showerhead film cooled region of a turbine airfoil according to one embodiment;

**[0016]** FIG. **6** is an end view of the film-cooling holes depicted in FIG. **4**; and

**[0017]** FIG. **7** is a view transverse to the lengthwise direction of the shallow trench depicted in FIGS. **4** and **6** showing another view of the central axis of a film-cooling hole oriented in the lengthwise direction of the trench.

**[0018]** While the above-identified drawing figures set forth alternative embodiments, other embodiments of the present invention are also contemplated, as noted in the discussion. In all cases, this disclosure presents illustrated embodiments of the present invention by way of representation and not limitation. Numerous other modifications and embodiments can be devised by those skilled in the art which fall within the scope and spirit of the principles of this invention.

## DETAILED DESCRIPTION

**[0019]** FIG. **1** is a perspective view of an airfoil part **10** illustrating a plurality of film-cooling holes **12** inside a shallow trench **14** known in the art. Part **10** is cooled by a fluid coolant passing through an interior of the part **10**. The fluid coolant may be compressor extraction air or another fluid having known thermodynamic properties such as nitrogen. Some of the coolant passes through film-cooling holes **12** to an exterior of part **10**. Part **10** may have several such shallow trenches, though only one is shown here for purposes of illustration.

**[0020]** FIG. **2** illustrates an end view of the trench **14** depicted in FIG. **1** showing the angular relationship between the shallow trench **14** side walls **16** and the central axis **18** of each film-cooling hole **12**. Hot gases **30** shown in FIG. **3** flow in a direction transverse to the lengthwise direction of channel **14**. Coolant passes out through film-cooling holes **12** in a direction substantially parallel to the flow of the hot gases **30**, spreads within the trench **14** prior to coming out of the trench, and cooling airfoil part **10**. Because the central axis **18** of each film-cooling hole **12** forms an angular relationship with the shallow trench **14** side walls **16**, some of the coolant exiting the film-cooling holes **12** are blocked or otherwise restricted to prevent the maximum amount of coolant **32** from mixing with the hot gases **30** to impede optimization of airfoil part cooling. FIG. **3** is a perspective view illustrating film-cooling flow **32** due to lateral flow blockage for the film-cooling holes **12** shown in FIG. **1**.

**[0021]** FIG. **4** is a perspective view illustrating a plurality of film-cooling holes **42** inside a shallow trench **14** located on an airfoil part **40** in which each hole **42** includes a central axis **44** oriented in the lengthwise direction **46** of the trench **14** according to one embodiment. Part **40** is cooled by a fluid coolant passing through an interior of the part **40**. The fluid coolant may be compressor extraction air or another fluid having known thermodynamic properties such as nitrogen. Some of the coolant passes through film-cooling holes **12** to an exterior of part **40**. Part **40** may have several such shallow trenches, though only one is shown here for purposes of illustration.

**[0022]** Hot gases may flow in any direction relative to the lengthwise direction **46** of shallow trench **14**, but the majority of applications will have hot gases flowing substantially transverse to the lengthwise direction **46** of shallow trench **14**. Coolant passes out through film-cooling holes **42** in a direction substantially parallel to the lengthwise direction **46**, filling the trench **14** prior to exiting the trench, and cooling airfoil part **40**. Because the central axis **44** of each film-cooling hole **42** is substantially parallel with the shallow trench **14** side walls **16**, substantially all of the coolant exiting the film-cooling holes **42** is allowed to fill in the length of the trench **14** and avoid immediate mixing with the hot gases, thereby also exiting the trench **14** as a more continuous cooling layer in the lengthwise direction **46** of airfoil part **10** to maximize optimization of airfoil part **40** cooling.

**[0023]** FIG. **5** illustrates a plurality of film-cooling holes **42** inside corresponding shallow trenches **14** applied to a showerhead film cooled region **50** of a turbine airfoil part according to one embodiment. Each film-cooling hole **42** has a central axis oriented substantially in the lengthwise direction **46** of the corresponding shallow trench **14** and substantially parallel to the side walls **16** of the corresponding shallow trench **14**.

**[0024]** FIG. **6** is an end view of the film-cooling holes **42** inside the shallow trench **14** located on the airfoil part **40**. A substrate **60** represents the wall of an airfoil part which requires cooling on one or more surfaces, e.g., the wall of airfoil part **40** in FIG. **4**. The substrate **60** includes hot surface **62** and cooler surface **64**. Combustion gases enumerated **30** in FIG. **3** are conventionally channeled over the airfoil part **40**, i.e., over coated surface **73**. Coolant air **32** flows upwardly from the cooler surface through film cooling holes **42**. The holes have an average throat diameter **76**. Substrate **60** is partially coated with a bond layer **70** and an overlying thermal bather coating (TBC) **72**. In this embodiment, shallow trench **14** is formed within the bond layer **70** and TBC **72**, and has a desired depth. Usually (but not always), the side-walls **16** of the shallow trench **14** are substantially perpendicular to surface **62** of the substrate **60**. (Thus, the side-walls **16** are usually substantially perpendicular to the bottom surface **80** of trench **14**).

**[0025]** According to one embodiment, the centerline **44** of the film cooling holes **42** is oriented between about 15 degrees and about 50 degrees relative to the bottom surface **80** of the trench **14** illustrated in FIG. **7**. According to another embodiment, the centerline of the film cooling holes **42** is oriented between about 20 degrees and about 35 degrees relative to the bottom surface **80** of the trench **14**. The width of the trench **14** is substantially equal to the maximum exit width of the film cooling hole **42** according to one aspect of the invention. If a film cooling hole is perfectly aligned in the lengthwise direction of its corresponding trench, then the width is equal to the film cooling hole diameter for a round hole. If the film cooling hole **42** is aligned somewhat off angle, such as up to 20 degrees, then the width would be greater. It shall be understood that the trench width can be greater than the film hole exit and still work well to achieve the desired cooling results according to the principles described herein, whether the film hole is perfectly aligned or not. One embodiment employs a trench width from about 1.0 to about 1.5 times the maximum exit footprint width of its corresponding film cooling holes **42**. It shall also be understood that a trench **14** need not have perfect square-edged features. Any one or more of the top corners of the trench **14** can be somewhat rounded or chamfered, and any one or more of the internal corners of the trench **14** can have small fillets.

**[0026]** In some embodiments, the depth of the shallow trench **14** is less than the average throat diameter of the film cooling holes **42**. In other embodiments, the depth of the shallow trench **14** is less than about 50% of the average throat diameter of the film cooling holes **42**. These relative dimensions are in marked contrast to deep slots often used in the prior art.

**[0027]** As shown in FIG. **6**, trench **14** serves as a "spillway" trench for coolant **32** exiting cooling holes **42**. Side-walls **16** direct the flow of the coolant **32**. As a result, the coolant spreads into the trench prior to exiting the trench along hot surface **73** (i.e., surface **62** as-coated). The coolant thus stays in close contact with the hot surface, rather than separating from it quickly, as the increased coolant spreading over the hot surface is now less susceptible to freestream turbulence effects, and also is more tolerant to effects due to deposits on the surface. This in turn results in greater cooling effectiveness for the airfoil part **40** as stated herein before.

**[0028]** FIG. **7** is a view transverse to the lengthwise direction **46** of the shallow trench **14** depicted in FIGS. **4** and **6** showing another view of the central axis **44** of a film-cooling hole **42** oriented in the lengthwise direction **46** of the trench **14**.

**[0029]** In summary explanation, a structure and method is described herein for improving film cooling for a variety of turbine airfoil locations, including without limitation, the showerhead film and the film holes on the forward endwall regions of a turbine airfoil. Rows of film holes, or with holes oriented axially along the trench width inside shallow trenches, are replaced by holes having corresponding central axis oriented substantially in the lengthwise direction of the corresponding trenches. The use of the shallow trench increases spreading of the film cooling, making the film cooling less susceptible to freestream turbulence effects, and also more tolerant to effects due to deposits on the surface of the turbine airfoil. It shall be understood that the embodiments described herein are in no way restricted to use of round holes and that many other hole shapes may be employed to provide the advantages in accordance with the principles described herein.

**[0030]** The orientation of film holes, generally rows of film holes, angled through the substrate but along the direction of the trench rather than transverse to the direction of the trench (i.e., oriented along the trench width) cause the film jets to issue into the trench without hitting the side walls or other obstructions. The coolant flow more easily fills the trench before issuing onto the external component aerodynamic surface as a nearly uniform layer of film cooling. This structure is particularly beneficial for rows of film holes that are otherwise constrained by manufacturing to be oriented in fixed directions, such as showerhead film rows that are radial, and also forward endwall film rows that are circumferential (azimuthal). Film cooling hole orientation along the length of the trench also benefits film rows with greater spacing between the individual holes, since the trench acts as a buffer region for coolant spreading before the coolant interacts with the hot mainstream gases.

**[0031]** The shallow trench(s) can be formed in the protective coatings of the component according to one embodiment. The shallow trench(s) can be partially in the substrate according to another embodiment. These embodiments improve film cooling effectiveness for common airfoil locations that are constrained in geometry and manufacturing. Such regions would not otherwise be able to employ axially oriented film holes or even shaped film hole exits. Particular embodiments were found to improve regional airfoil film cooling by about 25% over that achievable with known structures. The embodiments described herein provide an advantage in ability to reduce total cooling flow for the turbine and increase efficiency offered commercially.

**[0032]** It shall be understood that bond layers, also known as bondcoats, as well as the TBC topcoats can be comprised of multiple layers or compositions. The embodiments described herein are not to be limited to a simple bondcoat and topcoat each of one composition only. Exemplary products today use at least a two-layer bondcoat system. Furthermore, the shallow trench might be formed only in the topcoat, or into the bondcoat, or even into the substrate, since it depends on the relative thicknesses used.

**[0033]** While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

**1**. A turbine airfoil comprising at least one shallow trench, each trench comprising a plurality of film holes disposed therein as a single row and located along the lengthwise direction of the corresponding trench and angled through a corresponding airfoil substrate substantially in the lengthwise direction of the corresponding trench.

**2**. The turbine airfoil according to claim **1**, wherein the shallow trench is disposed within a showerhead region of the turbine airfoil.

**3**. The turbine airfoil according to claim **1**, wherein an angle between a central axis of each hole and the bottom surface of its corresponding trench is between about 15 degrees and about 50 degrees.

**4**. The turbine airfoil according to claim **1**, wherein an angle between a central axis of each hole and the bottom surface of its corresponding trench is between about 20 degrees and about 35 degrees.

**5**. The turbine airfoil according to claim **1**, wherein the shallow trench is disposed on a forward endwall region of the turbine airfoil.

**6**. The turbine airfoil according to claim **1**, wherein the depth of the shallow trench is less than the average throat diameter of the corresponding film cooling holes.

**7**. The turbine airfoil according to claim **1**, wherein each trench comprises a width substantially equal to the maximum exit width of a corresponding film hole measured in the direction as that which defines the trench width.

**8**. The turbine airfoil according to claim **1**, wherein each trench comprises a width between about 1.0 and about 1.5 times the maximum exit footprint width of a corresponding film hole.

**9**. The turbine airfoil according to claim **1**, wherein each trench is substantially rectangular and comprises side walls having an angle between about 70 degrees and about 90 degrees with respect to the bottom surface of the trench.

**10**. The turbine airfoil according to claim **1**, wherein each trench is substantially rectangular comprising at least one rounded or chamfered top corner and at least one filleted internal corner.

**11**. A method of film cooling a turbine airfoil, the method comprising:

configuring a turbine airfoil with at least one shallow trench having a lengthwise direction in a desired location; and

providing a plurality of film cooling holes within each trench disposed therein as a single row, each film cooling hole having a central axis oriented substantially in the lengthwise direction of the corresponding trench such that film jets emanating from the plurality of film cooling holes issue into the corresponding trench substantially parallel to the lengthwise direction of the corresponding trench.

**12**. The method according to claim **11**, wherein at least one shallow trench is disposed within a showerhead region of the turbine airfoil.

**13**. The method according to claim **11**, wherein at least one shallow trench is disposed on a forward endwall region of the turbine airfoil.

**14**. The method according to claim **11**, wherein configuring a turbine airfoil with at least one shallow trench comprises configuring the depth of each shallow trench to be less than the average throat diameter of the corresponding film cooling holes.

**15**. A film-cooled aerodynamic component comprising at least one shallow trench having a length and a width, each trench comprising a plurality of film holes disposed therein as a single row along the lengthwise direction of the trench, each film hole angled through the aerodynamic component substantially in the lengthwise direction of the corresponding trench.

**16**. The film-cooled aerodynamic component according to claim **15**, further comprising:

an aerodynamic component substrate;

a bond layer bonded to a surface of the aerodynamic component substrate; and

an overlying thermal barrier coating attached to the opposite side of the bond layer, wherein the shallow trench penetrates the bond layer and the overlying thermal barrier coating, and further wherein each film hole penetrates the aerodynamic component substrate.

**17**. The film-cooled aerodynamic component according to claim **15**, wherein the shallow trench further partially penetrates the substrate.

**18**. The film-cooled aerodynamic component according to claim **15**, wherein at least one shallow trench is disposed within a showerhead region of a turbine airfoil.

**19**. The film-cooled aerodynamic component according to claim **15**, wherein at least one shallow trench is disposed on a forward endwall region of a turbine airfoil.

**20**. The film-cooled aerodynamic component according to claim **15**, wherein an angle between a central axis of each hole and the bottom surface of its corresponding trench is between about 15 degrees and about 50 degrees.

**21**. The film-cooled aerodynamic component according to claim **15**, wherein an angle between a central axis of each hole and the bottom surface of its corresponding trench is between about 20 degrees and about 35 degrees.

**22**. The film-cooled aerodynamic component according to claim **15**, wherein the depth of each shallow trench is less than the average throat diameter of the corresponding film cooling holes.

**23**. The film-cooled aerodynamic component according to claim **15**, wherein each trench comprises a width substantially equal to the maximum exit width of a corresponding film hole measured in the direction as that which defines the trench width.

**24**. The film-cooled aerodynamic component according to claim **15**, wherein each trench comprises a width between about 1.0 and about 1.5 times the maximum exit footprint width of a corresponding film hole.

**25**. The film-cooled aerodynamic component according to claim **15**, wherein each trench is substantially rectangular and comprises side walls having an angle between about 70 degrees and about 90 degrees with respect to the bottom surface of the trench.

**26**. The turbine airfoil according to claim **15**, wherein each trench is substantially rectangular comprising at least one rounded or chamfered top corner and at least one filleted internal corner.

* * * * *